The American Helicopter

An Overview of Helicopter Developments in America 1908-1999

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Executive Summary

The first powered vertical flights in the US began only five years after the US had taken the lead in aeronautical engineering with the first powered flight of the Wright Brothers. But it was not until over 35 years later that the first practical US helicopter was flown, some five years behind the Europeans. The events of World War II and the widespread technological innovations, however, soon unleashed a flood of helicopter designs in the US. In contrast to the widespread consolidation in the US aerospace industry, all of the major helicopter developers of the 1950s are still active today. Over 60,000 American helicopters have been produced, roughly half of the worldwide total. In addition, nearly 2/3 of the helicopters now sold worldwide – approximately 800 annually – are American helicopters.

Acknowledgments

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About the Author

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Introduction

On a windy December morning at Kill Devil Hill, North Carolina nearly 100 years ago, Orville and Wilbur Wright took off into history. The event was not widely publicized or even believed at the time. All around the world, in France, Germany, Russia and in the United States, the greatest scientists, many of them well financed, were attempting to be the first humans to fly. It was hard to believe that these two bicycle mechanics could have accomplished this incredible feat, the start of the aviation age. [18] Two years later, however, Thomas Edison, who had himself made a number of experiments in vertical flight during the 1880s, made the remark, “The aeroplane won’t amount to a damn thing until they get a machine that will act like a hummingbird. Go straight up, go forward, go backward, come straight down and light like a hummingbird [20].”

The Wright Brothers had three main innovations that allowed them to leapfrog the leading aircraft researchers: a high power-to-weight engine*, highly aerodynamic lifting surfaces, and the ability to control the aircraft through an effect they called “wing warping.” These factors (power, lift and control) are critical to all aircraft. Their applicability to vertical flight aircraft are discussed below:

The continued advancements in development of the gasoline-powered piston engine and its widespread use developed ever improved power, power to weight, fuel economy and reliability. This, coupled with the ability of a fixed wing aircraft to stay aloft efficiently by aerodynamic lift, promoted rapidly advancement of the airplane. Just over 10 years after the Wrights first flew with a power to weight of 0.016 lb/hp, Igor Sikorsky flew 1,600 miles (2,575 km) round trip (over several days) from St. Petersburg to Kiev in the four engine *Il'ya Muromets,* with a power to weight ratio of 0.045 [7]. In comparison, the first machine capable of vertical flight that was able to make a 0.6 mile (1 km) circuit was not until 10 years later and had a power to weight of 0.06 hp/lb.

For a vertical flight machine, the requirement for power and lift combine to become a need for vertical thrust. Whereas a glider can fly for hours with a thrust to weight of zero, a helicopter cannot achieve vertical flight without a thrust to weight of greater than one. The problem of achieving vertical flight, therefore, is two-part: having a high power to weight powerplant that can cause sufficient lift generation with acceptable efficiency. A simplified equation defining the ideal horsepower required to hover out-of-groined effect was generally well know by the early vertical flight pioneers. In fact, many of the early pioneers installed engines twice as powerful as required under ideal conditions. They did not, however, adequately take into account the need for rotor efficiency. The Wrights constructed a wind tunnel to adequately understand the need aerodynamic lift. Sufficient understanding of rotor aerodynamics did not occur until the late

* It was not, however, the best internal combustion engine of its era. Samuel Langley's Manly-Balzer engine produced an amazing 4.4 times more sustained power but was only 37% heavier. [8]

1920s, when the blades changed from simple flat shapes like windmill blades to more modern airfoils.

Prior to the Wright Brothers' first powered flight, they conducted an extensive amount of glider tests, as did Otto Lillenthal, Octave Chanute and other pioneers. This was critical to developing a method of controllability once airborne. Controllability of a helicopter, which is inherently unstable, required years of development. Each piece of the puzzle had to be found and assembled: torque negation, vibration damping, periodic rotor stability, blade articulation, translational capability. So whereas it was just a matter of time until the power of piston engines was sufficient for helicopter use, the controllability was something that required rotor-specific research and experimentation. Tables of characteristics of early rotorcraft and timelines of helicopter development are found in the Appendix.

Early Vertical Flight Machines

The first vertical flight was accomplished in Doaui, France, by Louis Breguet and Professor Charles Richet's *Gyroplane* on August 24, 1907, less than 4 years after the first horizontal powered aircraft flight had been made by the Wright Brothers (and just 10 months after the first European airplane flight by Alberto Santos-Dumont, also in France). Breguet's gigantic crucible-shaped structure, spanning over 60 ft (18 m), had a 45 hp (34 kW) eight cylinder Antoinette engine located just above the pilot which powered four four-bladed biplane rotors. Diagonally opposed rotors counter-rotated to negate torque. Gross weight was 1,274 lb (578 kg). Thrust to weight was just sufficient to achieve vertical flight, but there was no means whatsoever of providing stability or control except to use four men, each one holding the end of one of the arms (see Figure 1). Several flights were made over the course of a month or two, but Breguet turned his attention to hybrid fixed/rotor wing convertaplanes, before becoming a successful conventional aircraft designer. [5,15,23]

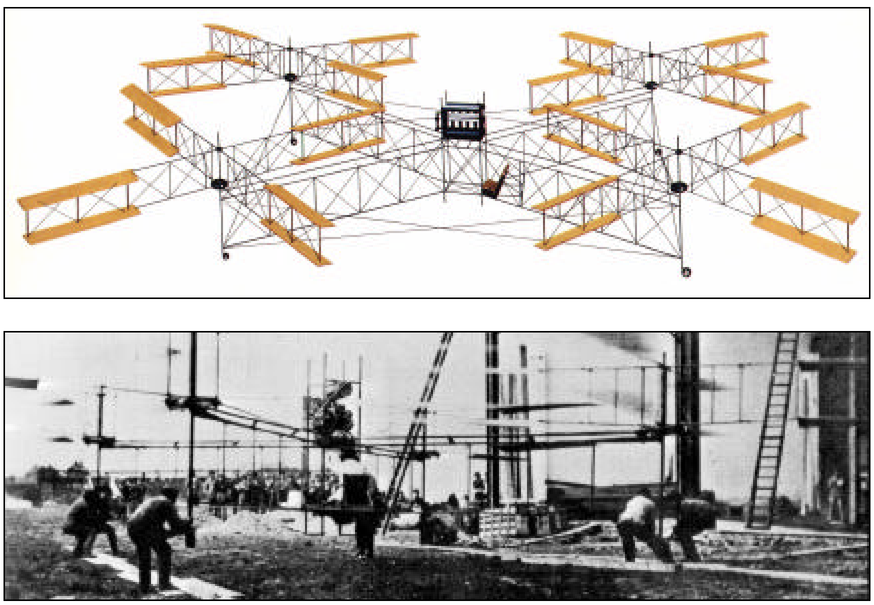


Figure 1. Breguet's 1907 *Gyroplane No. 1*.

Also in 1907, another Frenchman named Paul Cornu built an aircraft that also lifted off the ground a few feet. Based on tests in model tests in 1906, Cornu had constructed a twin tandem-rotor machine powered by a 24 hp (18 kW) Antoinette engine, which practically sat in his lap. In the front and rear of the machine, two large fabric-covered paddles rotated around large spoked hubs (Figure 2). Similarly sized paddles below the rotors in the front and rear were intended to deflect the slipstream to achieve translation and control; there was, however, insufficient authority for effective control. Built in Lisieux, the 573 lb (260 kg) aircraft was able to make a free flight on 13 November 1907, reaching an altitude of about 1 ft for approximately 20 seconds. He eventually made over 300 test flights, but only 15 were piloted. The poor power to weight of the engine and inefficient lifting surfaces prevented further progress: maximum altitude was about 5 ft (1.5 m) with an endurance of about one minute. The lack of success and a lack of funds discouraged further development. Cornu also began working on convertaplanes. [5,14,15,23]

Figure 2. Cornu's 1907 machine.

The first manned US vertical flight machine appears to have been developed by Emile Berliner and John Newton Williams. Berliner was an inventor who developed the disk-type phonograph record and designed what may be the first production rotary aircraft engine, the 36 hp (27 kW) Adams-Farwell engine. In 1908, Williams constructed a coaxial machine for Berliner using two of these rotary engines. It reportedly lifted both Williams and the machine – a total of 610 lb (277 kg) – but was probably steadied from the ground. In May, 1908, Williams built another stand in Hammondsport, New York, as a member of the famed Aerial Experiment Association (which included Alexander Bell and Glenn Curtiss), using a 40 hp (30 kW) Curtiss engine. It made hovers around 3 ft, again steadied from the ground. [14,20]

Figure 3. Willams' May 1908 machine.

In Russia, student Igor Sikorsky built two rotary wing test machines constructed primarily of wood. The first, built in Kiev in June 1909, weighed 450 lb (204 kg), and had a twin, two-blade coaxial rotor system. But the most powerful engine that was available to the 20 year old researcher, a 25 hp (20 kW) Anzani engine, was too weak and the blades too inefficient to get it off the ground: it only produced a thrust of 350 lb. The following February, Sikorsky built a new machine that was 50 lb (23 kg) lighter and had a three-blade rotor system, but it could still just barely hop off the ground with no pilot. The coaxial arrangement also required more stiffness than the lightweight wooden structure could provide, causing the machines to shake and vibrate violently.

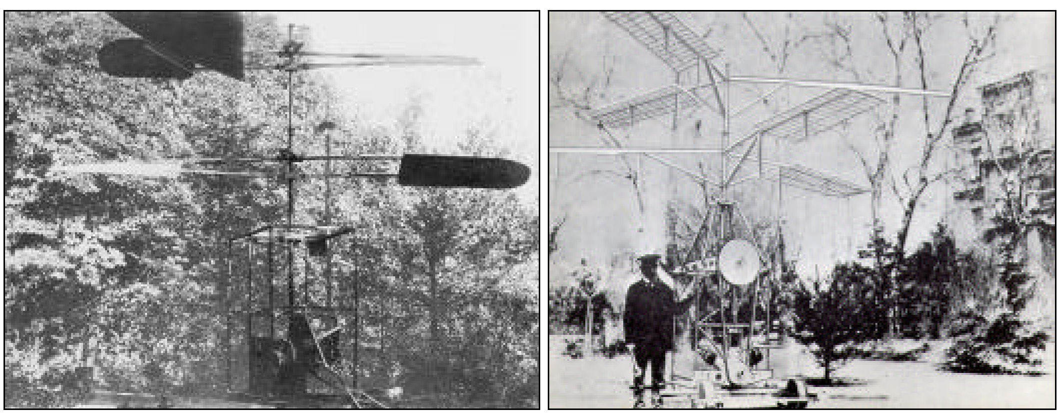


Figure 4. Sikorsky's 1909 (left) and 1910 (right) machines.

Another Russian student, Boris Yuriev in Moscow, built a single rotor test vehicle in 1912 powered by an Anzani engine. A small counter-torque rotor was at the tail. The whole machine weighed about 445 lb (202 kg). During ground tests, however, the main rotor shaft failed due to flexure. [5,7,14]

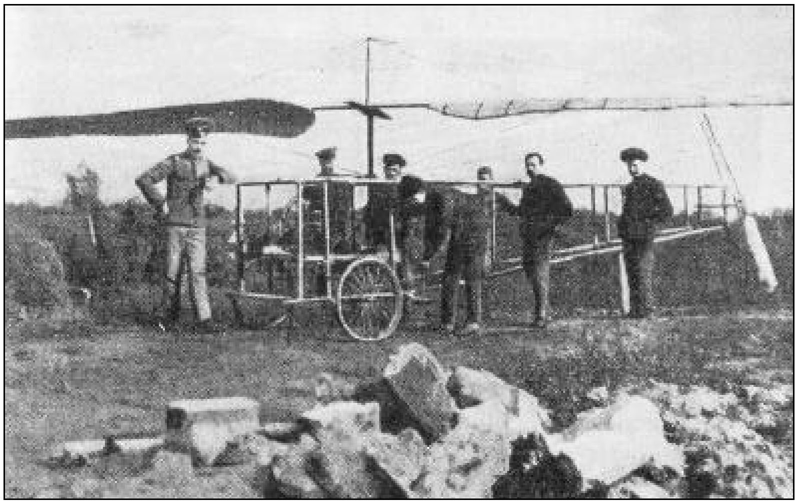


Figure 5. Yuriev's 1912 single main rotor machine.

Dane Jacob Ellehammer, built a co-axial machine in 1912 powered by a 36 hp (27 kW) engine which he also designed. The engine drove two counter-rotating rotors through a hydraulic clutch and gearbox, as well as a propeller. The lower rotor was covered with fabric for increased lift in forward flight, making it both a compound and a convertaplane. The rotors were each 19.6 ft (6 m) diameter rings, and both had six 5 ft (1.5 m) long vanes spaced around the perimeter. For control, the pilot could vary the cyclic pitch of the vanes. Untethered vertical takeoffs were made late in 1912, including demonstrations to the Danish Prince Axel. Thrust was too low to rise more than a few feet off the ground, and control was insufficient for translation. Tests continued until September 1916, when the machine turned over and was destroyed. Ellehammer continued studying convertaplanes for several years. [15,23]

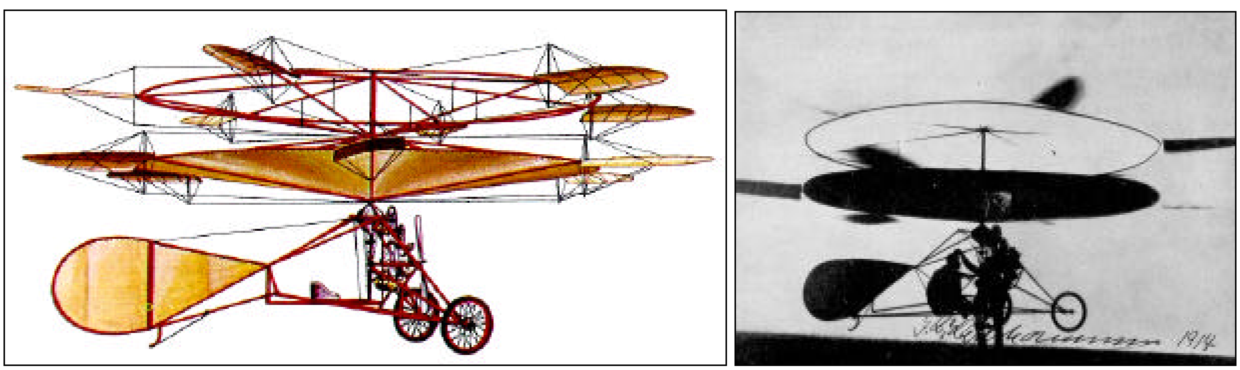


Figure 6. Ellehammer's 1912 compound.

Many other inventors studied the helicopter and built test rigs and machines intended to become airborne. Some of these pioneers, such as Breguet, Sikorsky, Yuriev and others, would eventually be successful. But, despite the fact that some of these machines were able to leave the ground for a few moments, none of them had sufficient thrust to rise out of ground effect with a pilot, or sufficient controllability for practical flight. A great number of additional challenges would first have to be overcome.

Slow Progress

Prior to the First World War, it seemed that no one quite knew what the helicopter was good for, much less how to solve the problems associated with it. A balloon could certainly accomplish the primary requirements for the helicopter: vertical take-off and landing, and hover. With the success of the airplane, it seemed to many that the rotary wing inventors were wasting their time with helicopters and had missed the news that powered flight had been achieved.

Fixed wing aircraft quickly found military uses during World War I, however, first for reconnaissance, and then as bomber and fighter aircraft. The aircraft was also found to be quite adept at shooting down enemy reconnaissance balloons. The balloon, however, had a much needed capability that the airplane lacked: the ability to connect a telephone line to the ground to report the events from the battlefield. During the war, Lieutenant Stefan von Petróczy of the Austrian Army Balloon Corps initiated a project to develop a tethered, armed aerial observation platform that could be quickly reeled in when needed. Under the technical guidance of the now legendary Theodore von Kármán, with assistance from Ensign Wilhelm Zurovec, a 1,433 lb (650 kg) full-size machine, referred to as the PKZ 1, was begun in Budapest in October 1917. A 190 hp (142 kW) Austro-Daimler electric motor was used to drive two propellers in front of the observer and two behind. The electrical power was transmitted through a cable but still the motor weighed 430 lb (195 kW). Four test flights were made in March 1918 up to a height of 20 ft (6 m), but the motor burned out, preventing further tests.

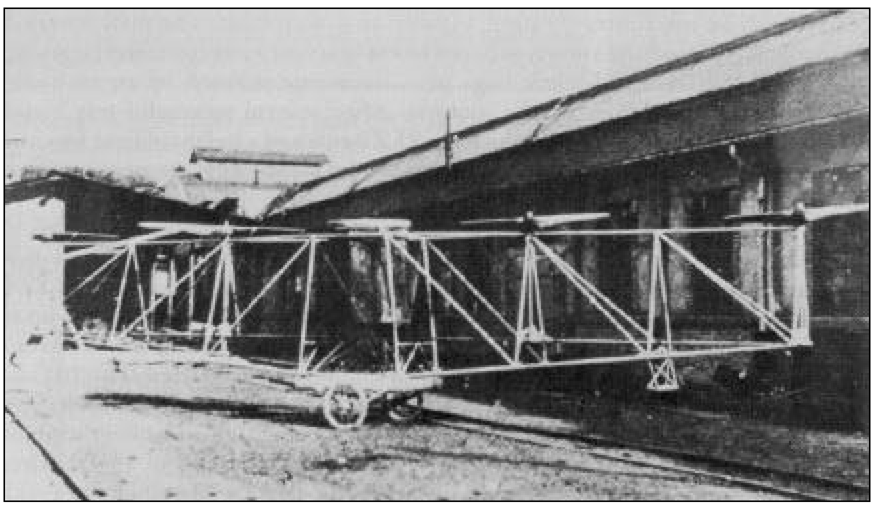


Figure 7. The 1917 PKZ 1 tethered observation machine.

This research was followed by the 3,087 lb (1,400 kg) PKZ 2, primarily developed by Zurovec. The triangular structure used three 100 hp (75 kW) Gnome rotary engines powering two counter-rotating propellers. The engines were soon replaced with 120 hp (89 kW) Le Rhône engines and flight tests resumed that May. The vehicle was flown over 30 times, eventually with a second observer, and reportedly achieved a tethered height of 164 ft (50 m) and an endurance of 30 minutes. A crash during a military demonstration ended the project and the conclusion of the war terminated further study. The PKZ 1 and 2 demonstrated that the thrust to weight deficiency could be overcome and that useful vertical flight could be attained. Since they were tethered, however, they did not in any way attempt to address the controllability challenges. [18]

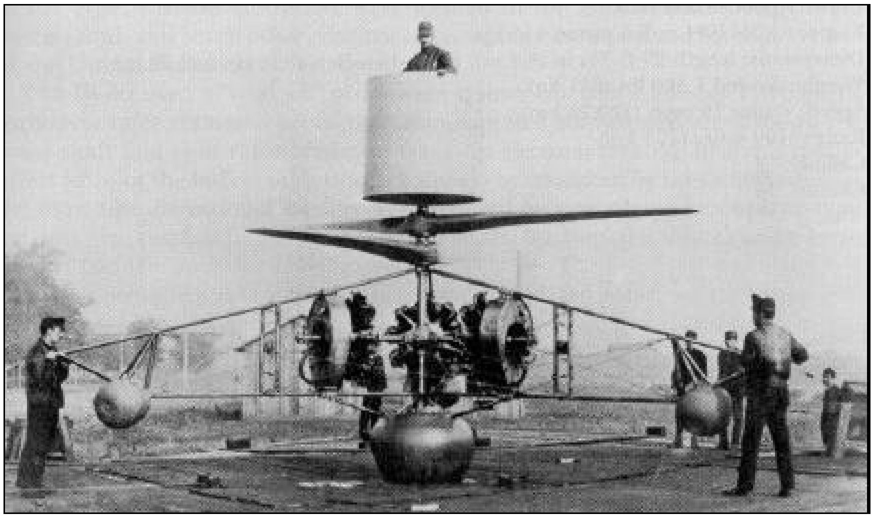


Figure 8. The 1918 PKZ 2 tethered observation machine.

Emile Berliner's son, Henry, continued exploring vertical flight machines when his father suffered a nervous breakdown in 1914. In June 1919, Henry Berliner built a machine with two co-axial propellers with vanes to vector the downwash for pitch control. Hovering flights again had to be steadied. Three years later Berliner used the fuselage of a Nieuport biplane with a 14.8 ft (4.5 m) rotor mounted on an outrigger on either side of and slightly forward of the cockpit. Control vanes, similar to those used on their 1919 coaxial machine, were used in the slipstream. Longitudinal control was by a small variable pitch lifting propeller near the tail. Hovering up to 12 feet (3.3 m) was accomplished in June 1922, and flew about 100 yards (91.5 m). Despite the fact that overall performance was unsatisfactory, the Smithsonian Institute considers the Berliner machine as the first helicopter to make a controlled flight on the basis of these tests. Berliner continued his efforts and built two additional machines, but they were short take-off convertaplanes incapable of vertical flight. [5,14]

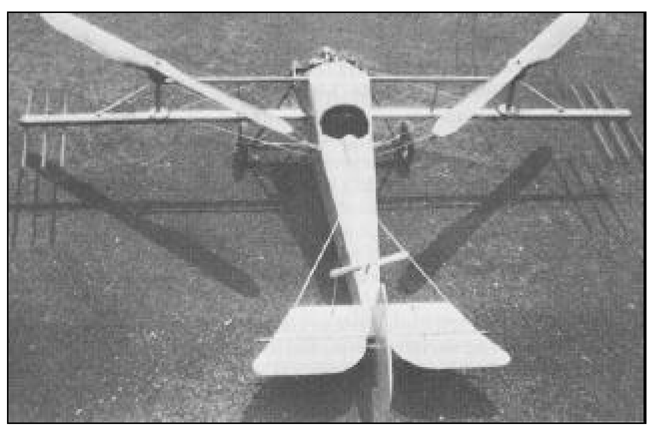


Figure 9. The 1919 (left) and 1922 (right) Berliner machines.

In January 1921, the US Army Air Corps awarded a contract to Dr. George de Bothezat and Ivan Jerome to develop a vertical flight machine. The 3,700 lb (1,678 kg) "X"-shaped structure supported a 26.5 ft (8.1 m) diameter six-blade rotor at each end of the 30 ft (9 m) arms. At the ends of the lateral arms, two small propellers with variable pitch were used for thrusting and yaw control. A small lifting rotor was also mounted above the 180 hp (134 kW) Le Rhône radial engine (which it also cooled) at the junction of the frames, but was later removed as unnecessary. Each rotor had individual collective pitch control to produce differential thrust through vehicle inclination for translation. The aircraft weighed 3,748 lb (1,700 kg) at take-off and made its first flight in October 1922. The engine was soon upgraded to a 220 hp (164 kW) Bentley BR-2 rotary. About 100 flights were made by the end of 1923 at what would eventually be known as Wright Field near Dayton, Ohio, including one with three "passengers" hanging onto the airframe. Although the contract called for a 300 ft hover, the highest it ever reached was about 15 ft (5 m). After expending $200,000, de Bothezat demonstrated that his vehicle could be quite stable and that the practical helicopter was theoretically possible. It was, however, underpowered, unresponsive, mechanically complex and susceptible to reliability problems. Pilot workload was too high during hover to attempt lateral motion. In the late 1930s, de Bothezat built a single seat, coaxial helicopter with even less success. [5,14,18]

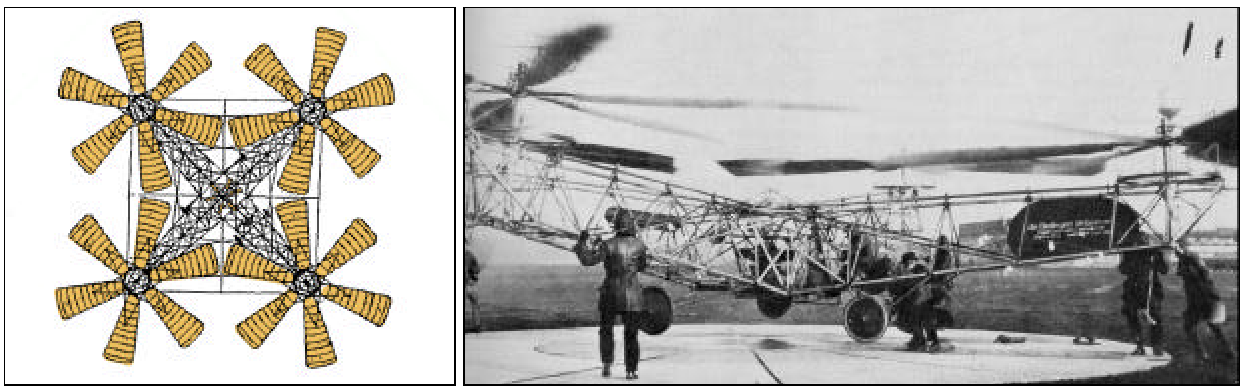


Figure 10. The 1921 de Bothezat machine.

In France, Etienne Oehmichen, a young engineer at Peugeot, began rotary wing experiments in 1920, building a total of six different machines. When his first machine failed to develop enough lift with its 25 hp (19 kW) motor, he added a large hydrogen balloon for added lift. His second machine, however, flew for the first time on 11 November 1922. Similar to de Bothezat's machine, it was an "X"-shaped, tubular machine with a wide two-blade rotor at the end of each arm. For control and lateral movement, eight small propellers were used: five horizontal propellers with variable and reversible pitch for lateral stability, another propeller at the nose for steering, and another pair of pushers for forward motion. By 1923, the Oemichen No. 2 was able to remain airborne for several minutes and on 14 April 1924, it established the first rotary wing distance record: 1,181 ft (360 m). On 4 May, it completed the first 3,280 ft (1 km) closed circuit flight by a rotary wing vehicle in 7 minutes 40 seconds to win a 90,000 franc prize (Figure 11). Maximum endurance was 14 minutes. Despite the fact that it was able to demonstrate sufficient controllability and power in ground effect for this historic flight, it was not a practical flying machine. With separate propulsion systems for hover and translation, it did not significantly contribute to resolving the difficulties of rotary wing flight. In recognition of the impracticality of the machine, Oemichen developed a series of aircraft with a single-main rotor and two anti-torque rotors, but had little success. [5,15]

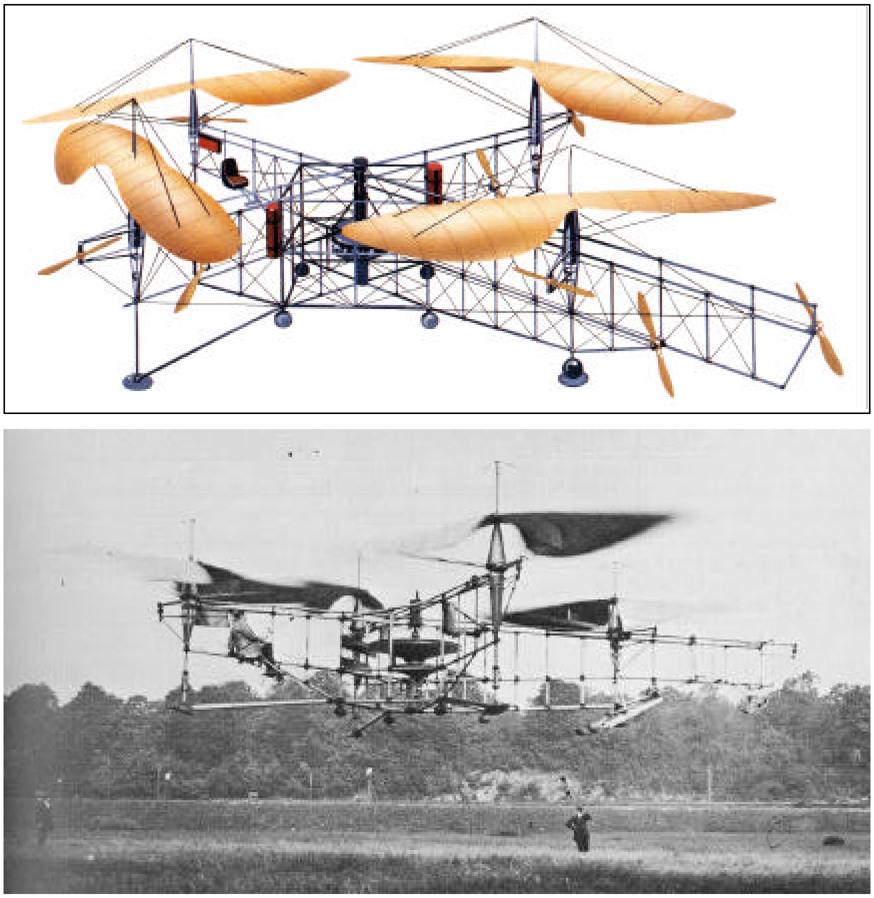


Figure 11. The 1922 Oemichen No. 2.

In stiff competition with Oemichen, Spanish engineer Marquis Raul Pateras Pescara began building rotary wing machines in Barcelona in 1919. His first apparatus was a co-axial contraption; each 21 ft (6 m) rotor had 6 pairs of biplane blades. Initially Pescara used a 45 hp (33.5 kW) motor. After replacing it with a 170 hp (127 kW) Le Rhône engine, he could just managed to get it off the ground in May 1921. The next year he moved to France where his second, similar machine was able to hover at about 5 ft (1.5 m). The Pescara No. 3, however, was completed in 1923 and by January 1924, Pescara was conducting endurance tests of over 10 minutes.

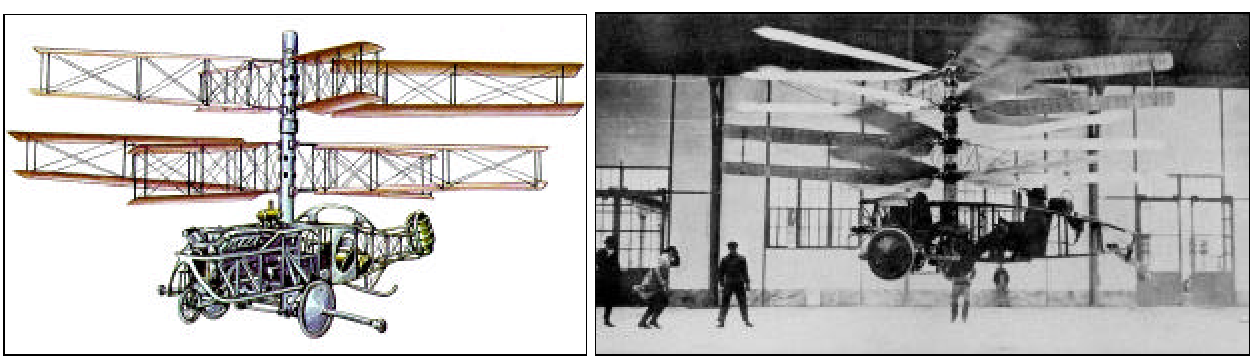


Figure 12. The 1919 Pescara No. 3.

The 1,874 lb (850 kg) No. 3 machine used 23.6 ft (7.2 m) diameter 4-blade biplane rotors (seen in Figure 13) and a 180 hp (134 kW) Hispano-Suiza V-8 engine. No other propulsion mechanisms were used: the pitch of the 16 lifting surfaces could be altered in flight by a method similar to the Wright's wing warping. The rotor hub could be tilted for some measure of forward motion, but speed was only about 8 mph (13 km/hr). This was the first credible use of cyclic and collective pitch control. The rotors would also have been capable of autorotation, had it ever achieved enough altitude to need it. In September 1923, Pescara almost became the first person to complete the 1 km circuit, but the machine crashed and was severely damaged. The next spring, four days after Oemichen's first FAI distance record, Pescara doubled it to 2,415 ft (736 m). Although not powerful enough to leave ground effect, this machine solved an important problem in rotary wing flight. [5,15]

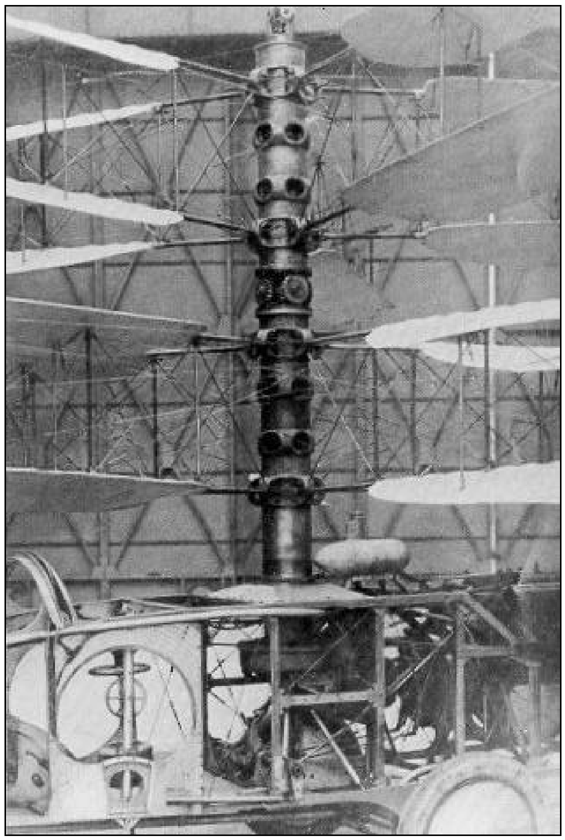


Figure 13. Pescara rotor hub with 4 blade counter-rotating biplane rotors.

At the Royal Air Establishment in Farnborough, England, Louis Brennan conducted experiments on the propeller-driven rotor concept from 1919 to 1926. The 3,000 lb (1,360 kg) empty weight machine used a single 60 ft (18 m) rotor. Propellers at the rotor tips produced torqueless rotation and were powered by a 230 hp (172 kW) Bentley BR-2 driving transmission shafts that ran down the length of the rotor blades. Compressed air was used to control the rotor pitch angle, effecting translation through cyclic control. Tethered flights were conducted during 1924 in a hanger with free flights the following May. Power was sufficient to lift four "passengers" when tethered, but stability and control were still very poor. Over 80 take-offs were made, but the maximum altitude was only 8 ft (2.4 m) and maximum distance only about 600 ft (183 m). The machine crashed in 1926, ending the tests. A similar design was developed between 1929 and 1935 by

Italian Vittorio Isacco. Isacco's "Helicogyre", however, used small engines at the end of each rotor blade driving a propeller, eliminating the long drive shaft. Isacco was even less successful. In the US during the late 1920s, Maitland Bleecker convinced the Curtiss Company to fund development of a propeller-driven rotor helicopter. Propellers at the rotor mid-spans produced torqueless rotation and were powered by a 230 hp (172 kW) Bentley BR-2 driving transmission shafts that ran down the length of the rotor blades. Compressed air was used to control the rotor pitch angle, effecting translation through cyclic control. The machine was able to perform hover tests but was not satisfactory for further development. [5,14,23]

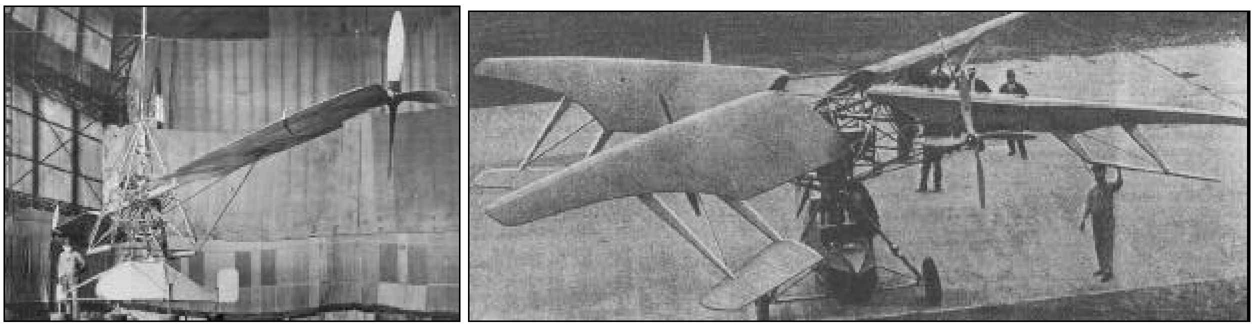


Figure 14. The 1923 Brennan (left) and 1927 Bleecker (right) propeller-driven rotors.

Many other inventors around the world tried numerous different ideas for achieving a practical helicopter. In the Netherlands, A.G. von Baumhauer used a single main rotor with a small tail rotor powered by a separate engine to counter the torque. It also had a method for periodically varying rotor blade angle for stability and control, similar to today's swash-plate system, but the machine never achieved adequate thrust to rise more than 6 ft (2 m), and controllability was still poor.

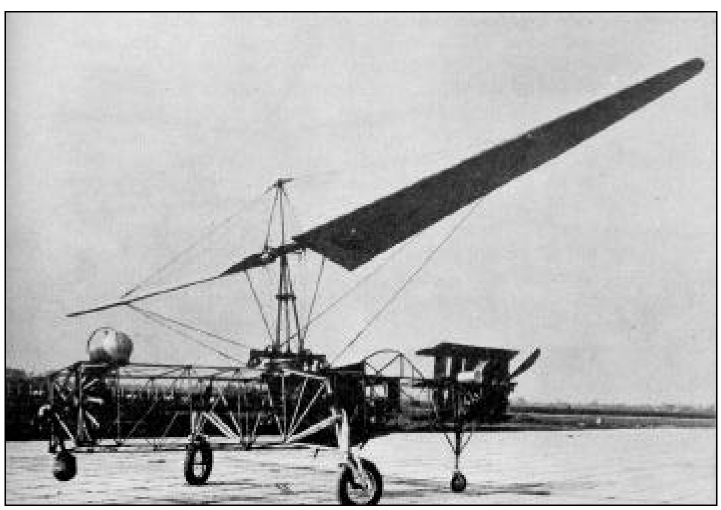


Figure 15. The 1925 von Baumhauer machine with separate tail motor.

In Italy, Corridion D'Ascanio built a machine with two 43 ft (13 m) counter-rotating coaxial rotors, each with a trailing elevator which could be used to vary the rotor blade angle of attack. Two small propellers at the ends of long arms were used for additional control. The propulsion/control system was powered by a 95 hp (71 kW) Fiat engine. The vehicle set three

Fédération Aéronautique Internationale (FAI) world records on October 8, 1930: an altitude of 59 feet (18 m), a distance of 3,538 ft (1078 m), and endurance of 8 minutes and 45 seconds.

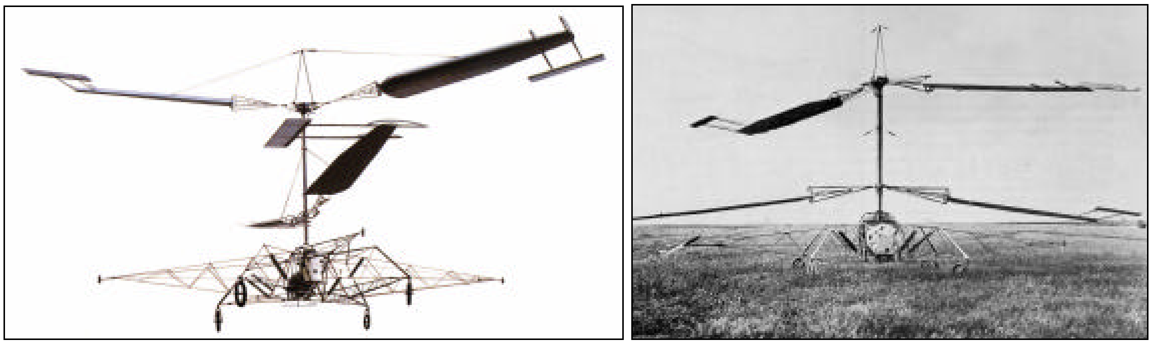


Figure 16. 1930 D'Ascanio co-axial helicopter.

Hungarian engineer Oscar von Asboth, who had worked on the two PKZ machines, designed and tested four different helicopters between 1928 and 1931. His final machine, the AH-4 used counter-rotating coaxial main rotors powered by a 110 hp (82 kW) Clerget rotary engine with multiple hinged vanes in the rotor downwash. Control was very poor, but by mid-1930 the aircraft reportedly attained an altitude of 100 ft (30 m) and covered 2 miles (3.2 km) at about 12 mph (19 km/hr).

Figure 17. 1931 von Asboth co-axial machine.

The first twin tandem rotor machine to fly was built by Nicolas Florine in Belgium. First flown in April 1933, it soon attained an altitude of 20 ft (6 m) and an endurance of 8 minutes. Although the rotors did not counter-rotate, they were tilted slightly in opposite directions to counter torque. [5]

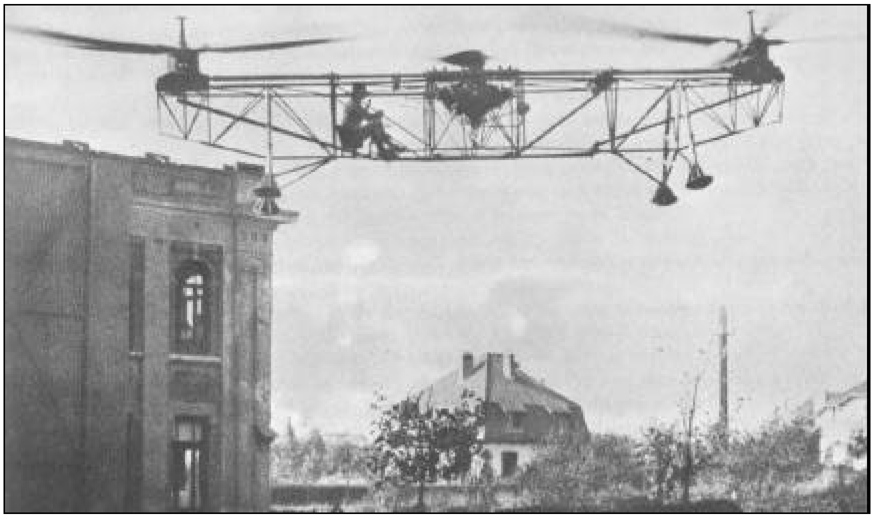


Figure 18. 1933 Florine tandem rotor machine.

By the early 1930s, the future of the helicopter had not significantly brightened. Although some progress had been made, by then fixed wing aircraft had achieved phenomenal success. Meanwhile, another kind of rotary wing aircraft, the autogyro, had been developed. The autogyro seemed to be a compromise that combined cruise performance near that of fixed wing aircraft, with take-off and landing capabilities that could fulfill many of the applications for the helicopter. While not capable of hover or true vertical flight, the autogyro was capable of taking off and landing in extremely short distances. Fortunately, the development of the autogyro also solved another challenge for the helicopter.

Autogyros

Juan de la Cierva became interested in rotary wing flight in 1919 as a means to prevent airplane stalls. After near accidents by both himself and his brother early in their flying careers, Cierva began to wonder if the forward motion of an aircraft alone could spin a freely mounted rotor to the point where it would generate enough lift for flight, obviating the need for a powered rotor. His first machine, the C.1, was completed in 1920 and used a wingless 1911 Deperdussin monoplane with coaxial freely turning rotors mounted just behind the cockpit. It rolled over while taxiing. He built two more autogyros with single rotor systems, but they were also unsuccessful because of the destabilizing effect of the rotor blades which were rigidly attached to the mast: the airspeed of the advancing blade was higher than that of the retreating blade. This caused a disymmetry of lift resulting in a rolling moment. [10,23]

In 1922, Cierva built a scale model with articulated hinges that allowed the blades to move about the hinge point. Each retreating blade could therefore flap downward as the advancing one's airspeed lifted it up, so that the lift forces were more closely balanced. This minimized the aircraft's tendency to roll over while accelerating in flight. Cierva's C.4, powered by a 110 hp (82 kW) Le Rhône 9JA rotary engine and equipped with a 4-blade rotor, made its first flight on 9 January 1923. By the end of the month, it could match the Wright Brother's performance of 19 years earlier, completing a 2.5 mile (4 km) closed circuit in 4 minutes at an average height of 100 ft (30 m). [10,15,23]

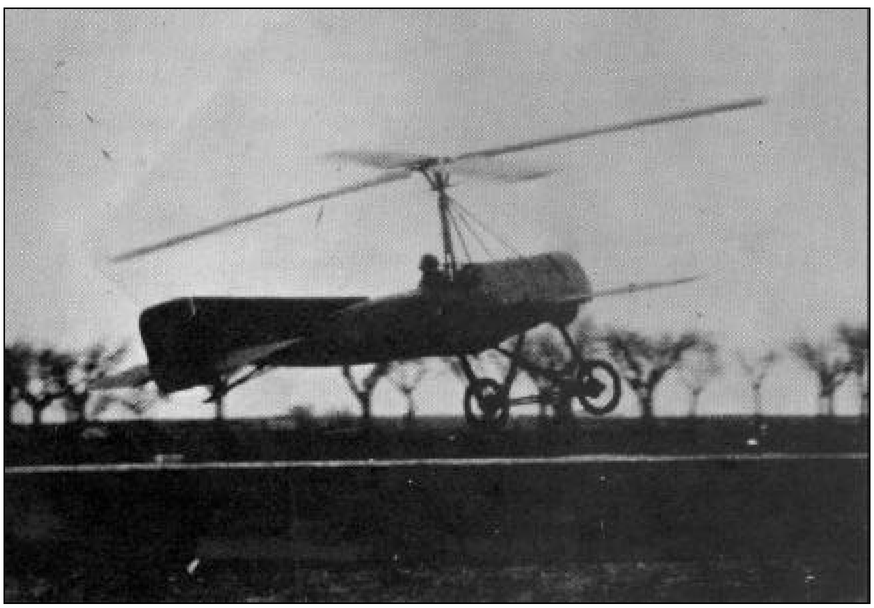


Figure 19. First flight of the Cierva C.4 autogyro.

Cierva developed the C.5 and then, with Spanish government sponsorship, the C.6A. This aircraft was based on the Avro 504K aircraft with its 110 hp (82 kW) Le Rhône engine. It underwent military trials in May 1924, reaching 655 ft (200 m), achieving a minimum speed of 16 mph (25 km/hr) and a maximum speed of 68 mph (110 km/hr). After the failure of a rotor in flight in February 1927, Cierva made another important innovation. He added a drag hinge to the blade/mast junction, allowing the blade to pivot forward or rearward slightly during rotation.

This fully articulated hub relieved the stress on the blade root. Problems with ground resonance led Cierva to fit drag dampers to the hinges. This is the basis for the modern fully articulated rotor head, depicted in Figure 20. [10,23]

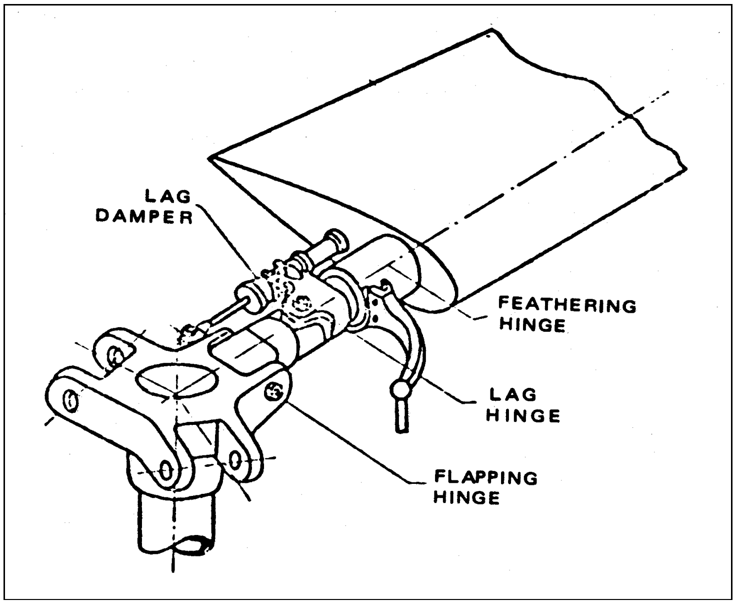


Figure 20. A fully articulated rotor head.

On 18 September 1928, Cierva, with a French journalist as a passenger, made the first crossing of the English Channel by a rotary wing aircraft on his way to Le Bourget airport near Paris from Croydon, England. The C.8L Mk II was powered by a 200 hp (149 kW) Armstrong Siddeley Linx IVc engine, and reached a maximum speed of 100 mph (160 km/hr). The maximum range was 255 mi (410 km), compared to the pure vertical flight machines of the time, which were struggling to achieve a distance of 1 mile (1.6 km). [10,23]

In order to take off in a short distance, the autogyro rotor had to be pre-spun by pulling a rope wound around the shaft. Beginning with the C.30 in 1933, a shaft off of the engine could spin the rotor prior to take-off and then be disengaged in flight. Another innovation was the tilting rotor head, so that the rotors (and thus the lift vector) could be tilted toward any direction to produce the desired maneuver. Take-off runs could be accomplished in about 90 ft (27 m), with landings in less than 9 ft (3 m). In 1933, Cierva began to develop a jump take-off, effected by revving the engine and suddenly releasing the clutch. A modified C.30 aircraft, which became the prototype for the 1936 C.40 autogyro, perfected the development of a rotor system that could rise vertically off the ground. Unfortunately, Cierva was killed in a fixed wing airplane crash in 1936, perhaps robbing the world of significant technological innovations for years to come. [10,23]

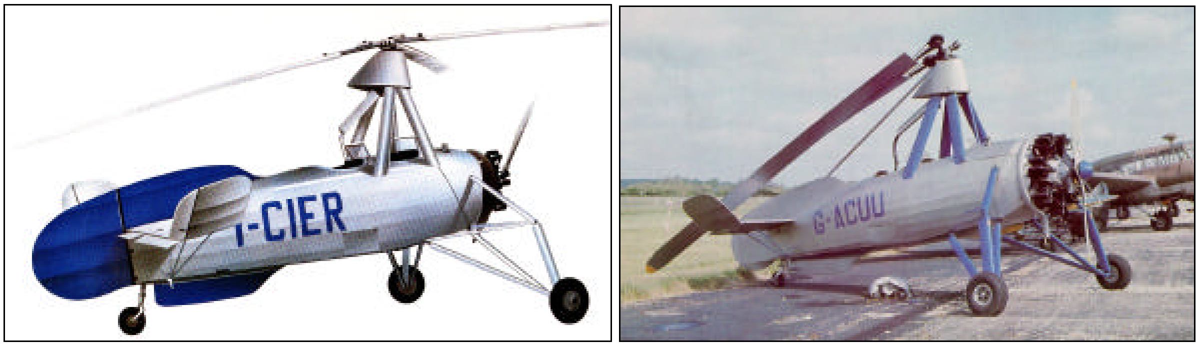


Figure 21. Cierva C.30 autogyro.

A number of companies became Cierva licensees, with Avro in the UK being the largest autogyro manufacturer. Harold Pitcairn received a license to produce the Cierva autogyros in the US, while Kellett received a license to develop its own autogyros. Other companies in Britain, France, German and Japan were also granted licenses. Some designs just mounted the Cierva rotor system on whatever airframe was readily available, while others were purpose-designed aircraft. [23,24]

Autogyros were also developed in the Soviet Union. The first Soviet rotary wing aircraft, the KaSkr-1, was designed by Nikolai Kamov and Nikolai Skrzhinskii, and made its first flight in September 1929. The aircraft was underpowered, so it was rebuilt as the KaSkr-2 with the 240 hp (179 kW) Soviet license built Gnome-Rhône Titan. Mikhail Mil also worked on the project.* In 1931, the three Soviet designers were assigned to the Central Aero-Hydrodynamic Institute (TsAGI). The first TsAGI autogyro was designated 2-EA, powered by a Soviet Titan engine. Maximum speed was nearly 100 mph (160 km/hr) and endurance was well over 1 hr. The 2-EA was tested extensively for two years. A slightly bigger engine and other refinements led to the A-4, a few of which were assigned to the Soviet Air Force. [18,23]

Kamov began the design of the A-7 to ambitious requirements in 1931, with first flight in 1934. A 480 hp (358 kW) M-22 radial engine (a license of the Bristol Jupiter) powered the 5,070 lb (2,300 kg) aircraft to speeds of up to nearly 120 mph (200 km/hr). The 3-blade rotor was 49.8 ft (15.2 m) in diameter. The observer/gunner had three 7.62 mm PV-1 machine guns in forward and rear defense positions. Several aircraft were produced and supported the July 1941 battle against the Germans at Smolensk. The much smaller (around 1800 lb or 800 kg, loaded) A-6, A-8, A-13 and A-14 autogyros were also developed between 1933 and 1935. The larger A-12 began testing in 1936 and the A-15 in 1937. None entered production. [18,23]

Worldwide, the autogyro was quite successful, with about 500 built in the 1930s and 1940s. A list of characteristics of representative autogyros is found in the appendix at Table 2. Despite the improvements, and the near zero take-off and landing lengths, it could not achieve the sometimes essential requirement to hover. Certainly the primary missions that the helicopter was first employed for – rescue and transportation of large slung loads – could not be accomplished by an autogyro. By this time, however, the helicopter was finally catching up and coming into its own.

* During the war, Kamov and Mil became the heads of the two preeminent Soviet helicopter design bureaus.

Pre-WWII Helicopters

The first vertical flight machine that one can truly call a helicopter was developed by Louis Breguet, the same man who built the first vertical flight machine, the Gyroplane, and its convertaplane derivatives. Breguet had meanwhile become a very successful designer of fixed wing aircraft. In 1931, he founded the *Syndicat d'Etudes du Gyroplane* with René Dorand, who became the technical director. They designed a coaxial rotor aircraft, which they designated the *Gyroplane Laboratoire*. This airframe, like nearly all vertical flight machines up to that point, was a steel tube open framework, supporting the engine, fuel tank, rotors and pilot. However, the rear booms supported plywood tail surfaces, and a wide track landing gear on outriggers with nose and tail wheels made the aircraft look a lot more like a viable helicopter (see Figure 22). But the differences were a lot more than aesthetic. The 52.5 ft (16 m) *Laboratoire* rotors were metal with an airfoil cross section and were mounted to the central hub by universal joints: this was the first time that articulated blades were used on a helicopter. Cyclic pitch was used lateral and longitudinal translation, and collective pitch effected vertical movement. Finally all the necessary basic ingredients were present for the first successful helicopter design. [5,15,23]

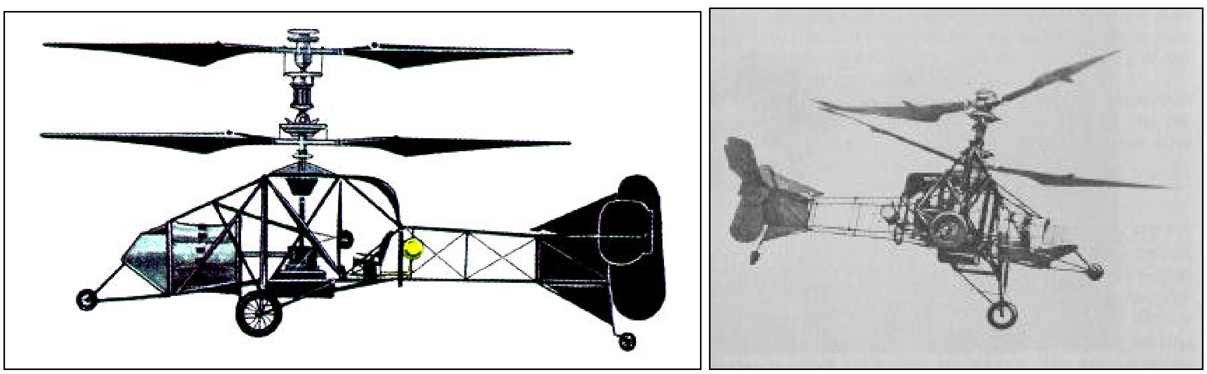


Figure 22. The 1936 Breguet *Gyroplane Laboratoire* helicopter.

The *Laboratoire* helicopter was powered by a 350 hp (260 kW) Hispano 9Q radial engine. The 3,153 lb (1,430 kg) machine had a gross take-off weight of 4,475 lb (2,030 kg). It made its first flight on 26 June 1935. After some initial problems with instability, this aircraft demonstrated the necessary power and controllability for truly successful vertical flight. The *Laboratoire* helicopter soon began setting FAI-recognized records: on 22 December 1935, the helicopter achieved a speed of 67 mph (108 km/hr); on 26 September 1936, a height of 518 ft (158 m) was set; and, on 24 November 1936, an endurance of nearly 63 minutes and a closed-circuit distance of 27.3 miles (44 km). In 1937, the helicopter made its first autorotation landing. But it was not the first helicopter to do so: by this time, the amazing leap forward of the *Laboratoire* had been eclipsed by the performance of the Focke Achgelis Fw 61. [10,15]

Dr. Heinrich Focke, the head of the Focke Wulf Aircraft Company, began building Cierva C.19 and C.30 autogyros under license in 1932. In 1934, he built and successfully flew a scale model helicopter. After another two years of research and testing of rotor and transmission systems, Focke built the Fw 61, which made its first flight, lasting 28 seconds, on 26 June 1936. Powered by a BMW Bramo Sh 14A engine* producing 160 hp (119.4 kW), and weighing 2,090 lb (949 kg) at take-off, the Fw 61 used two three-blade fully articulated rotors mounted on outriggers on either side of the fuselage, which came from a Fw 44 biplane trainer. This placement of the 7 m (23 ft) rotors avoided vibrational problems encountered with coaxial arrangements. A small propeller on the engine was used for cooling only. Blade angle of the rotors was varied for lateral movement. In May 1937, the Fw 61 made the first autorotation landing in a helicopter. In February 1938, public demonstrations were conducted for two weeks inside the *Deutschlandhalle* sports stadium (Figure 23). A second aircraft was also built and tested. A number of FAI records were made from 1937 to 1939, including: maximum speed of 77 mph (124 km/hr), maximum distance of 143 miles (230 km), and maximum altitude of 11,243 ft (3427 m). Focke was dismissed from the company by the Nazis in 1938 for being politically unreliable, but continued his research under the Focke Achgelis company, with renowned pilot Gerd Achgelis. [14,15,21]

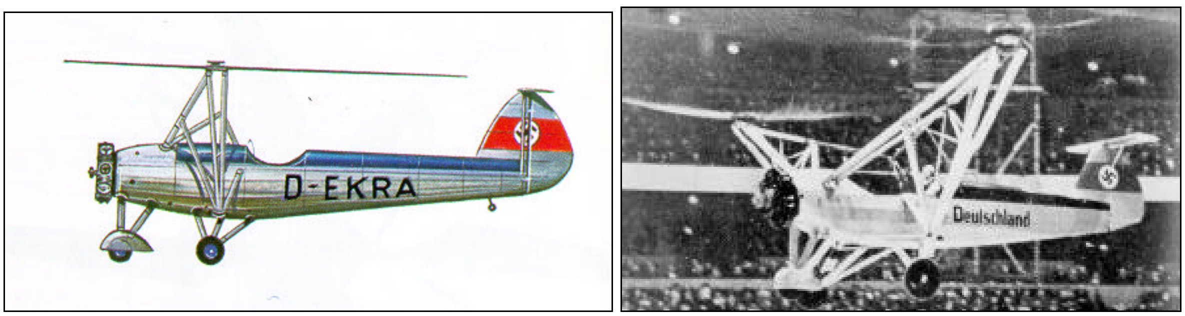
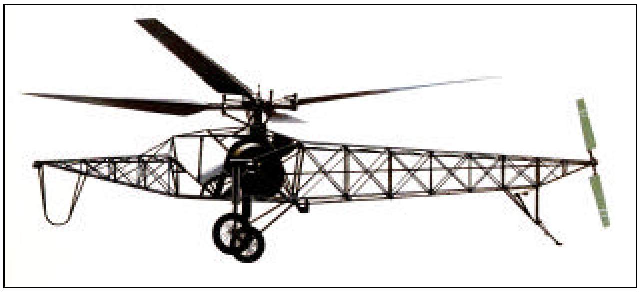


Figure 23. The 1937 Focke Wulf Fw 61 helicopter.

Meanwhile, in the Soviet Union, TsAGI also began investigating helicopters. Boris Yuriev was put in charge of their efforts in 1925. The first machine, the 1-EA, began tethered tests in August 1930. It had a single 36.1 ft (11 m) 4-blade rotor and small anti-torque/steering rotors at the nose and tail. The 2,525 lb (1,145 kg) machine was powered by two 120 hp (90 kW) M-2 rotary engines, which gave it adequate power, but there was insufficient control authority. Maximum forward speed was nearly 100 mph (160 km/hr). On 14 August 1932, the 1-EA reached an altitude of nearly 2,000 ft (610 m), and on 15 June of the following year remained airborne for 14 minutes. Ivan Bratukhin, who had designed the 2-EA autogyro, redesigned the 1-EA rotor system for a new machine, the 5-EA. The 5-EA had a single 6-blade rotor, with three 25.5 ft (7.8 m) blades and three 39.3 ft (12 m) blades. It was intended that the larger blades would provide lift while the smaller blades were for steering. First flight was in 1933, but performance was much worse, with forward speed being only about 12 mph (20 km/hr). [18,23]

* The engine was developed by Siemens und Halske Flugmotorenwerk (hence the "Sh"), a subsidiary of Siemens. The company became independent in 1936 as the Branderburgische Motorwerke (Bramo) which was acquired by BMW in 1939.



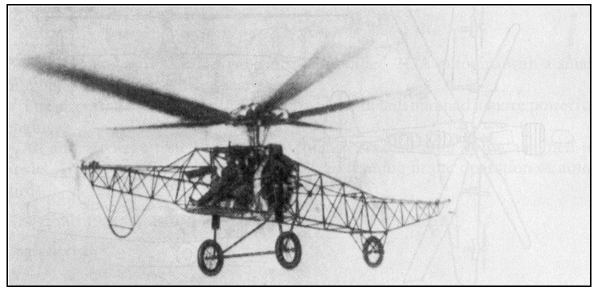


Figure 24. The TsAGI 1930 1-EA (left) and 1933 5-EA (right).

Bratukhin then built the 11-EA, a much larger machine, powered by a single 630 hp (470 kW) Curtiss Conqueror mounted in the nose. The 11-EA had a rotor system similar to, but much larger than, the 5-EA. Propellers were mounted on stub wings for torque control and forward propulsion. Tethered tests in 1936-38 were not satisfactory. Bratukhin then modified the aircraft, which became the 11-EA PV (Propulsion Variant) in 1939 with the propellers replaced by four rotors at the end of lattice outriggers. Sustained flight of nearly 1 hr with two men on board was conducted. The machine eventually had to be grounded in 1941 because the engine and other components were wearing out. [15,19]

WWII Helicopter Development

A scaled-up version of the Fw 61, the 6-passenger transport Fa 266 Hornisse ("Hornet"), was built for Lufthansa in late 1939. With the outbreak of war, however, this was converted into a Luftwaffe transport, redesignated the Fa 223 Drache ("Dragon"), with first flight the following June. A BMW Bramo 323 Fafnir radial engine producing 1,000 hp (745 kW) powered the twin 39 ft (11.9 m) rotors, propelling the aircraft to speeds of up to 109 mph (176 km/h) and distances of up to 200 miles (320 km). Maximum take-off weight was 11,020 lb (5,000 kg). The aircraft was extensively evaluated, including providing a mountain battery with ammunition and supplies, a job that normally required 40-50 mules. Later, an entire battery of 7.5 cm infantry guns were moved from a valley to a 6,500 ft (2,000 m) high mountain position by a single Fa 223. Engines and even entire airplanes could also be transported. Based on the capabilities demonstrated, 100 aircraft were ordered for planned roles of antisubmarine patrol, reconnaissance, rescue, and cargo transport, but only 10 were flown before Allied bombing destroyed the plant. [15,17,18,21]

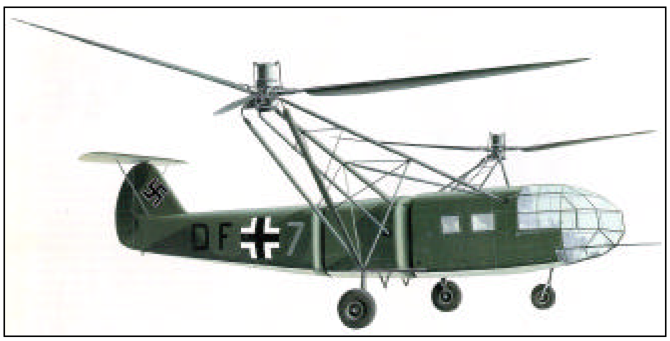


Figure 25. The 1940 Fa 223 Drache transport helicopter.

Anton Flettner began rotary wing experiments in 1922. In late 1936, he built a partially powered autogyro, the Fl 184, but the prototype caught fire in flight and was destroyed. Flettner's Fl 185 had a single 39.5 ft (12 m) three-blade rotor with two small propellers mounted on outriggers, one facing forwards and one rearwards. In forward flight, both propellers could provide thrust and the rotor was allowed to autorotate as an autogyro.

Figure 26. The Flettner Fl 185 powered autogyro.

Flettner then developed a series of helicopters using counter-rotating intermeshing rotors with the hubs close together and angled slightly outward. The first was the Fl 265, which made its first flight in May 1939. Six prototypes were tested.

Figure 27. The Flettner Fl 265 with intermeshing-rotors.

The aircraft was ordered into production in 1940, but deferred because the two seat Fl 282 Kolibri ("Humming Bird") was by then being tested for liaison and communication roles. In 1942, the Fl 282 became the first helicopter to enter operational military service. It was more highly developed and flew more hours than any other German helicopter. The German air force and navy ordered production of 1,000 aircraft, but only about 30 survived Allied bombing long enough to be completed. Each of the Flettner rotary wing aircraft were powered by the Sh 14A radial engine and weighed around 2,200 lb (1,000 kg). Maximum level speed for the Fl 265 was 100 mph (160 km/hr) and for the larger Fl 282 was 93 mph (150 km/hr). [15,18,21]

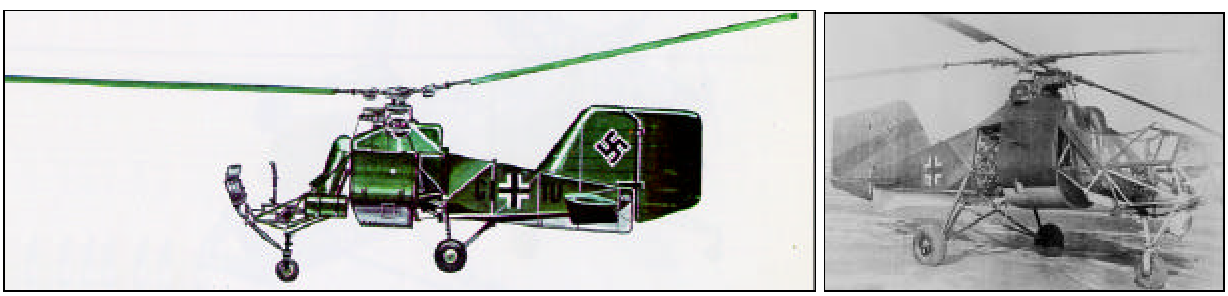


Figure 28. The Flettner Fl 282 Kolibri.

Another German rotorcraft tested during the war was the WNF Wn 342 tip jet observation helicopter, designed by Dr. Friedrich von Doblhoff, Dr. A. Stepan, and Theodor Laufer. Four prototypes were built with a maximum weight of 1,410 lb (640 kg), the first being tested in 1943 in Vienna. A centrifugal supercharger supplied a fuel-air mixture through the rotor blades to small jets at each tip. The final test aircraft, V4, used the 140 hp (104 kW) BMW Bramo Sh 14A radial engine. High fuel consumption, however, led to a selective clutch that enabled the rotor to autorotate during flight, with the aircraft propelled by a pusher propeller. [15,18,21]

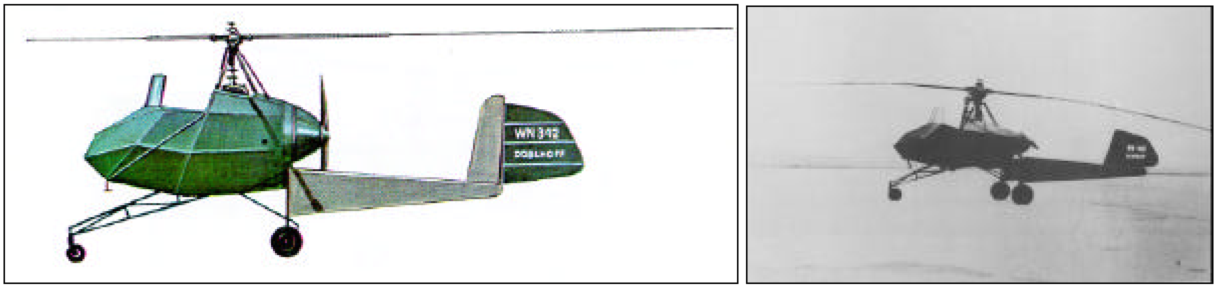


Figure 29. The WNF Wn 342 V4 tip-jet helicopter.

In the US, Igor Sikorsky had fled Russia for the US in 1918 after establishing reputation as an aircraft highly successful designer and innovator. In 1938, Sikorsky's design team built a rotor test stand to study lift and torque forces. The following spring, they began the design of a simple test vehicle. The VS-300 was powered by a 65 hp (48 kW) Lycoming engine, driving a 28 ft (9 m) 3-blade main rotor and a single blade, counter-balanced tail rotor. Gross weight was 1,092 lb (495 kg). The framework structure was specifically designed to be easily modified. [5,7]

As the war broke out in Europe, Sikorsky made the first flight of his VS-300 on 14 September 1939. The machine was tethered to heavy weights to improve stability and safety. Over the next several months, Sikorsky and other pilots explored the stability and control of the machine. A sudden crosswind on 9 December 1939 flipped the aircraft over, causing severe damage. Over the next several months, the vehicle was extensively modified. A longer tail structure was added with two small horizontal rotors in addition to the anti-torque rotor. The main rotor cyclic control was removed and translation was effected by using the tail rotors to tilt the aircraft in the desired direction. On 13 May 1940, the VS-300 began making a number of increasingly successful flights. The new configuration was significantly more stable. [3,5]

Meanwhile, the US Army Air Corps had solicited proposals for rotary wing military aircraft. Five autogyro designs were submitted. Platt-LePage submitted a twin-rotor design similar to the Fw 61, with counter-rotating rotors extended from the fuselage on pylons. Sikorsky submitted a slightly larger version of the initial VS-300 design; it was later updated to the May 1940 configuration, but Platt-LePage won a development contract in July 1940 for its XR-1. [5,7]

Work continued on the VS-300. The engine was updated with a 90 hp (67 kW) Franklin and the machine continued to improve. Another crash in October 1940 allowed the team to make additional modifications, particularly to the tail rotor configuration. Flight testing resumed in January 1941. That month, Sikorsky also was awarded an Army contract to build a two seat observation helicopter, designated XR-4. On 6 May, the VS-300 broke the Fw 61's endurance record with a time of 1 hour, 32 minutes and 26 seconds. That fall, a number of different tail configurations were again tested. On 8 December 1941, the VS-300 made its first flight in its final configuration (Figure 44): full cyclic control of the main rotor with a single tail rotor for torque and yaw control. A change to the main rotor dampers on the last day of 1941 damped the fore and aft motion of the blades, providing a dramatic improvement in performance. [5,7]

The XR-4 made its maiden flight on 14 January 1942, incorporating the final modifications evaluated on the VS-300. Sikorsky flew the XR-4 to Wright Field in Dayton, Ohio: a five day, 761 mile (1,225 km) journey. Extensive evaluation tests were conducted and on 21 December 1942, Sikorsky received a contract for 15 YR-4 service test helicopters as well as another contract for 5 prototypes of a heavier (4,896 lb or 2,221 kg) aircraft, the XR-5. A total of 131 R-4s were built; the R-4 was the only Allied helicopter that saw significant use during the war, primarily for rescue missions in Alaska, Burma and other areas with harsh terrain. 65 R-5s were built, as were 229 of the more refined version of the R-4, the R-6. [5,7,18]

Figure 30. The Platt-LePage XR-1A.

The Platt-LePage XR-1, meanwhile, had made its first flight in May 1941. A Pratt & Whitney R-985 radial engine provided 440 hp (328 kW) to two 30.5 ft (9.3 m) rotors. The aircraft weighed 4,730 lb (2,147 kg) at take-off. Performance was adequate, with a maximum speed of 110 mph (177 km/hr). A second aircraft, designated XR-1A, was also built. It was 600 lb (250 kg) heavier and used a 450 hp (335 kW) R-985 engine. The XR-4, however, was half the weight and was considered to be much simpler in design, so the XR-1 was not put into production. [5,7,18]

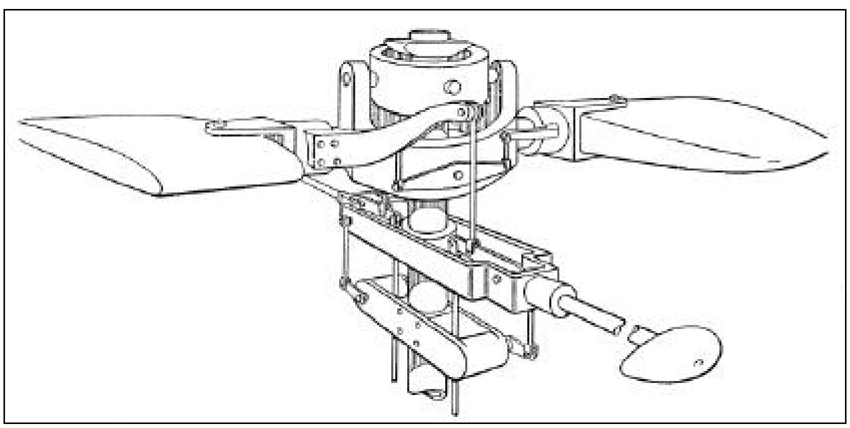


Figure 31. The Bell rotor system.

In September 1941, Arthur Young made a presentation to Bell Aircraft in Buffalo, New York. He was successful in convincing the company to fund construction of two demonstrator helicopters. Young had become intrigued by the helicopter in 1928 and tested a remote control model in 1941. Young designed a two-blade rotor system that obviated the need for articulation as well as flapping, drag or other hinges (Figure 31). Instead, it used a stabilizer bar mounted at a 90° angle to the blades and attached to the hub; the stabilizer was not affected by gusts and helped bring the main rotor blades back into their original plane of rotation after perturbations. This simplified the controls and reduced the weight and maintenance.

In December 1942, a demonstrator aircraft, the Model 30, was flown. It had a 32 ft (10 m) rotor, powered by a 160 hp (120 kW) Franklin engine. By June 1943, the first aircraft was flying at over 70 mph (113 km/hr). Two more test aircraft were built, before the first flight of the production version, the Model 47, on 8 December 1945. [5,14]

Meanwhile, a group of University of Pennsylvania engineering students formed the P-V Engineering Forum, led by Frank Piasecki, to design and build a helicopter. The PV-2 was a single rotor helicopter that featured the first dynamically balanced rotor blades, a rigid tail rotor, and full cyclic and collective rotor pitch control. The first flight was made on 11 April 1943. Based on this experience, Piasecki built the PV-3, designated XHRP-X "Dogship", which first flew on 7 March 1945. The signature Piasecki tandem rotor design, however, earned it the nickname, the "Flying Banana." Three test aircraft and 20 production helicopters were built. The aircraft was capable of carrying 1,800 lb (816 kg) of payload. The HRP-1 used two 600 hp (447 kW) Pratt & Whitney R-1340 engines to power a 41 ft (12.5 m) rotor at the front and rear of the fuselage. Loaded weight was 6,900 lb (3,133 kg) and it could carry eight troops. Maximum speed was 99 mph (159 km/hr) and range was 265 miles (427 km). [5,23]

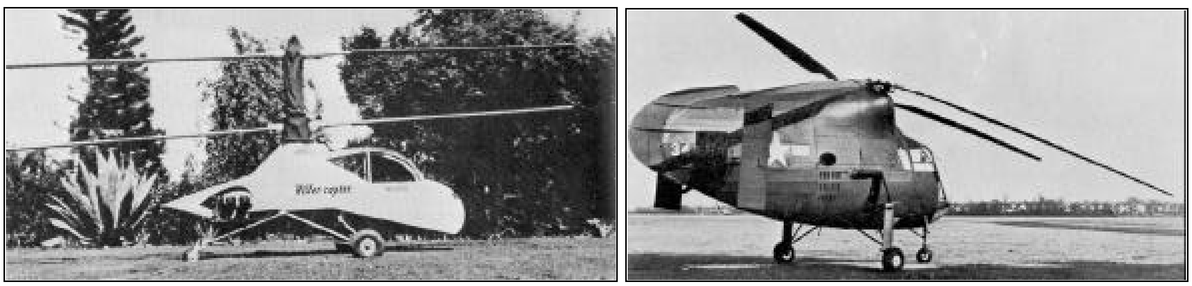


Figure 32. The Hiller XH-44 coaxial (left) and the Kellett XR-8 (right) intermesh.

Several other American helicopters made their first flights in 1944. Stanley Hiller flew the first successful American co-axial helicopter, the XH-44, in July 1944. It also featured the world's first successful all-metal rigid-rotor blades. Kellett flew the first intermeshing rotor helicopter in the US, the XR-8, in August. By the end of 1945, a number of other U.S. companies also produced demonstrator helicopters, including the Landgraf Helicopter Company, Higgins Industries, Firestone, Aeronautical Products, and Bendix Helicopters; none of these companies, however, succeeded in reaching production. Successful indigenous helicopters were also developed in England, France, Germany, Japan, Canada, Czechoslovakia, Poland, and many other countries. [23]

Improvements In Thrust To Weight

The number of serious efforts to develop a manned, powered lift aircraft far exceeded attempts for a fixed wing aircraft until the late 1880s. By the time the Wright Brothers flew the first successful airplane in 1903, more than 40 vertical flight machines had been built. Without the high power to weight ratio of the piston engine, however, they were all doomed to failure. Prior to Nicolaus Otto's invention of the four-stroke internal combustion engine in 1876, available powerplants (usually steam powered) were simply too heavy for practical flight. [3]

As an illustration of the necessity of the internal combustion engine for aeronautical propulsion, consider Sir Hiram Maxim's giant biplane of 1884. It was powered by two steam engines burning naphtha to drive counter-rotating propellers. Each engine weighed only 310 lb (141 kg) and produced 180 hp (134 kW) – a remarkable 0.58 power to weight. Add to that, however, 2,400 lb (1,089 kg) for the boilers, piping and water, and the power to weight dropped to an intolerable 0.067. [8] It was not just a matter of improving the technology: in 1933, the first (and only) full-size airplane to be successfully powered by a steam engine, the Travel Air 2000 biplane, made its maiden flight. At 150 hp (112 kW), the system weighed 665 lb (302 kg): still only a 0.23 power to weight, about a quarter the power to weight of the state of the art piston engine. Although the feasibility of steam powered flight was demonstrated, the additional weight, volume, complexity and inefficiency, made it starkly inferior to the internal combustion engine. [11,16]

The improvement of the aircraft piston engine was remarkable during the first half of this century. The performance and power to weight was increased not only by improvements of the basic engine components –such as cylinder blocks, pistons and valves – but also to subsystems, internal cooling, superchargers, and variable pitch propellers (for fixed wing aircraft). Fuels and lubricants also significantly contributed to additional performance, being credited with as much as 50% of the improvement. Compared to the impressive Samuel Langley's 1903 Manly-Balzer engine, by the end of World War II, maximum horsepower had increased 100 times (Figure 33), power to weight had increased by a factor of five or more (Figure 34), and power to displacement volume improved 10 times (Figure 35). This is in addition to remarkable improvements in specific fuel consumption, durability and reliability. [8]

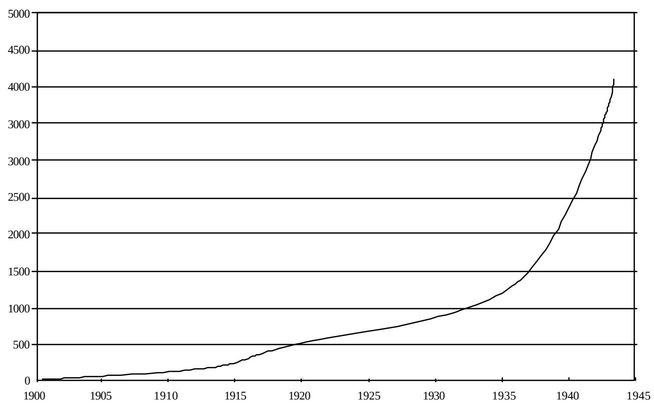


Figure 33. Piston engine performance trends, 1900-1945: Maximum power rating (hp). [8,11,16]

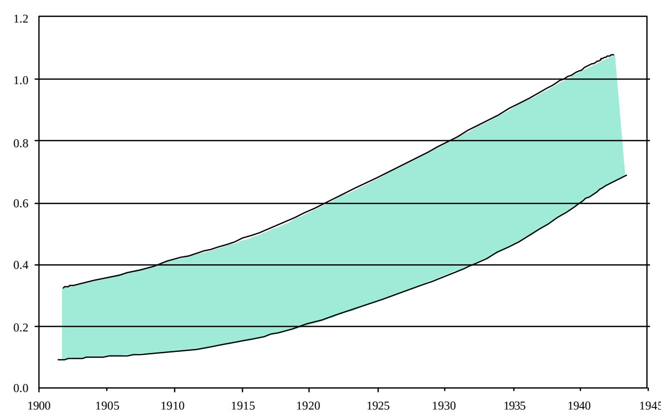


Figure 34. Piston engine performance trends, 1900-1945: Power/weight (hp/lb). [8,11,16]

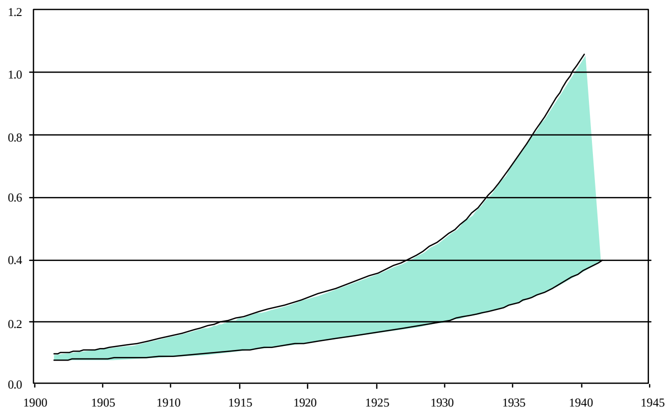


Figure 35. Piston engine performance trends, 1900-1945: Power/displacement (hp/in^3). [8,11,16]

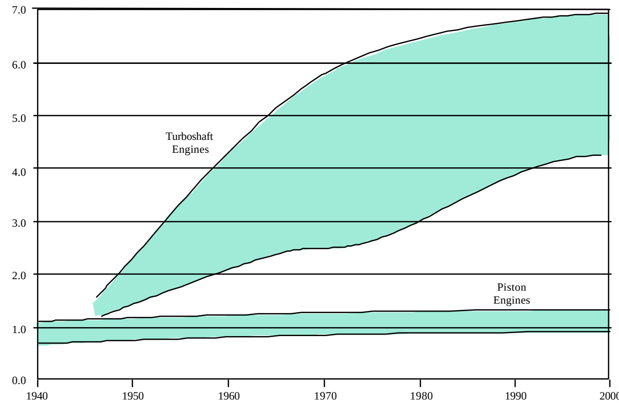


Figure 36. Engine performance trends, 1940-2000: Power/weight (hp/lb). [3,6,11]

The continued improvements discussed above were fueled by demands for higher performance transportation systems for land, air and sea. These developments, however, made engines of sufficient power to weight available for vertical flight machines as well. The high performance piston engines available prior to the Second World War provided the power, while the continued research and improved understanding of rotor blades allowed the development of efficient lifting surfaces that could produce sufficient thrust to lift the machines off the ground.

With the development of the turboshaft engine, the available power to weight of a powerplant increased from a nearly asymptotic value of about 1.0 hp/lb at the end of WWII, to 3.0 hp/lb by 1960, and around 6.0 today (see Figure 36). The higher power to weight of gas turbine engines has dramatically reduced the percentage of aircraft volume and weight occupied by the propulsion system, facilitating lower drag vehicles and increased efficiency. So, the improvements in power to weight of the piston engine prior to WWII made the helicopter possible. The introduction of the turboshaft engine after WWII made the helicopter more productive. Improvements since then have made the helicopter more efficient. For propeller and rotor propelled V/STOL aircraft, advances in power from the piston engine (Transcendental 1G and the Bell XV-3) to the turboshaft (the Bell XV-15 and the V-22) have facilitated a similar improvement in capability. [3,6,11,12]

The turbojet/turbofan similarly increased in thrust to weight ratio from about 1:1 in WWII to 4:1 in 1960 and around 9:1 today. Like the piston and turboshaft engines, these improvements have been accomplished while simultaneously reducing fuel consumption and detectability, as well as increasing durability and reliability. For the short term durability of lift engines, thrust to weights of 16:1 were achieved in the 1960s. These lift engines made high speed V/STOL flight possible, by designing a relatively conventional jet supplemented by lift engines for vertical flight. As discussed above, however, the additional volume of the propulsion system precluded the addition of much useful load. The unique design of the Harrier, with a single high thrust to weight engine, made jet-borne V/STOL practical. Continued improvements in thrust to weight have allowed the design of such aircraft as JSF, which seeks to make high speed V/STOL more efficient. [11]

Improvements In Control

In addition to the development of a high thrust to weight propulsion system, the development of a practical vertical flight machine required adequate control in hover and during translation. The use of cyclic (Ellehammer, 1912) and collective pitch control (de Bothezat, 1922) and blade articulation – i.e. flapping hinges (Cierva, 1923) and drag hinges (Cierva, 1927) – were essential for the helicopter to achieve control. Pescara (1924) was the first to combine cyclic and collective pitch control in a single machine, while Breguet's *Gyroplane Laboratoire* (1935) was the first helicopter to use pitch control and blade articulation. It was not until these innovations were integrated on a machine that the helicopter could become successful, as the vertically mounted propeller could not begin to accommodate the complex interactions required for forward flight, clearly shown in Figure 37.

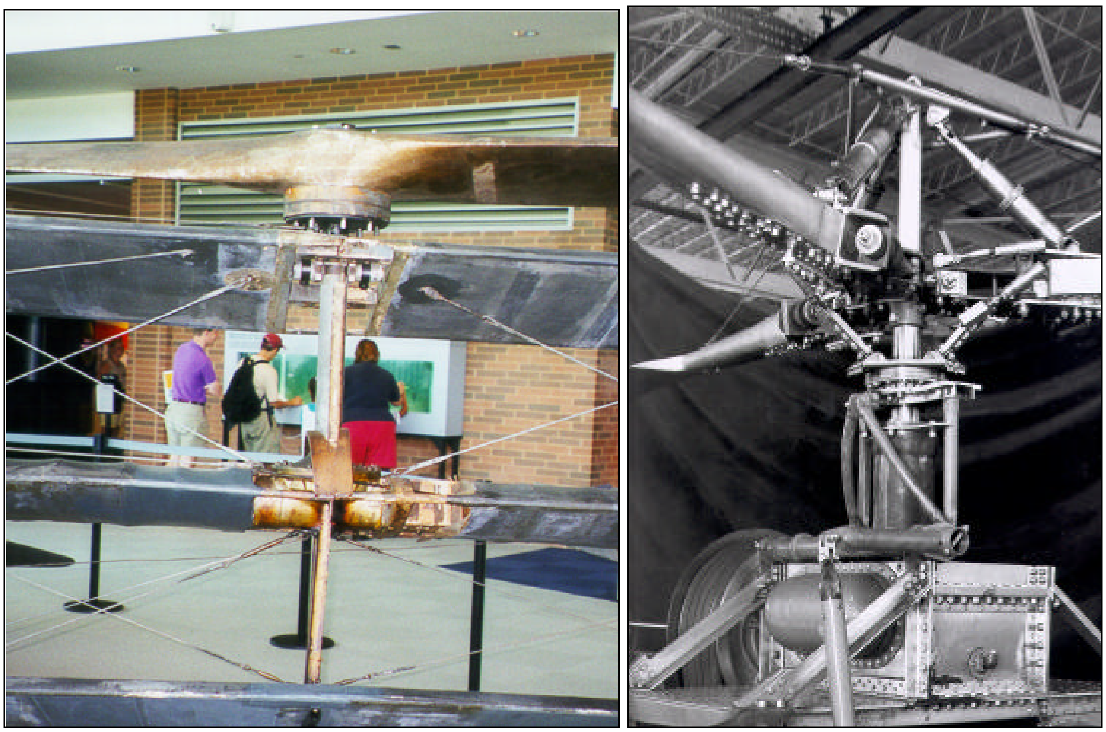


Figure 37. The 1922 Berliner rotor (left) and the 1940 Sikorsky rotor head (right).

Ironically, these control effectors had been conceived several years before they were successfully demonstrated on a full-scale machine: Charles Renard invented flapping hinges in France in 1904, Gaetano Crocco proposed cyclic pitch control in Italy in 1906, and Yuriev suggested collective control in 1911. Even more so than with the development of conventional aircraft, there was a gulf between theorists and vertical flight aircraft builders. With the fixed-wing aircraft, the Wright Brothers conducted extensive aerodynamic experiments – building a wind tunnel and testing gliders – to bridge this gap. This is why they were able to fly their demonstrator aircraft when so many others had failed:

> The Wright's sophisticated totality of the pre-flying tradeoffs and design integration along with minimization and focus are not evident features when analyzing contemporary flying machines…. [Similarly,] The helicopter experimenters showed no sense of the priorities as did the Wrights, and bundled all the development problems in one grand trial and error effort with prototypes. [14]

Another challenge was the difficulty in testing a full-scale vertical flight machine. The Wrights began developing their control system and understanding of aerodynamic flight with gliders in 1900. For their first powered flight, the Wright Brothers were able to use a launching track, ground effect, and a headwind. These crutches would have been of no use to the early vertical flight pioneers. It did, however, allow the Wrights to continue to perfect the controls for their flying machines, so that by 1906 – before any other powered machine had left the ground – the Wright Flyers were capable of flying for a distance of nearly 25 miles (40 km) with an endurance of well over a half hour. It would be 30 years before a helicopter would have the controllability to match that performance.

The development of the autogyro, which could not hover and was not a true vertical flight machine, was nonetheless instrumental in solving the critical control problem of blade articulation for the helicopter. It furthermore provided a general acceptance of rotary wing aircraft, and offered extremely short take-offs and landing distances with respectable cruise performance. A comparison of the performance of typical small fixed wing aircraft to autogyros and helicopters during the first half of the century is shown in the following graphs, Figure 38 through Figure 40.

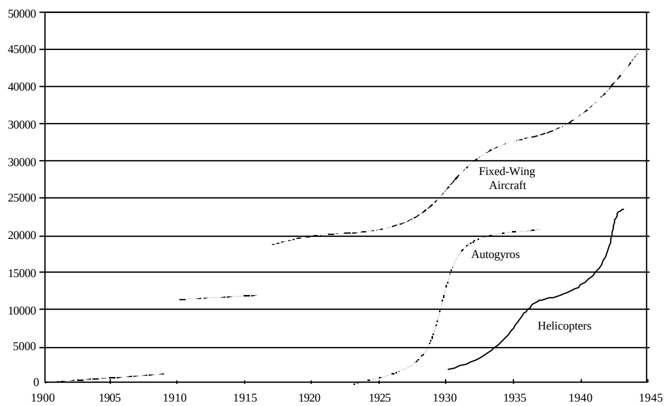


Figure 38. Aircraft performance trends, 1900-1945: altitude (ft). [15,24]

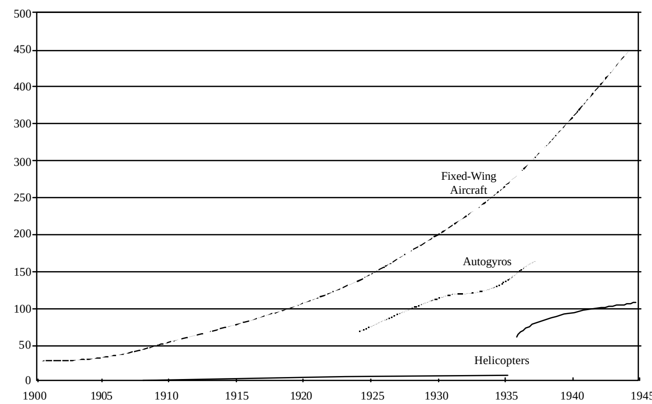


Figure 39. Aircraft performance trends, 1900-1945: speed (mph). [15,24]

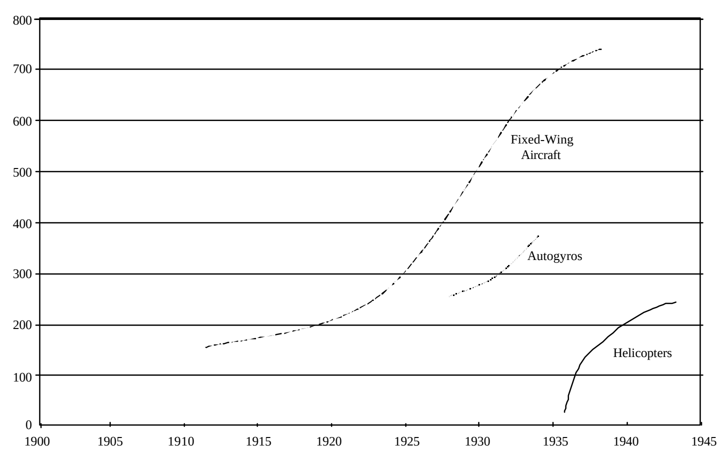


Figure 40. Aircraft performance trends, 1900-1945: range (miles). [15,24]

Part II
The American Helicopter:
A Directory of American Helicopters 1940-2000

Introduction

Following WWII, a number of alternative methods of propelling helicopter rotor blades were examined. As will be discussed in the following pages, Doblhoff ended up at McDonnell, where both tipjet and ramjet propulsive rotors were flight tested. The Hiller Hornet also had tip ramjets. The American Helicopter XA-5 Top Sergeant, using a modified Sikorsky R-6 fuselage and a pulse-jet engine, first flew in 1948; it led to several additional pulse-jet test aircraft including the XH-26 Jet Jeep in 1952. Other designs, such as the Dutch H-2 and H-3 Kolibrie, of which a handful were produced in the mid-1950s, also used ramjets to drive the rotors. The RotorCraft RH-1 Pinwheel was the first rocket-powered helicopter, using 90% hydrogen peroxide propellant, making its first flight in April 1954. [15,19,23]

The largest rotor ever flown was the 130 ft (37.6 m) two blade rotor of the 43,500 lb (19,750 kg) Hughes XH-17 in 1952; fuel and compressed air were piped to the blade tips and burned. The Hughes XV-9 was first flown in November 1964 to evaluate hot-cycle propulsion, where hot exhaust gases from the engines are ducted to the rotor tips. The Sud-Aviation S.O. 1221 Djinn, designed with assistance by the WNF's Theodor Laufer, was the first production helicopter to make use of the 'cold-jet' principle, where compressed air was used to drive the rotor without burning. The first prototype flew in September 1953 and the first production aircraft in January 1956. With this exceptions, most of the concepts were not put into production: specific fuel consumption, reliability, weight, complexity and other factors prevented them from being competitive with conventional rotor propulsion methods. [15,19,23]

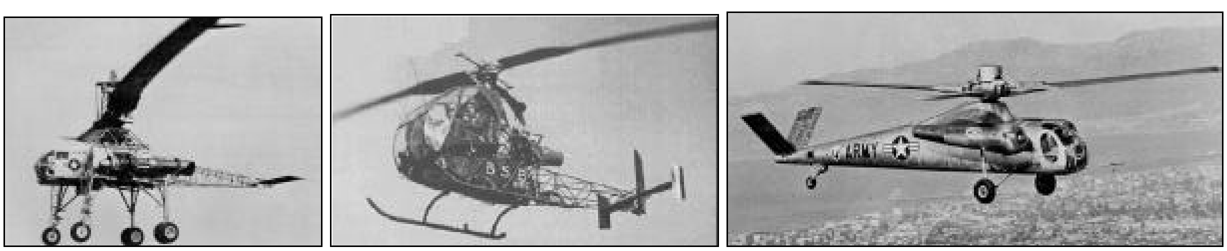


Figure 41. The Hughes XH-17 tip jet helicopter (left), the Sud Aviation Djinn cold cycle helicopter (center), and the Hughes XV-9 hot cycle helicopter (right).

Other small 'personal' man-carrying research vehicles were also tested during the mid-1950s and early 1960s. Hiller and Gyrodyne developed the portable Rotorcycles that could be air-dropped and assembled by one man under combat conditions in five minutes. A number of one-man flying platforms were also tested, primarily consisting of handrails to hold on to (or later, a seat) and propellers or rotors spinning just below the pilot. The standing platforms included the deLackner DH-4 Helivector and DH-5 Aerocycle, which used 15 ft (4.5 m) open counter-rotating rotors; and the Hiller VZ-1 Pawnee, which had 5 ft (1.5 m) ducted propellers. These standing platforms were steered by leaning in the desired direction. A slightly larger platform, (allowing a sitting position) was the Bensen B-10 Propcopter, which had a 4 ft (1.2 m) propeller fore and aft of the seat, each powered by a separate engine. With the introduction of turboshaft engines, the Army began researching 'flying trucks', such as the four-propeller Curtiss-Wright VZ-7, and the twin-rotor Chrysler VZ-6 and Piasecki VZ-8 Airgeep. Although smaller and more maneuverable than helicopters near the ground and capable flying close to or even under obstacles, the small propellers or rotors had a very high disk-loading and consequently higher fuel consumption and shorter endurance. Various other strap-on or hang-on rotor, tip jet, turbofan, and rocket-powered devices were also tested for the purpose of combat surveillance or troop mobility. [14,18,19]

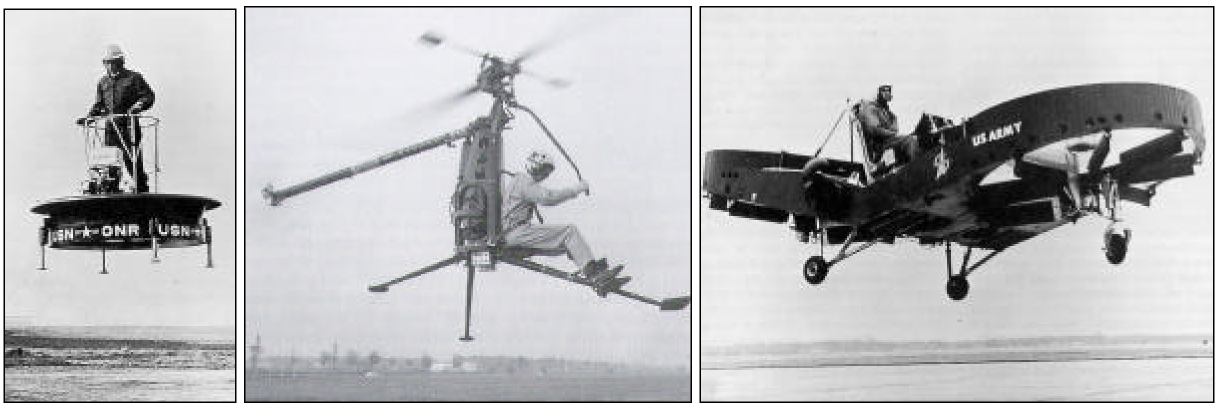


Figure 42. The Hiller VZ-1 Pawnee (left), the Hiller Rotorcycle (center) and the Piasecki VZ-8P Airgeep II.

The combat environments of Korea and Vietnam did much to spur rapid development of vertical flight aircraft. Helicopters were used for troop and equipment transport, medical evacuation, and attack. The introduction of the turboshaft engine greatly improved the power to weight, speed and payload (although at increased fuel consumption) of the helicopter and led to further developments in vertical flight. [3]

Sikorsky

Igor Sikorsky had fled Russia for the US in 1918 after establishing a reputation as a highly successful aircraft designer and innovator. He began a flourishing business building seaplanes in Connecticut. In 1929, Sikorsky Aircraft became a division of United Aircraft (known as the Vought-Sikorsky Division until 1943). In 1930, he began sketching single rotor helicopter designs. The following June, Sikorsky filed a patent describing a helicopter with cyclic pitch control that used trailing edge flaps on the single main rotor blades. After several more years of study, Sikorsky convinced the management of his parent company, United Aircraft, to fund development work. In 1938, the design team built a rotor test stand to study lift and torque forces. The following spring, they began the design of a simple test vehicle. The VS-300 (Vought-Sikorsky – helicopter No. 3) was powered by a 65 hp (48 kW) Lycoming engine, driving a 28 ft (9 m) 3-blade main rotor and a single blade, counter-balanced tail rotor. Gross weight was 1,092 lb (495 kg). The framework structure was specifically designed to be easily modified. [5,7]

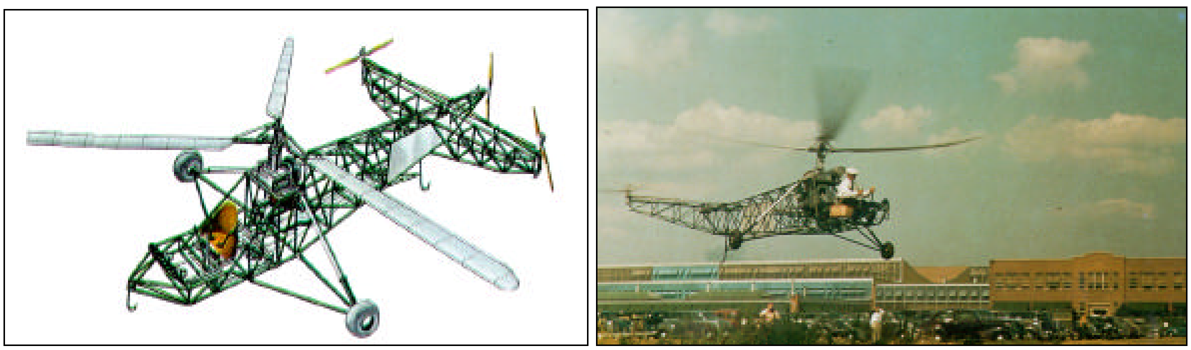


Figure 43. The Sikorsky VS-300 in 1940.

As the war broke out in Europe, Sikorsky made the first flight of his VS-300 on 14 September 1939. The machine was tethered to heavy weights to improve stability and safety. Over the next several months, Sikorsky and other pilots explored the stability and control of the machine. A sudden crosswind on 9 December 1939 flipped the aircraft over, causing severe damage. Over the next several months, the vehicle was extensively modified. A longer tail structure was added with two small horizontal rotors in addition to the anti-torque rotor. The main rotor cyclic control was removed and translation was effected by using the tail rotors to tilt the aircraft in the desired direction. On 13 May 1940, the VS-300 began making a number of increasingly successful flights. The new configuration was significantly more stable. [3,5]

Meanwhile, the US Army Air Corps had solicited proposals for rotary wing military aircraft. Five autogyro designs were submitted. Platt-LePage submitted a twin-rotor design similar to the Fw 61, with counter-rotating rotors extended from the fuselage on pylons. Sikorsky submitted a slightly larger version of the initial VS-300 design; it was later updated to the May 1940 configuration, but Platt-LePage won a development contract in July 1940 for its XR-1. [5,7]

Work continued on the VS-300. The engine was updated with a 90 hp (67 kW) Franklin and the machine continued to improve. Another crash in October 1940 allowed the team to make additional modifications, particularly to the tail rotor configuration. Flight testing resumed in

January 1941. That month, Sikorsky also was awarded an Army contract to build a two seat observation helicopter, designated XR-4. On 6 May, the VS-300 broke the Fw 61's endurance record with a time of 1 hour, 32 minutes and 26 seconds. That fall, a number of different tail configurations were again tested. On 8 December 1941, the VS-300 made its first flight in its final configuration: full cyclic control of the main rotor with a single tail rotor for torque and yaw control. A change to the main rotor dampers on the last day of 1941 damped the fore and aft motion of the blades, providing a dramatic improvement in performance. [5,7]

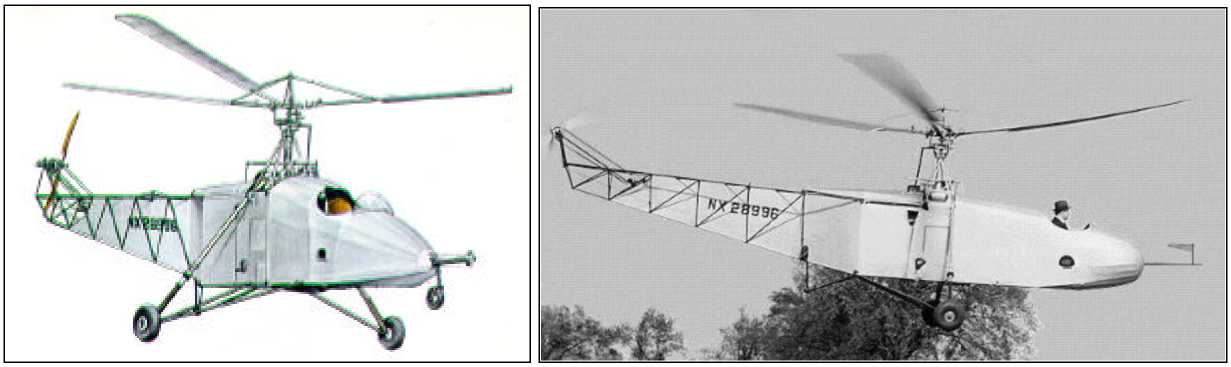


Figure 44. The Sikorsky VS-300 in 1941.

The XR-4 made its maiden flight on 14 January 1942, incorporating the final modifications evaluated on the VS-300. Sikorsky flew the XR-4 to Wright Field in Dayton, Ohio: a five day, 761 mile (1,225 km) journey. Extensive evaluation tests were conducted and on 21 December 1942, Sikorsky received a contract for 15 YR-4 service test helicopters as well as another contract for 5 prototypes of a heavier (4,896 lb or 2,221 kg) aircraft, the XR-5. A total of 131 R-4s were built; the R-4 was the only Allied helicopter that saw significant use during the war, primarily for rescue missions in Alaska, Burma and other areas with harsh terrain. A total of 65 R-5s were built. [5,7,18]

The Platt-LePage XR-1, meanwhile, had made its first flight in May 1941. A Pratt & Whitney R-985 radial engine provided 440 hp (328 kW) to two 30.5 ft (9.3 m) rotors. The aircraft weighed 4,730 lb (2,147 kg) at take-off. Performance was adequate, with a maximum speed of 110 mph (177 km/hr). The XR-4, however, was half the weight and was considered to be much simpler in design, so the XR-1 was not put into production. [5,7,18]

Figure 45. The Sikorsky R-4 (left), R-5 (middle) and R-6 (right).

A refined version of the R-4, the R-6A, was powered by a 245 hp Franklin engine and first flew on 15 October 1943, as the XR-6A. Severe vibration and control problems, however, took months to resolve. The Army Air Force ordered 26 YR-6A prototypes, which were built under license by Nash-Kelvinator in order for Vought to continue production of other more critical wartime aircraft. In September 1943, contracts were awarded for 731 production vehicles, including 36 for the Navy. Deliveries began in February 1944, but when the war ended in September, all contracts were cancelled. At the end of the war, 128 R-4s, 65 R-5s and 219 R-6s had been delivered for operational use by the Army. 209 additional R-6s were accepted and placed in storage. Thus, a total of 617 Sikorsky helicopters were delivered between May 1942 and September 1945. [5]

After the War, the R-5 was improved and redesigned with four seats as the S-51 for commercial use. Gross weight was 5,000 lb and first flight was on 16 February 1946. Commercial approval was in April 1947, the second helicopter to be certificated. This was developed for the Navy as a plane-guard (rescuing personnel in the water around a carrier) as the HO3S-1 and for the Air Force as the R-5D (later changed to H-5D). Through 1950, 161 of the helicopters were delivered to the services and another 53 to commercial and foreign customers. Over 150 were built under license by Westland in the UK. Another derivative of the R-5, the S-53 or XHJS-1, was developed for the US Navy for testing in the utility, observation and rescue roles. It had three to five seats and was powered by a 500 hp Continental engine. First flight was in 1948, but it did not go into production, partly because of the superior ability of the competing Piasecki HUP to accommodate large changes in center of gravity during in loading. [5,18]

Figure 46. Air Force H-5D.

The S-51, however, built to military standards, was seen as too expensive for the civilian market. A smaller version, the two seat S-52 was developed and first flew in 1947. It was soon awarded the third civil certification. It was the first production helicopter with metal rotor blades, and had a revised offset-hinge rotor head that provided improved controllability. It could not compete against the lower cost Bell 47 or the Hiller 360, but with the outbreak of the Korean War, the S-52 with four seats and a 245 hp Franklin engine was evaluated as the H-18 for the Army and 89 were produced as the HO5S for the Marines. [5,18,34]

Figure 47. The S-52 in Coast Guard markings.

As a replacement for the R-5 (by then designated H-5) for the Air Force, Sikorsky developed the S-55, or H-19 Chickasaw, a ten-place helicopter with a 600 hp P&W engine in the nose below the pilot's feet. This engine placement allowed the loads to be placed close to the center of gravity below the main rotor. First flight was on 21 November 1949, and deliveries began in 1950. A total of 1,067 were built in the US over ten years for the Air Force and Army (the H-19 Chickasaw), Navy and Coast Guard (as the HO4S), the Marines (HRS). Another 547 were built by foreign licensees in Britain (called the Whirlwind), France and Japan. A further 33 countries also purchased S-55s. It received FAA certification in March 1952. [18,34]

Figure 48. The S-55 as the Army H-19 Chicasaw.

An improved version of the H-19 became the H-34 Choctaw (Sikorsky S-58), a 13,000 lb, four blade, 20 passenger helicopter, with more than twice as much horsepower. First flight was on 8 March 1954; service introduction was in August 1955. Over the next 25 years, over 2,300 S-58 helicopters were produced by Sikorsky and its licensees in many different versions. Some of the more widely produced were the HSS-1 Seabat for the Navy (371 built), HUS-1 Seahorse for the Marines, and the H-34A for the Air Force (437 built). Civil certification was in August 1956. [5,18]

Figure 49. Marine S-58 (HUS-1) retrieving astronaut Alan Sheppard.

Meanwhile, in 1951, the Marines contracted with Sikorsky to develop an assault transport helicopter that could carry 23 fully equipped troops. The prototype S-56, designated XHR2S-1, first flew in December 1953 and the first production helicopters were delivered in 1956. This was Sikorsky's first twin-engine helicopter, with two P&W radial engines generating 2,100 hp each, enclosed in pods below the five-bladed rotor on either side of the fuselage. The main landing gear also retracted into these pods. The nose had clamshell doors below the pilot's cabin for loading and unloading. Empty weight was 20,831 lb and gross take-off was 31,000 lb. A total of 154 S-56s (designated HR2S and later CH-37), were delivered to the Navy and the Marine Corps; a further 91 were built for the Army as the H-37 Mojave. [18]

Figure 50. The H-37 Mojave.

The first production turbine-powered Sikorsky helicopter was the S-61. Designed for the Navy's antisubmarine warfare (ASW) mission, the H-3 Sea King, originally designated HSS-2, first flew on 11 March 1959 and began service in September 1961. It had two 1,250 shp General Electric T58 engines and a boat-type hull for water landings. Gross take-off weight was around 20,000 lb. It was the first helicopter to exceed 200 mph, with a demonstrated speed of 210.6 mph, and broke several other speed records. The Air Force and US Coast Guard also procured the S-61R with an extensively revised fuselage, as the HH-3E Jolly Green Giant and HH-3F Pelican respectively for search and rescue (SAR), as well as a utility cargo version (CH-3C/E). Sikorsky built 651 military S-61 helicopters, while foreign licensees had built over 400 by early 1980. [18]

Figure 51. The S-61 as the VH-3 VIP transport.

The S-62 bore a superficial resemblance to a mini S-61 and was also able to make water landings. It used the dynamic components of the S-55/H-19 and a single T58 engine. It received FAA certification in 1960 as the first US turbine powered civil helicopter. First introduced to the Coast Guard in 1963, by 1970, that service had also procured 99 for search and rescue as the H-52. Maximum weight was 8,300 lb. [18,34]

Figure 52. The S-62 prototype.

On 25 March 1959, an S-60 flying crane, using the engines and rotor system of the S-56/H-37, made its first flight. This led to the turbine powered, purpose built S-64 Skycrane, designated CH-54A Tarhe. First flight was on 9 May 1962. Nine test aircraft were built. Service with the Army began in 1965. 60 were built, powered by two 4,500 shp P&W T73 engines. Empty weight was 19,234 lb and maximum loaded weight was 42,000 lb. The seat for the load master looked backwards under the fuselage. The later CH-54B had 4,800 shp engines and additional lifting capacity; 29 were built. The Tarhe holds several international records for payload-to-height and time-to-height. About 10 commercial variants were also sold, but they were very expensive to operate. [18,34]

Figure 53. The S-64 Skycrane.

The S-65 used an enlarged version of the S-61/H-3 Sea King fuselage with the dynamic components of the S-64/H-54 Skycrane. The first prototype flew on 14 October 1964, and it entered service with the Marines in 1966 as the CH-53A Sea Stallion heavy assault helicopter. Powered by two GE T64 engines and with a maximum gross weight of 42,000 lb, it was the largest production helicopter outside the USSR. It could carry 37 troops and cruise at speeds of nearly 200 mph. The later "D" models had uprated 3,925 shp engines. The Air Force developed the HH-53B "Super Jolly" for SAR, and Navy the RH-53D for minesweeping. Deliveries were also made to Austria, Germany, Iran and Israel. [18]

Figure 54. Marine Corps CH-53A Sea Stallion.

The prototype of the much larger S-65A/CH-53E first flew on 1 March 1974. The fuselage is 6.5 ft longer, as are the titanium rotor blades. The addition of a third engine, each rated at 3,670 shp (continuous), and a sixth rotor blade allowed it to double the lift capacity of the CH-53D. Empty weight is 32,048 lb and maximum weight is 70,000 lb. The main rotor is 79 ft in diameter, and the tail rotor is 20 ft. [18]

Figure 55. The Navy MH-53E.

A number of Sikorsky helicopters were tested with compound jets in the 1960s and 1970s. An HSS-2 Sea King was modified with two P&W J60 turbojets producing 2,900 lb of thrust in May 1965. The Sikorsky S-69 Advancing Blade Concept (ABC), first flown in July 1973, used two counter-rotating coaxial rotors augmented by two 3,000 lb (13.3 kN) thrust P&W J60 turbojet engines. The XH-59 ABC used two closed-coupled coaxial rigid rotors with only the advancing blades generating lift to off-load the retreating blades permitting speeds of up to 322 mph (518 km/hr). The Sikorsky S-72 Rotor Systems Research Aircraft (RSRA) was built as a rotor testbed. It used two 9,200 lb (4,173 kg) GE TF34 turbofans for cruise propulsion, with first flight in October 1976. [18,19,23]

Figure 56. The S-69 ABC (left) and the S-72 RSRA (right).

The S-67 Blackhawk was a company-funded design begun in August 1969 as a high speed, highly maneuverable gunship. It could carry 15 troops or 8,000 lb of weapons. First flight was in August 1970, using two 1,500 shp GE T58 engines. Testing was conducted through September 1974 and set a record speed of nearly 217 mph for a conventional helicopter. A ducted fan version was also tested. [18]

Sharing a nearly identical name but little else, the YUH-60 Black Hawk first flew on 17 October 1974 as part of the Army's Utility Tactical Transport Aircraft System competition. Three prototypes were built and competed against those from Boeing Vertol. Sikorsky's S-70 was selected in December 1976, and service introduction was in June 1979. The UH-60 is powered by two GE T700 engines generating 1,543 shp each and is designed to survive significant combat damage. It has a crew of three and can carry 11 combat troops; maximum loaded weight is 16,450 lb. Maximum speed is 224 mph. The Navy version, the SH-60 Seahawk, is the platform for the LAMPS III (Light Airborne Multi-Purpose System). [18]

Figure 57. The UH-60A Black Hawk (left), SH-60B Seahawk (center) and HH-60 Seahawk (right).

Design of the commercial S-76 was begun during 1975, using scaled down rotor and tail components from the S-70, and the first flight was on 13 March 1977 with Allison 250 engines. Three prototypes were tested and FAA certification was received in April 1978. By the time deliveries began in early 1979, some 200 S-76s had been ordered. But the poor economy in the late 1970s/early 1980s coupled with teething pains led to the S-76B or S-76 Mark II with a beefier structure and more powerful P&W PT6B engines. The S-76 seats up to 13 (in addition to the pilot), has a maximum gross weight of 11,700 lb and a useful load of 3,326 lb. The latest version, the S-76C+, uses two Turbomeca Arriel 2S1 turboshafts with a maximum take-off rating of 856 shp. [34,36]

Figure 58. The S-76 executive transport.

In June 1985, Sikorsky and Boeing teamed to begin studies in the Army's Light Helicopter Experimental (LHX) competition. At the time, as many as 6,000 helicopters were envisioned. By 1988, they had arrived at a basic solution: an all composite, tandem seat, stealthy helicopter with a shrouded counter-torque rotor in a T-tail. The Sikorsky/Boeing team was selected as the winner of the competition in early 1991; the helicopter was subsequently designated the RAH-66 Comanche for reconnaissance and light attack. The first YRAH-66 prototype flew in March 1996, the second in March 1999. The Comanche entered Engineering and Manufacturing Development on 1 June 2000. Currently, over 1,200 Comanches are expected. The 10,600 lb Comanche is powered by two 1,380 shp LHTEC (Allison/Allied Signal now Rolls Royce/Honeywell) T800 turboshaft engines. [34,36]

Figure 59. The Sikorsky-Boeing YRAH-66 Comanche prototype.

The latest commercial helicopter under development is the S-92 Helibus. It uses the dynamic components of the UH-60/SH-60 and a cabin for 19-22 passengers; gross weight is 25,200 lb. Formally launched in mid-1995, it has several risk-sharing development partners in Japan, China, Spain, Taiwan, and Brazil. It's targeted for airline transport, offshore missions, SAR, military and VIP transportation. First flight was in December 1998, and five development aircraft are active in the flight development program for certification in 2001. Power is provided by two GE CT7 (T700) engines producing 2,400 shp at take-off. [34,36]

Figure 60. A prototype S-92 Helibus.

Bell

In September 1941, Arthur Young made a presentation to Bell Aircraft in Buffalo, New York. He was successful in convincing the company to fund construction of two demonstrator helicopters. Young had become intrigued by the helicopter in 1928 and tested a remote control model in 1941. Young designed a two-blade rotor system that obviated the need for articulation: flapping, drag or other hinges. Instead, it used a stabilizer bar mounted at a 90° angle to the blades and attached to the hub; the stabilizer was not affected by gusts and helped bring the main rotor blades back into their original plane of rotation after perturbations. This simplified the controls and reduced the weight and maintenance. [5,14]

Development work began on 1 November 1941. Young and his apprentice, Bartram Kelley, were given a small shop in nearby Gardenville in June 1942. In December 1942, a demonstrator aircraft, the Model 30, was completed and tethered flights were made. It had a 32 ft (10 m) rotor, powered by a 160 hp (120 kW) Franklin engine. By June 1943, the first aircraft was flying over 70 mph (113 km/hr). Two more test aircraft were built with two seats and enclosed cabins; the third prototype had a wrap-around bubble canopy. With the end of the war approaching, however, Bell moved its facilities, including helicopter development, to Niagara Falls, New York, in June 1945. [5,41]

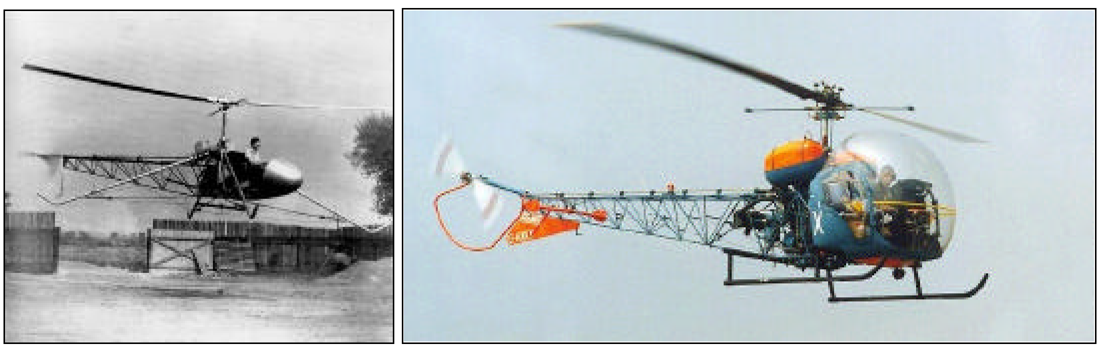


Figure 61. The Bell Model 30 aircraft 1 (left) and the Model 47 (right).

The first flight of the production version, the Model 47, was on 8 December 1945. Civil certification, as the first certificated helicopter, was granted on 8 March 1946. Over 6,000 Model 47 helicopters would be produced worldwide until 1974, in many different configurations for both military (as the H-13 Sioux) and civilian purposes. [5,15]

The Model 42, powered by a P&W R-985 engine rated at 450 hp, looked like a luxury sedan, and was targeted towards the private owner. The five-seat helicopter weighed 5,100 lb, and used a scaled-up rotor system of the Model 30. Not designed or built by Young's group, it was a disaster. A coaxial helicopter design was also built and tested during this time by Young. [34]

The first production Model 47A was delivered to the Army Air Force on New Year's Eve 1946, as the XR-13. As the H-13B, it was the first light helicopter in service with the Army and was used by the Navy as the HTL-2. The commercial version, the Bell 47D, received certification in late 1947. Agricultural sales accounted for the largest portion of Model 47 sales in the late 1940s, although these were often sold in single increments. Improvements over the Bell 47B included an increase in gross weight to 2,200 lb – a useful load of 718 lb – and a two-piece bubble canopy. [34]

Arthur Young retired in 1948; Bart Kelley was named head of helicopter engineering the same year and senior vice president of Bell in 1971. [41]

Two prototypes of the five-seat Bell 48 were delivered to the Air Force in May 1948 for testing as the XR-12 (later H-12). The pre-production YH-12B had eight seats; the production H-12 had ten seats. In September 1948, Bell was selected to develop the Bell 54 for the Air Force as the XH-15. This used a scaled-up Model 47 rotor powered by a 550 hp P&W R-1340 engine. Neither the H-12 nor the H-15, however, were produced in large numbers. [34]

Figure 62. The Bell H-12.

Meanwhile by the end of 1948, Bell had shrunk to 4% of its war time peak: a mere 1,861 employees. Losses were 23 times greater than sales. This was the bottom of the decline for Bell, which slowly started to rebound. [34]

In June 1950, Bell was selected to build the first dedicated ASW helicopter. The 26,000 lb Model 61, designated HSL, was a large all-metal helicopter with a 1,900 hp P&W R-2800 radial engine with tandem Bell rotors (the only US non-Piasecki tandem helicopter). Three XHSL-1 prototypes were built. The radial engine was very large, but still not powerful for the airframe; consequently, interior noise was very high and performance was very poor. Although over 100 were initially ordered, only 50 were built and most were never used. [34]

Figure 63. The Navy HSL-1.

Days after the HSL was ordered, the Korean War began, changing the way helicopters were used and viewed forever. The war also had a tremendous impact on the viability of Bell Aircraft, due in part to increased production of the Bell 47. Over 15,000 troops were evacuated by Bell helicopters. By the end of 1953, Bell was back up to levels of WWII, with employment at nearly 17,000, but this was down to 3,000 again by 1960. [34]

In 1951, the helicopter programs were officially designated the Bell Helicopter Division and relocated to Ft Worth, Texas. Initially with just 256 employees, it grew to ten times that many in 1953. The 1000th Bell 47 was delivered in April 1953. The following month, the definitive Bell 47G was unveiled with a 200 hp Franklin engine and improved rotor blades and control system. A larger Lycoming engine was used on the Bell 47G-2 Trooper, built for the Army as the OH-13H Sioux. The restyled 47H had a wider cabin, targeted for the executive transport market, and the stretched 47J allowed four seats, but sales of these two versions were limited. The 5,800th Bell, a 47G-3B2A, was the last one off the Ft. Worth production line on 14 February 1974. License production continued abroad until 1978. [34]

In 1951, Bell began studies for a side-by-side rotor helicopter that could tilt the rotors 90° for high speed forward flight. This was the beginning of nearly 50 years in developing the tilt-rotor. Bell was actually preceded, however, by the Transcendental Aircraft Company, which had flown its 1,750 lb (794 kg) Model 1G in July 1954 – as well as the later 4,000 lb (1,814 kg) Model 2 – with limited success. When Robert Lichten left Transcendental and came to Bell, he led their design effort. The 4,800 lb (2,177 kg) Bell XV-3, first flown in August 1955, proved the capability to tilt the rotors in flight to attain faster horizontal speeds. Although underpowered at the time, it eventually led the way to the 13,000 lb (5,900 kg) turboshaft-powered Bell XV-15 Research Tilt Rotor aircraft in May 1977 and today's Bell Boeing V-22 Osprey. [5, 19]

Figure 64. The Bell XV-3 (left) and XV-15 (right).

Bell's rotorcraft business was spun off as the Bell Helicopter Corporation in 1956. Two years later, the company was acquired by Textron Inc. It would be renamed Bell Helicopter Textron in 1976. [34]

On 23 February 1955, Bell was selected to develop the next generation Army medical evacuation helicopter, the Model 204, initially designated XH-40. Using a Lycoming 700 shp XT53 turboshaft engine, it made its first flight on 22 October 1956. Testing was completed in September 1957, after which 16,000 would be produced as the UH-1 Iroquois "Huey" and its commercial derivatives. Service introduction was in 1959 with the Army. [34]

Figure 65. Marine UH-1.

Performance was so impressive it soon found new roles. The larger, more powerful UH-1B Huey Hog was eventually used as a close-support gunship; 1,033 were built through 1965. The UH-1C had greater speed and range. The larger cabin UH-1D could carry a squad of 12 and entered service in 1963. The 1,400 shp T53 was installed in UH-1Cs and UH-1Ds to create the UH-1M and H series. The production rate went from 20 per month in 1963 to 160 per month in 1967 and then 10 per month in 1973. The Model 204B civil Huey was unveiled in September 1960; certification was in April 1963. [34]

Ft. Worth had 3,500 employees when it officially became Bell Helicopter Corporation in 1956. Bell developed its Model 206 for the Light Observation Helicopter (LOH) competition. The design was submitted in January 1961. A contract for five prototypes, designated OH-4, was awarded late that year. Hughes Aircraft Division won the competition with its OH-6, but had difficulty meeting production requirements. Meanwhile, the Bell 206 had been developed into a successful commercial helicopter, called the Bell JetRanger, powered by the Allison 250-C20. Certification was in late 1966. The 1,000th JetRanger was delivered in March 1973, and the 4,000th in February 1988. [34]

Figure 66. The Bell OH-4 prototype (left) and the Bell 206 JetRanger (right).

A second LOH competition in 1968 resulted in an award for 2,200 of the Bell 206, as the OH-58 Kiowa. Powered by an Allison T63 with 317 shp, the 3,000 lb OH-58 could carry two troops. Bell also received a contract from the Navy for its Model 206, to be developed as the OH-57 SeaRanger trainer. In September 1981, Bell was awarded a contract to modify OH-58As with a mast mounted sight, integrated sensors, and armed with missiles rockets and guns, as the OH-58 Kiowa Warrior. In the mid-1970s, the seven seat 206L LongRanger and five seat 206B were introduced. [18,34]

Figure 67. The OH-58D Kiowa Warrior.

In June 1962, Bell built a mock-up of an armed attack helicopter, the Model 209, using the standard UH-1 rotor system with a tandem seat fuselage only 3 ft wide. Developed in secret, the first prototype flew on 7 September 1965. Initial vibrations due to the low inertia of the narrow fuselage were corrected by reversing the cyclic control linkages. On 19 September, the prototype soon hit 200 mph. The first contract for the 9,500 lb AH-1G HueyCobras was awarded in April 1966, with the first ones arriving in Vietnam in August 1967. The Marines ordered the twin engine AH-1J SeaCobra, which could take off at nearly 14,000 lb. Entire development cost was just over $1M. [18,34]

Figure 68. Marine Corps AH-1T.

A 40% larger version of the AH-1, the Model 309 KingCobra was developed, but not produced. Bell's entry into the Advanced Attack Helicopter (AAH) competition was the even more powerful YAH-63. First prototype flew on 1 October 1975, but Hughes won the competition with the YAH-64. [18,34]

In 1970, Bell developed an improved rotor system that eliminated two per revolution vibrations. Announced in November 1972, this was called the "nodamatic" system. Two horizontal "nodal beams" attached to each side of the base of the rotor pylon. Each beam had two points where vibrations were eliminated; this allowed the fuselage to be suspended from these four points. This system was incorporated into all of its future two-bladed helicopters. [34]

The twin engine Model 212 was developed as the UH-1N, using the P&W PT6T-2 Turbo Twin-Pac derated to 1,250 shp for take-off. First flight was on 16 April 1969. Commercial deliveries, begun in 1973, were as fifteen passenger executive and utility transports. The four- bladed Bell 412 began production in 1980. With two GE T700 turbines with 3,250 hp each, the 214ST Super

Transporter can carry nearly 8,000 lb of payload, and has been used extensively for off-shore oil rig support. [34]

Bell Helicopter Textron Canada was formed in 1983 and its plant at Mirabel, Quebec, opened in 1985, partly to help foster an indigenous helicopter industry there. Mirabel now builds all of Bell’s commercial helicopters, although the rotors and transmissions are still made in Fort Worth, Texas. Bell introduced the 407 in January 1995, with certification 13 months later. The 407 has the four-blade rotor system used on the OH-58D coupled with an Allison 250 engine and transmission providing 814 shp. [34,41]

Figure 69. The Bell 407.

The Bell 427 made its first flight in December 1997, and began deliveries in 1999. It is longer and more powerful than the 407. The Bell 430 was first flown in October 1994, with certification in February 1996. It is an enlarged version of the Bell 230. [41]

In April 1983, Bell and Boeing Vertol received a Navy contract for preliminary design of a Joint Services Advanced Vertical Lift (JVX) aircraft. First flight was in March 1989. The Bell Boeing V-22 Osprey is now becoming operational, 45 years after the first demonstration of the tilt rotor concept. The Osprey uses two 6,150 hp (4,586 kW) Rolls-Royce Allison T406 turboshaft engines, for an engine power to weight of over 6 hp/lb. Each engine/rotor produces approximately 24,000 lb (107 kN) of thrust, a thrust to weight of nearly 25. The control system is also relatively simple, using only rotor collective and cyclic pitch for hover control and nacelle angle to effect transition. Over 500 Ospreys are scheduled for delivery to the US Marines, Air Force, and Navy. A six to nine passenger civil tilt rotor, the Bell Agusta BA 609, is now under development, with first flight expected in 2001. Bell is now proposing a quad tilt rotor for applications around 20 tons.

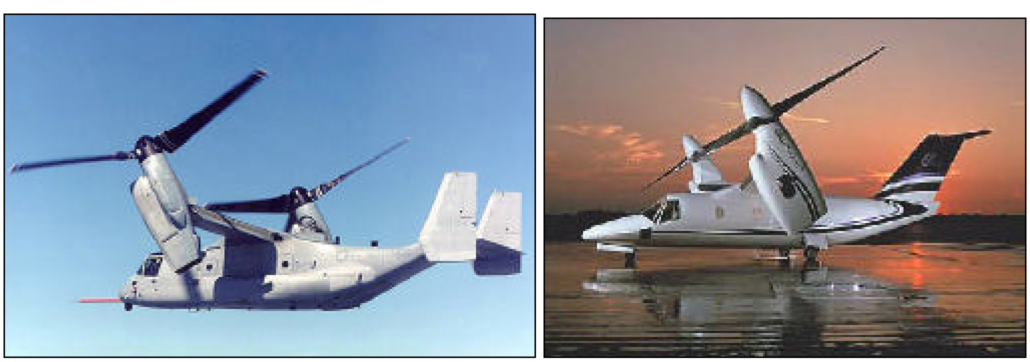


Figure 70. The Bell V-22 Osprey (left) and the BA 609 mock-up (right).

Over 32,000 Bell helicopters have been built worldwide, nearly 30% of which went to commercial operators. [34]

P-V / Piasecki / Vertol / Boeing Philadelphia

In 1943, a group of University of Pennsylvania engineering students formed the P-V Engineering Forum, led by Frank Piasecki, to design and build a helicopter. Piasecki had earlier worked as a mechanic for Kellet Autogiro as well as a mechanical designer at the National Machine Company and finally with Platt-LePage Aircraft Corporation. The PV-2 was a single rotor helicopter that featured the first dynamically balanced rotor blades, a rigid tail rotor, and full cyclic and collective rotor pitch control. The first flight was made on 11 April 1943. [5,18]

Figure 71. The Piasecki PV-2.

Based on this experience, Piasecki built the PV-3, designated XHRP-X "Dogship," which first flew on 7 March 1945. The signature Piasecki tandem rotor design, however, earned it the nickname, the "Flying Banana." Three XHRP-1 test aircraft and 20 production helicopters were built. The aircraft was capable of carrying 1,800 lb (816 kg) of payload. The HRP-1 Rescuer used two 600 hp (447 kW) Pratt & Whitney R-1340 engines to power a 41 ft (12.5 m) rotor at the front and rear of the fuselage. Loaded weight was 6,900 lb (3,133 kg), and it could carry eight troops. Maximum speed was 99 mph (159 km/hr) and range was 265 miles (427 km). Service with the Navy began in 1947 and with the Coast Guard and Marines the following year. By this time, the group had changed their name to the Piasecki Helicopter Corporation. [5,23]

Figure 72. Piasecki HRP-1 Rescuer.

An improved version of the Rescuer, the HRP-2, had a streamlined, all-metal fuselage skin for increased performance; first flight was 10 November 1949 and service use began the following year. Although the Navy only bought four, the Air Force bought 214, designated H-21 Workhorse, and a further 334 went to the Army, designated H-21 Shawnee. The H-21 featured twice as much power with a Wright R-1820 radial engine. The Shawnee was the workhorse of the early Vietnam War, from December 1961 to late 1963, when the UH-1 arrived. In 1953, the H-21 set a world speed record (146.7 mph) as well as a record for altitude (22,110 ft). An H-21 also made the first non-stop helicopter flight across the US in 37 hours by refueling in fight. Total production was 557 for the US services and 150 for foreign use. [5,18]

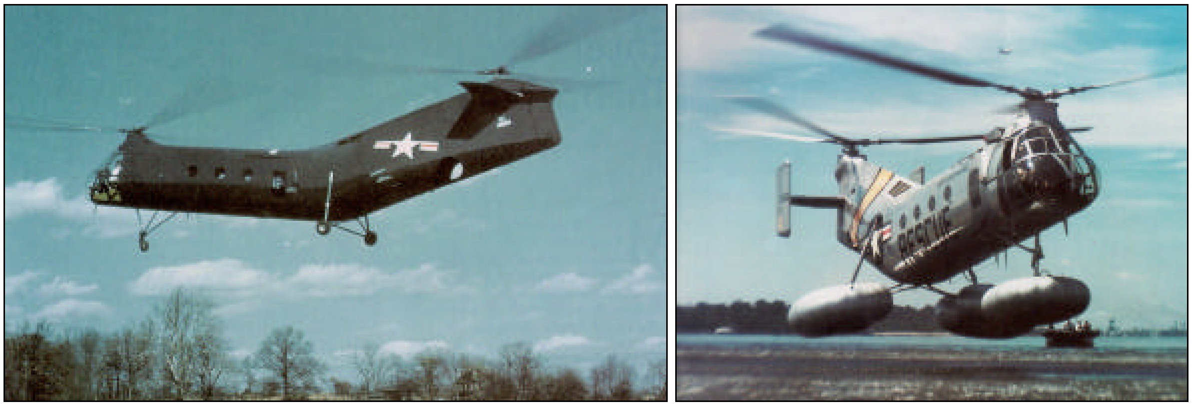


Figure 73. The HRP-2 (left) and H-21 Workhorse (right).

Following the initial tests of the HRP, the Navy ordered an improved version, the HJP – soon renamed the HUP Retriever – for shipboard utility and rescue, particularly for the rescue of pilots after aborted carrier take-offs or landings. The HUP had a single Continental R-975 radial engine. The rear rotor was mounted on the tall vertical tail, allowing the rotors to overlap for a more compact footprint aboard ship. Service use began in February 1949. 339 HUPs were built, including sales to the Royal Canadian and French Navies, as well as 70 for the Army as the H-25 Army Mule; 50 of these were later transferred to the Navy.

Figure 74. The HUP Retriever.

The H-16 Transporter was developed in response to an Air Force requirement for a long range helicopter to pick up stranded bomber pilots. At the time, it was the largest helicopter in the world. The rotor was 82 ft in diameter, the fuselage was 134 ft long and the gross weight was over 32,000 lb. The first prototype, the XH-16 had two 1,650 hp P&W R-2180 radials (one in front and one in back) and first flew on 23 October 1953. The second prototype, the YH-16 had two Allison YT38 turboshafts of 1,800 hp each, and set an unofficial speed record of 166 mph in early 1956. The failure of a temporary instrumentation conduit resulted in a fatal crash of the YH-16, and the program was subsequently cancelled. [5,18]

In May 1955, however, due to disagreement with the board of directors, Frank Piasecki was forced out of his company; in March 1956, it was renamed “Vertol” (an acronym for Vertical Take-Off and Landing). Piasecki then formed the Piasecki Aircraft Corporation (PiAC). By the late 1950s, Vertol claimed to have a greater backlog of orders than all other helicopter companies in the free world combined.

In 1958, Vertol began studies for a turbine powered replacement to the H-21, designated Model 107, that could carry a squad of soldiers. Development was begun on company funds, borrowing rotors and dynamic components from the H-21. The Army lent Vertol two 825 shp Lycoming T53 turboshaft engines for a demonstrator; first flight was 22 April 1958. The V-107 demonstrator was extensively flown, including demonstrations abroad. Two months later, Vertol received a contract from the Army for ten improved aircraft, designated YHC-1A. At the same time, the Army also released a request for proposal for a larger transport helicopter that could carry a whole platoon. This design was designated the Model 114. In March 1959, Vertol was declared the winner of this study, and contracted for a mock-up, five YHC-1B prototypes; the number of YHC-1As was reduced to three to use the funds for the larger design. The next year five pre-production HC-1Bs were requested. The primary difference between the two designs was that the 114 was much larger, had full-length sponsons, and external engines for easier servicing. First flight was on 27 August 1959 for the YHC-1A and 26 September 1961 for the YHC-1B. [34]

Meanwhile, on March 31, 1960, Vertol was purchased by the Boeing Airplane Company and became known as Boeing Vertol. In May 1961, Boeing renamed itself The Boeing Company in recognition of its expanded product line. Boeing provided much needed finances for V-107 and V-114 development, improved production facilities, and an engineering philosophy for increased reliability. [34]

An improved Model 107-II with upgraded GE T58 engines (1,400 shp) first flew on 25 October 1960, and was selected by the Marines in February 1961. Initially called the HRB-1, it was redesignated CH-46 Sea Stallion after the unified aircraft nomenclature system was put into effect in 1962. The 23,000 lb aircraft entered service with the Marines in 1964, and was also used by the Navy for Vertical On-board Delivery. Early problems were resolved and over 650 H-46s were produced through 1971, including exports to four other countries. The Model 107-II received FAA certification in 1962 and was licensed-built by Kawasaki as the KV-107 for civil and military applications. [34]

Figure 75. The CH-46E Sea Stallion.

In 1962, the HC-1B was redesignated the CH-47A Chinook. It had two Lycoming T55 engines producing 2,850 shp each, and, at 33,000 lb, could carry 44 troops or 12,000 lb of external load. The first Chinooks arrived in Vietnam in late 1965, and eventually retrieved over 10,000 downed airplanes and helicopters, many from behind enemy lines. With the conclusion of Sea Stallion production and the end of Vietnam reducing Chinook deliveries, Boeing Vertol developed a commercial version, designated the Model 234. FAA certification was granted in 1980, but only about 8 were sold. Boeing built 732 military Chinooks for the Army, and several hundred more for export customers. Beginning in 1980, 436 older Chinooks were converted to CH-47Ds, with a larger fuselage, improved transmission, fiberglass rotor blades, and 3,750 shp T55 engines. Vertical lift capability more than doubled to 28,000 lb. About two dozen MH-47E Chinooks were delivered beginning in September 1993 for the US Special Operations Command. In the mid-1980s, Boeing built an all-composite helicopter, the Model 360, that resembled a Chinook. It reached a speed of 246 mph. [18,34]

Figure 76. The CH-47 Chinook.

An even larger helicopter, the XHC-62 was built for the Army's Heavy Lift Helicopter (HLH) program, begun in November 1960. This would have been the first fly-by-wire helicopter. It was to carry a load of 20 tons for a radius of 20 nm, using three Allison T701 turboshaft engines producing 8,079 shp each. The advanced rotor components were flight tested on a Chinook testbed, designated the Model 347. Unfortunately, the program was cancelled prior to completion in August 1974, in favor of the Sikorsky CH-53E. [18,34]

As part of the Utility Tactical Transport Aircraft System (UTTAS) Huey replacement, Boeing developed its YUH-61, with first flight on 29 November 1974. This, however, was also won by Sikorsky, with the UH-60 Black Hawk. Sikorsky then received the companion contract for the SH-60 Seahawk. [34]

For four decades, from 1960 to 2000, not a single new Boeing design reached production. Fortunately the long production run of the Chinook buoyed the company through those times. In the mid-1980s, Boeing teamed with Sikorsky for the RAH-66 Comanche, which should begin service in 2006. About the same time, Boeing also teamed with Bell for the V-22 tiltrotor, with the first production unit delivered on 18 May 1999. Boeing Vertol was officially renamed Boeing Helicopters in 1988. Today, it is commonly referred to as "Boeing Philadelphia," since Boeing now produces the former Hughes AH-64 in Mesa, Arizona. [34]

Piasecki Aircraft Corporation (PiAC)

The new Piasecki company, formed in 1955, concentrated on V/STOL aircraft and helicopters capable of heavier lift and higher speeds. A number of studies were conducted for the military, and several "flying jeeps" were built and tested. In the late 1950s, Piasecki began designing a 1,600 lb (725 kg) test aircraft called the 16H-1 Pathfinder. It featured a "Ring Tail," which was a ducted pusher propeller exhausting through vanes for thrust vectoring and yaw control. The first flight was in February 1962. Power and control were adequate, but despite several major modifications, some under military funding, and speeds eventually reaching 225 mph (362 km/hr), neither a military nor civilian aircraft was developed. [5,18]

Figure 77. The Piasecki 16H-1 Pathfinder.

Later studies looked at using helicopter-augmented airships for logging operations. A test aircraft, the PA-97 Heli-Stat, using four H-34 Choctaw helicopters was tested on 1 July 1986, but was destroyed shortly after landing. Later studies that continue today involve retrofitting a Ring Tail to operational helicopters. Piasecki is currently modifying a CH-60 with a Vectored Thrust Ducted Propeller for the US Navy for flight testing in 2003.

Hiller

Stanley Hiller flew the first successful American co-axial helicopter, the XH-44, in July 1944, when he was only 19 years old. It also featured the world's first successful all-metal rigid-rotor blades. Hiller had learned to fly from his father at an early age, and at 16, Hiller had started a business building small gasoline engine model cars; revenue eventually grew to $100,000. Hiller became interested in helicopters in 1937 when he saw pictures of the Focke Wulf Fw 61, as well as Sikorsky's VS-300 in 1939. Hiller felt the tail rotors used on the VS-300 and the outriggers on the Fw 61 were wasteful and possibly unnecessary. The XH-44 evaluated three different rotor configurations: rigid, articulated, and semi-rigid, which was selected. The engine was uprated from a 90 hp Franklin to a 125 hp Lycoming. The XH-44 was the first successful helicopter west of New York, and Hiller made public demonstrations of the XH-44 in nearby San Francisco. [4,34,35]

Figure 78. The Hiller XH-44.

This led to Hiller Aircraft becoming a division of Kaiser Cargo. A number of draftsmen and engineers from Kaiser Shipyards joined Hiller, but no one in the company had any aeronautical experience. Funding from Kaiser and the US Navy for a more advanced version, the X-2-235 or UH-1X, was sparse; three were built, but only one made even a tethered flight due to complicated control problems. [34,35]

Kaiser refused to fund the $3M that was anticipated to bring it to production. Hiller became an independent company again, United Helicopters, after nearly $1M of stock was sold. Eventually the two-place coaxial UH-4 Commuter with a 225 hp engine was flown; the first time in July 1946. Hiller won first prize at the World Inventors Congress in 1947 for building the first successful two-seat coaxial helicopter. Three were built and it was demonstrated to a large crowd at the Army's Presidio post, but it became apparent that there was no market for personal helicopters, and it did not reach production. [34,35]

At the same time, however, Hiller was also developing a single main rotor helicopter that initially used an enlarged engine cooling fan augmented by power plant exhaust to provide counter torque, the first single main rotor helicopter with no tail rotor. This aircraft, originally designated J-5 ("J" for "jet torque" exhaust) was used as a test bed for control techniques. Built from scratch without engineering drawings, the first flight was two months before the UH-4. The final control system was very simple, with a direct linkage between the pilot and the rotor blades consisting of only seven components. The jet exhaust system did not provide sufficient yaw control and the second J-5 was built with a conventional tail rotor. A two-seat version originally designated J-10, which was then under construction, was left unfinished. Two more single-rotor versions were built, this time with tail rotors, and all of these (including the J-5 and the J-10) became known as the UH-5. [4,34,35]

The second UH-5 crashed in November 1946 due to poor stability, particularly in the roll axis. As a result, Hiller developed the "Rotormatic" cyclic control system. This was based on an idea Stanley Hiller had drawn in 1940: using airfoil "paddles" to aerodynamically boost the main rotor controls. These paddles were mounted on the rotor head at right angles to the blades. When the pilot moved the cyclic control stick, this adjusted the paddles, which in turn affected the main rotors. This system provided positive dynamic stability, reduced the input force required, and eliminated severe vibrations on the control stick from the main rotors. The redesigned UH-5 was so stable, it could be hovered hands off or even without a pilot. [34,35]

By this time, four years after beginning the XH-44, Hiller had tested eight helicopters in 14 different configurations. In July 1947, development began on a production prototype called the Hiller 360 or UH-12. This helicopter was developed with three-across seating, a 160 hp vertically mounted Franklin motor, an overhead control stick, and two wooden rotor blades. The prototype, the 360X, first flew on 11 November 1947, and was publicly demonstrated one month later. It was heavily marketed for agricultural use. With a $20,000 price tag, it was far less expensive than any other contemporary helicopter. Three more pre-production aircraft were built to speed civil certification, which was granted in October 1948. By this time, Hiller had moved the company into a permanent headquarters on 61 acres in Palo Alto, California, and completed a $150,000 production factory. An improved version, the UH-12A, received supplemental certification in May 1950. It featured new rotor blades and a 10% grow weight increase. 194 of these early UH-12/As were built. [34,35]

The onset of the Korean War meant a sudden need by the Army for more helicopters. In September 1950, the Army began testing a UH-12A with enclosed litter carriers and military radios, designated YH-23. The Army ordered 105 H-23A Ravens at the end of 1950; in addition, 16 UH-12As had been previously ordered by the Navy as trainers, but when the war broke out, these HTE-1s were converted to Army use. [18,34]

Figure 79. Army H-23 Ravens.

Early H-23 performance and reliability in Korea were inadequate. The H-23B used a 200 hp Franklin engine, landing skids instead of wheels, and a stronger structure. Flight testing began in September 1951 with first production deliveries two months later. By this time the company officially changed its name to Hiller Helicopters. Gross sales in 1952 reached $14.4M compared to $0.6M in 1949. Civil helicopter production was resumed in June 1952, with the UH-12B (H-23B). [34]

The UH-12C/H-23C was introduced in 1955 with all metal rotor blades and a goldfish bowl cockpit canopy. A total of 145 were delivered to the Army. An observation version, the OH-23D with a 320 hp Lycoming engine and an uprated gearbox found 483 more orders. The most highly produced version was the UH-12E/OH-23G. A four seat version, the Hiller 12E4/OH-23G, was also built. The Hiller L3 (12E-L) and L4 (12E4-L) used the new high inertia L rotor instead of the Rotormatic paddles used on previous Hiller designs. This L rotor used a Hamilton Standard stability augmentation system and new wide-chord metal rotor blades with high lift and inertia. These blades gave a smoother ride, more solid control feel. All together, more than 2,000 UH-12/H-23 helicopters were produced, including 300 in exports. [18,26,34]

The Hiller HJ-2 and HJ-1 Hornet, developed in 1950, had a two-blade rotor driven by tip ramjets, producing less than 40 lb thrust each. The Army evaluated 12 Hornets in 1952 with the designation H-32, and the Navy a single prototype as the HOE. Gross weight was only 1,078 lb; it had two seats and could be disassembled in minutes. The first US contract ever issued for an armed helicopter went to Hiller in 1955 for a modified Hornet, the YH-32 ULV (ultralight vehicle). Three were built and tested in 1957, firing rockets, wire guided missiles, land mine detectors and other equipment. This laid the groundwork for the Army's development of armed helicopters in Vietnam. Hiller also tested the feasibility of using turbojets and hydrogen peroxide rockets on rotor tips. [18,26,34]

Figure 80. The Hiller YH-32.

The even smaller YROE-1 Rotorcycle was first tested in January 1957 and seven were evaluated by the Navy and Marine Corps. The idea was that it could be air-dropped and assembled by one man under combat conditions in five minutes. It could also be dismantled and carried in a small container. It used a 43 hp Nelson engine and had an empty weight of 300 lb. [18,26]

A number of one-man flying platforms were built by several companies including Hiller during the mid-1950s and early 1960s. These platforms primarily consisting of handrails to hold on to (or later, a seat) and propellers or rotors spinning just below the pilot. The Hiller VZ-1 Pawnee had 5 ft (1.5 m) ducted propellers. Several larger versions were also tested. These standing platforms were steered by leaning in the desired direction. A Hiller also built a tiltwing transport prototype, designated the X-18, but engine performance was insufficient for hover. [14,18,19]

None of these excursions from conventional helicopters, however, reached production. Several more concepts were also developed which likewise did not provide the company with any production revenues. In July 1961, Hiller began flight testing the Ten99 (design 1099), a six-place all purpose helicopter with a derated 500 shp P&W PT6 turbine engine. Gross weight was 3,500 lb, with 1,000 lb available for payload in its 100 ft^3 cargo hold. The Ten99 lost out to the Bell UH-1 Huey and plans for an executive commercial version were abandoned. [34]

The Hiller Model 1100 was developed for the Army's light observation helicopter (LOH) competition. The design was submitted in January 1961, and soon declared the only acceptable technical design, but three contracts were awarded for five prototype each to Hiller, Bell and Hughes. First flight of the 1100/OH-5A was on 26 January 1963. It featured the L rotor and impact absorbing landing skids. Meanwhile, seeking a stable parent company, Hiller was purchased by Fairchild in May 1964, which was renamed the Fairchild Hiller Corporation. Stanley Hiller became Vice President of the Hiller Aircraft Division. Shortly thereafter, Republic Aircraft joined the company. Despite having what was considered to be the best design, Hiller lost to the Hughes OH-6 in May 1965, when Hughes submitted a bid that was less than $20,000 per helicopter. Nonetheless, Hiller had already begun development of the FH-1100 and 246 were built for the civilian market. Meanwhile, Stanley Hiller departed the company in 1965, leaving behind a seemingly stable business base and several promising development contracts. [27,34]

Figure 81. The FH-1100.

Stung by the loss of the OH-5 contract, however, which Hiller felt had been stolen by Hughes, Hiller Aircraft refused to bid on the next Army contract. This resulted in Bell winning the OH-58, and the virtual end of Hiller helicopters when production finished in 1973. Ownership soon passed to Rogerson Aircraft, and was finally repurchased in July 1994 by Stanley Hiller's son and a group of Thai investors. The Hiller UH-12E3 and the turbine powered UH-12E3T (using the Allison 250-C20B) are being produced. Over 200 turbine-powered UH-12Es have been produced or converted. [27,34,42]

Kaman

During WWII, Charles Kaman was chief of aerodynamics for Hamilton Standards' helicopter activities. In response to Igor Sikorsky's development challenges with the VS-300, Kaman began experimenting with aerodynamic servo flaps to achieve ease of control along with handling stability in flight. The main principle was to use the inherent rotor flexibility as an asset and let the external flaps position the rotor blade at an angle that would produce adequate lift and control. After building a test rig in 1945, the 26 year old Kaman was released from his obligations at Hamilton, since both he and Sikorsky worked for divisions of United Aircraft Corporation in Connecticut. [5]

Thus, Kaman Aircraft Corporation was formed in December 1945 and within 13 months, was flying an intermeshing rotor helicopter with an innovative servo-flap system, designated the K-125. In April 1949, an improved version, the K-190, was granted a Civil Aeronautics Authority (CAA) certificate for commercial use. Shortly thereafter, a 225 hp version, the K-225 was also certificated, and 11 were produced, primarily for crop dusting. In March 1950, three K-225s were evaluated by the Navy and Coast Guard. On delivery, the first K-225 performed the first loop by a helicopter. With an enclosed fuselage, 29 of the aircraft were delivered to the Navy as the HTK-1 trainer between 1951 and 1953. The three seat HTK-1, with the Kaman designation K-240, had a 240 hp Lycoming piston engine, but in December 1951, a modified K-225 equipped with a Boeing 502 engine became the world's first gas turbine powered helicopter. In March 1954, the first of two Kaman HTK-1s were modified to become the world's first twin-turbine powered helicopter, with the Boeing XT50 turboshaft; in this configuration, one engine was shut down during the less demanding cruise flight. Another aircraft was modified as the world's first pilotless helicopter, the HTK-1K. It was controlled by radio from a remote station, first flown on 30 July 1957. [5,18,27]

Figure 82. The agricultural K-225 (left) and Navy HTK (right).

In conjunction with production of the HTK-1, Kaman developed an all new observation helicopter, the K-600, or HOK-1, originally powered by a 600 hp P&W R-1340 radial piston engine. Two prototypes, designated XHOK-1, were built, with the first flight on 21 April 1953. Kaman increased in size from 25 employees to 750 workers during this time. 81 HOK-1s were delivered to the US Marines, 24 to the Navy as the HUK-1, and 18 to the US Air Force as the H-

43A; the helicopter began service in April 1958. The K-600-3, powered by a 825 shp Lycoming T53 turboshaft, was built for the USAF for crash rescue as the H-43B Huskie, with a total of 202 built (including foreign sales). Installation of the smaller turboshaft engine above the fuselage, rather than within the fuselage, enabled the cabin capacity to grow from seating four or five to up to ten. Kaman was the first helicopter manufacturer to completely switch to turboshaft engines in 1959. In 1964, a 1,150 shp T53 was installed, with 37 HH-53F helicopters delivered by 1968. A number of altitude (32,840 ft) and rate-of-climb records were set in 1961. The aircraft saw extensive rescue use in Vietnam, rescuing thousands of flyers, including 500 in 1967 alone. The safety record of the Huskie was one of the best ever established by a military aircraft, with an accident rate lower than the USAF fixed-wing average. [5,18]

Figure 83. Air Force H-43B Huskie.

The Kaman K-20 was developed to fulfill a 1956 Navy requirement for a 13-place long-range utility rescue helicopter capable of operating from small ships. Originally designated HU2K-1 Seasprite, it first flew on 2 July 1959. The first production aircraft was accepted as the UH-2A in December 1962; a version with less instrumentation was delivered as the UH-2B. 190 of these two types were built, powered by a single 1,250 shp GE T58 turboshaft engine. During 1967-72, these aircraft were rebuilt with twin T58 engines. In 1970, the Navy decided to modify its 105 Seasprites to an antisubmarine configuration, the SH-2 Light Airborne Multipurpose System (LAMPS), complete with avionics mission equipment to detect, classify, and destroy submarines. Ten years later, the Navy requested Kaman to put the Seasprite back into production as the SH-2F. First delivery was on September 1983. The latest version, the SH-2G Super Seasprite, with new avionics, mission electronics and 1,723 shp GE T700 engines, entered US Navy service in February 1993. Over 250 Seasprites, including two dozen Super Seasprites, have been delivered. [5,18, 28]

Figure 84. The Kaman SH-2F Seasprite.

In the 1950s, Kaman diversified into non-helicopter areas, with approximately 75% of sales coming from non-Defense related business. In addition, Kaman began to produce components for other helicopter manufacturers. In March 1960, Kaman developed and flew the first all composite main rotor blade. In July 1976, Kaman designed and began manufacturing the K-747 blade, the world's first production all-composite rotor blade for the Bell AH-1 Cobra helicopter. Total production exceeded 4,000 blades. In early 2000, MD Helicopters, Inc. (MDHI) of Mesa, Arizona, announced its selection of Kaman as the sole supplier of fuselages for its entire line of single-engine helicopters. [5,27,28]

Kaman also built a number of experimental aircraft. The K-16, which never flew, was a tiltwing flying boat. In 1958, Kaman built an experimental two-seat cold jet powered helicopter, designated K-17; a 400 hp Blackburn Turbomeca Turmo 600 turbine drove a compressor which fed compressed air to blade-tip nozzles. In January 1964, Kaman began flight tests of a modified H-2, designated the Tomahawk, with a 2,500 lb thrust GE J85 turbojet engine and wings from a Beechcraft Queen Air to off-load the rotor in flight; the aircraft achieved speeds of over 225 mph. 18,26,27]

In 1991, Kaman began testing its K-1200 K-MAX "aerial truck." The K-MAX is the first helicopter specifically designed, tested and certified for repetitive external lift operations and vertical reference flight, an important feature for external load work. The aircraft's narrow profile gives the pilot an unprecedented view of the load looking out either side of the aircraft. Like all of Kaman's helicopters except the Seasprite, the K-MAX has intermeshing rotors with servo-flap control. FAA certification was received in August 1994. The K-MAX uses a single Lycoming T53-17A with 1,500 shp for take-off. Commercially, K-MAX is being used in a variety of applications requiring up to three tons of lift capacity, including oil rig and pipeline construction, powerline work, fire-fighting and timber harvesting. Militarily, K-MAX has successfully demonstrated its capability to perform vertical supply replenishment of U.S. Navy ships at sea. Kaman is under contract with the U.S. Marine Corps to develop a remotely piloted K-MAX for use in demonstrating a new tactical concept for resupplying troops on land from fast moving ships at sea. [27,28]

Figure 85. The Kaman K-MAX.

In 1999, Charles Kaman suffered a stroke and stepped down as president and CEO from his company after 55 years. He was probably the longest service aerospace executive in the world. He remains chairman of the board. [28]

McDonnell

McDonnell Aircraft Corporation in St. Louis, Missouri, began its interests in helicopters in 1943, when it formed an agreement with the Platt-LePage company to gain experience with rotary wing aircraft. It took control of the company the next year and McDonnell won a US Navy contract to complete the develop of a Platt-LePage design that was a follow on to the XR-1A. The 11,000 lb (gross weight) helicopter first flew on 27 April 1946. This was the first US twin engine helicopter, using two P&W Wasp Junior radial engines with 450 hp each. The large, twin engine, ten-place, side-by-side tandem rotor, was designated XHJD-1 Whirlaway and was extensively tested until 1951. The outriggers provided about 10% of the lift in cruise. [5]

By this time, McDonnell had established a helicopter division (in 1946) and began to examine a number of alternative methods of propelling helicopter rotor blades. Dr. Friedrich von Doblhoff, a German engineer who had built four tip jet test helicopters (the Wn 342) during the War, ended up at McDonnell, where the XH-20 Little Henry first flew in May 1948; little more than a free flying test stand with seats, it was powered by a ramjet at the end of each rotor blade. This was followed by the larger, company-funded, McDonnell Model 120, which used engine exhaust for steering, but neither a commercial nor military customer was found. [18,37]

The same basic tip-jet driven rotor system was used on the 5,500 lb (2,495 kg) McDonnell XV-1. First flight of the aircraft was on 14 July 1954. The nine-cylinder radial engine powered two air compressors feeding burners at the tips of the 31 ft (9.5 m) rotor for vertical lift and drove a 6 ft (2 m) propeller for cruise. The rotor autorotated in forward flight and allowed the XV-1 to become the first rotary wing aircraft to exceed 200 mph (322 km/hr). The proposed liaison mission of the XV-1 was subverted by the noise, as well as the flash of the tip jets, and testing ended in 1957. [15,18,19]

Figure 86. The McDonnell tip-jet XV-1.

Two additional McDonnell projects were built at this time for military use, but not completed. The Model 78 was to be a heavy assault helicopter, designated XHRH-1. The 30,412 lb design had a jet-tip rotor, stub wings, and tractor Allison T56 turboshaft/props on each wing. Three aircraft were ordered in 1951, but the project had only reached the mock-up stage when cancelled two years later, in favor of the Sikorsky HR2S/H-37. When the HRH was ended, the rotor development continued on the 35,000 lb Model 86 or XHCH-1. This design, was to be a ship-to-shore flying crane. McDonnell received a contract in 1952 for three prototypes, but the project was cancelled in January 1959. It used a similar tip-jet rotor system. [18]

Hughes / McDonnell Douglas / Boeing Mesa

In 1949, the Hughes Aircraft Company acquired an Army-sponsored Kellet Aircraft test bed. It was a pressure tip driven rotor powered by two GE J35 turbojets. The engines supplied compressed air through ducts that led up the rotor shaft and out four nozzles on the tips of the two rotor blades. The rotor had a diameter of 130 ft (37.6 m), the largest ever flown. The rotor system was then mated with an airframe as the Air Force XH-17 Flying Crane. Gross weight was 43,500 lb (19,750 kg), of which half could be external payload. First flight was October 1952. A full-scale working mock-up of a planned XH-28 was built at over twice the size, but cancelled due to cutbacks in research during the Korean War. The concept was dropped due to problems with rotor-blade fatigue, noise, and high fuel consumption. [5,18]

The Hughes XV-9 was first flown in November 1964 to evaluate hot-cycle propulsion, where hot exhaust gases from the GE T64 turbojet engines are ducted to the rotor tips. Only 19 hours of flight test were conducted during the next year, which was enough to determine that there were few advantages over the tip jets tested on the XH-17. The aircraft also had poor handling and stability characteristics. [15,19,23]

In the mid-1950s, another Hughes division, Hughes Helicopters based in Mesa, Arizona, funded a small two-place conventional helicopter initially called the Model 269A for the commercial market. First flight was in October 1956s. Five were bought by the Army as the YHO-2 for tests and put into production as the TH-55 Osage trainer, powered by a 180 hp Lycoming HIO-360 flat four cylinder engine. A three-place version, the 269B, was also developed for commercial use. The 269A was re-designated as the Hughes 200 and the 269B as the Hughes 300. By the early-1980s, over 850 had been produced, with about 800 for the US Army. [5,18]

Figure 87. The Army TH-55 Osage.

A four seat derivative, the Model 369, was developed for the Army's Light Observation Helicopter (LOH) as the OH-6 Cayuse, with a 317 shp Allison T63 (Allison 250). First flight was 27 February 1963 and the OH-6 entered service in 1966. Hughes had a hard time making the required production rate and reliability. The initial price – which was only about 2/3 of the cost of manufacturing – was soon doubled, and Hughes lost the next round of competition in 1967 to the Bell OH-58. Nonetheless, over 1,400 were built. A commercial version was also developed, dubbed the Hughes 500, with production beginning in 1969, and a paramilitary version, the

Model 500 Defender; later models used an uprated Allison 250. Several more commercial versions were developed, as explained below. [18,34]

Figure 88. Army OH-6 Cayuse.

After the Lockheed AH-56 Cheyenne was cancelled, the Army had a competition for an all-weather antiarmor attack helicopter. The Hughes Model 77 prototype first flew on 30 September 1975. After Army evaluations against the Bell YAH-63, the Hughes design was selected for development in December 1976, as the AH-64. Deliveries began in January 1984 production. Power was from two GE T700 engines producing 1,546 shp. In total, 821 AH-64As were delivered to the U.S. Army and 116 to international customers by 1997, when production transitioned to the AH-64D and AH-64D Apache Longbow. The Apache Longbow is equipped with a radar so it can rapidly detect, classify, prioritize and engage stationary or moving enemy targets at standoff ranges in nearly all weather environments. An additional 1,000 Apaches are expected to be produced in the next ten years.

Figure 89. The AH-64A Apache (left) and the AH-64D Apache Longbow (right).

Twenty days before the first Apache delivery, on 6 January 1984, Hughes was sold to McDonnell Douglas. On 1 August 1997, just four months after the first Apache Longbow was delivered, McDonnell Douglas and Boeing merged. This portion of Boeing Helicopters is typically referred to as Boeing Mesa.

MDHI

On 19 February 1999, Boeing sold its light helicopter product lines to the Dutch RDM Holdings; the Mesa production subsidiary is MD Helicopters, Inc. (MDHI). MD Helicopters produces the McDonnell Douglas derivatives of the Hughes 500.

The MD 500D was developed in the early 1970s, with a fifth rotor blade and a new tail rotor, making the MD 500 significantly quieter than other helicopters. The MD 500E began deliveries in 1982, with a pointier nose and increased visibility and headroom than the MD 500D. The five-seat, 3,000 lb MD 500E can use the Allison 250-C20B or C20R engine for utility or executive transport. Research into reducing the noise further led to the NOTAR (No Tail Rotor) anti-torque system. The 3,350 lb MD 520N uses a Allison 250-C20R turboshaft rated at 450 shp (336 kW) and the NOTAR. Over 100 MD 520Ns, using a larger main rotor, have been delivered since late 1991. [38,39,42]

Figure 90. The MD 520N.

The MD 530F has the more powerful Allison 250-C30 (650 shp) and a conventional tail rotor and is designed for high altitude/high temperature operations up to 16,000 ft; maximum gross weight is 3,100 lb. Certification was in July 1983. A stretched version, the eight-place 4,100 lb MD 600N, has a single 808 shp Allison 250-C47 engine, a six-bladed main rotor and the NOTAR System. It was launched in 1994 and certified in May 1997. [38,39,42]

Figure 91. The MD 530F (left) and the MD 600 (right).

The 6,250 lb MD Explorer also launched in the 1980s and certified in December 1994, but first production delivery wasn't until three years later. It has two PW206E turboshaft engines and a NOTAR. The Turbomecca Arrius 2C is offered as an option. [38,39,42]

Figure 92. The MD Explorer.

Schweizer

In 1983, Schweizer Aircraft Corporation, then the primary manufacturer of sailplanes in the US and a leading aerospace subcontractor (including production of major helicopter components), received a license from Hughes Aircraft to manufacture the Hughes Model 300C helicopter. Schweizer became the sole producer of the Model 300C, and provided spares for the worldwide support of the entire fleet of Model 269/300 series helicopters. Three years later, in November 1986, Schweizer purchased the rights to the Model 300C program in its entirety (then held by McDonnell Douglas). The Model 300C is a light utility helicopter powered by a 190 hp Lycoming piston engine, with an empty weight of 1100 lb and a useful load of 950 lb. [29]

Figure 93. The Schweizer 300C.

Since that time, the company has expanded the family of Model 300 helicopters with a lower cost trainer version, the Model 300CB, and the turbine powered Model 330SP. The 330 first flew in 1988 and the improved 330SP in 1997. It uses a derated Allison 250 engine; empty weight is 1140 lb and the useful load is 1120 lb. In 2000, Schweizer began deliveries of its newest helicopter, the Model 333. The four passenger 333 uses advanced technology main rotor blades and an upgraded dynamic system for 30% more load and higher performance. [29]

Figure 94. The Schweizer 330SP.

The TH-55 and Model 300C helicopters have been the world's leading entry level military training helicopter for the past thirty years. Two dozen countries have purchased and operated over 1,100 of these helicopters for military training. Today, over 3,500 helicopters in the Model 269 series have been delivered to over 70 countries around the world, most of them the Model 300C. [29]

Lockheed

In the late 1950s, Lockheed engineer Irven Culver believed that with a rigid (or “hingeless”) rotor, it would be possible to achieve greater speed, stability, and maneuverability, as well as have a simpler construction and lighter weight rotor system. Culver predicted that the gyroscopic inertia of the rotating hub could balance the rotor system. Lockheed built the world’s first radio controlled model helicopter to test their ideas in 1959. Based on this experience, Lockheed built its first full-scale helicopter, the CL-475, powered by a 180 hp Lycoming piston engine. First flight was on 2 November 1959, just five months after the design was initiated. The initial two-bladed wooden rotor was replaced by a three-bladed rotor to reduce vibrations, first with blades of wood, then of aluminum, with a gyro stabilizer ring fastened to the swashplate. [25]

As a result of the successful tests of the company funded CL-475, Lockheed received an Army-Navy contract to develop two XH-51A high-speed demonstrators. First flight was on 2 November 1962, exactly three years after the first flight of the CL-475. Powered by a 550 shp P&W PT6B-9 turboshaft, the XH-51A achieved 174 mph (280 km/h) with a three-bladed rotor and 202 mph (374 km/h) with a four-bladed rotor. Maneuverability demonstrations, side firings of a 0.30 caliber machine gun, and shipboard compatibility tests all indicated that stability and control were excellent with the rigid rotor system. NASA also ordered a slightly larger version, the XH-51N, for tests, and two civil versions were built, designated Model 286. FAA certification was granted in 1966 and the aircraft demonstrated loops, rolls, split-S maneuvers. A change in corporate leadership, however, caused Lockheed to back away from the civil Model 286, and an order for a dozen aircraft was never concluded. [25]

In order to test the high-speed characteristics of their rigid rotor system, Lockheed was awarded an Army contract to modify one of the XH-51As into a jet engine-augmented test bed, dubbed the XH-51A Compound. Due to the very high fuel consumption (endurance was only 20 minutes), however, this was only done for the research purpose of getting the aircraft up to high forward speeds, and was not evaluated as a practical application. It was powered by a 500 hp (373 kW) P&W T74 turboshaft engine driving the off-loaded rigid rotor, and a 2,600 lb (1,180 kg) thrust P&W J60 turbojet. It first flew on 10 April 1965 and soon achieved a speed of 302.6 mph (487 km/h). [19,25]

Figure 95. The XH-51A Compound.

Lockheed soon began developing a 22,000 lb (10,000 kg) US Army helicopter to exceed 250 mph (400 km/hr), using a rigid rotor and a pusher propeller. First flight was in September 1967. Despite some rotor development problems, the AH-56 Cheyenne eventually reached 282 mph (454 km/hr) in a dive and 247 mph (398 km/h) in level flight. Nine flying prototypes were built, but the development was canceled due to budget cuts and a perceived duplication of capabilities with the Air Force A-9/A-10 program. This was the death knell of Lockheed's helicopter development efforts, which ended after constructing a total of 15 test aircraft. [15,18,19]

Figure 96. Lockheed AH-56A Cheyenne prototype.

Enstrom

Rudy Enstrom was a lumberman and mechanic in the 1940s and 1950s who built several prototype helicopters in Michigan. Eventually he received financial backing and founded the R.J. Enstrom Corporation in 1959. The first practical helicopter was the F-28, which received initial FAA certification in April 1965. Soon, a more powerful version, the F-28A was developed and certified in May 1968; more than 300 were built. A four cylinder 205 hp Lycoming engine provided power. [38,40]

Figure 97. The Enstrom F-28A.

In October 1968, a controlling interest in Enstrom was purchased by Purex Corporation, who wanted to develop a turbine powered version. Unfortunately, the engine selected was not suited for it, and piston engine production began to languish. F.Lee Bailey purchased the Purex stake in January 1971, changing the name to the Enstrom Helicopter Corporation. The F-28 was revived and a new model, the 280 Shark, was certified in September 1974. A turbocharger for the Lycoming engines was introduced and these models, the F-28C and 280C, were certified in 1975. A stretched 4 seat version, the 280L Hawk, first flew in December 1978, but Enstrom lacked funding to complete development. [38]

Under new private ownership in early 1980, engine power was increased to 225 hp on the F-28F and 280F; certification was in December 1980. A number of additional improvements, certificated in January 1985, were incorporated on the 280FX. Over 600 of the 2,600 lb F-28 series and more than 300 of the 280 series helicopters have been delivered today. The main difference between the two is the 280 has a longer, more aerodynamic cabin, as well as a covered tail rotor driveshaft, a faired landing gear, horizontal stabilize endplates, and a different engine inlet system. [38, 40]

Figure 98. The Enstrom F-28F (left) and the 280FX (right).

In 1988, Enstrom initiated the development of a larger, turbine powered helicopter. A three-seat trainer, the TH-28, and a five-seat commercial helicopter, the 480, were designed around the Allison 250-C20 derated to 289 shp for take-off. A 250 engine was tested in a 280FX in 1989, and the first TH-28 first flew the following year, receiving certification in September 1992. The first 480 began flight testing in 1993 and was certified in December 1994; over 40 of the 2,850 lb Enstrom 480s have been delivered. [38, 40]

Figure 99. Enstrom 480.

Brantly

Newby O. Brantly was the co-founder and vice president of an elastic company in the 1930s, but had begun flying in 1925, and during WWII, he became interested in helicopters. In 1945, he built and flew a coaxial rotor with two flapping hinges, one at 1.4% radius and a second at 38%. This reduced the bending movements and eliminated the need for blade dampers, resulting in a much smoother ride than other helicopters. High manufacturing cost of the coaxial design led to the development of the 500 lb (empty) single-rotor B-2 prototype in 1953, at which time Brantly Helicopter Corporation was born. The company moved from Philadelphia to a surplus military installation in Oklahoma and began sales and production. Certification was achieved in 1959. An improved B-2A was developed in 1962, followed by the B-2B in 1963, and the five seat B-305 in 1964. From 1959 to 1966, nearly 500 Brantlys were built. The company changed hands numerous times through Lear Jet Industries (1966), Aeronautical Research and Development Corp (1968), and later, Hynes Aviation Industries. In 1991 it was purchased by James Kimura, and is now renamed as Brantly Helicopter Industries, in Vernon, Texas. The modern B-2B was certificated in 1991, and has a 180 hp Lycoming piston engine, an empty weight of 1,020 lb and a maximum gross take-off weight of 1,670 lb. Production is approximately three dozen per year. [32,33]

Figure 100. The Brantly B-2B.

Robinson

Frank Robinson, previously a design engineer at Hughes, founded Robinson Helicopters in 1973. He began construction of his two-seat R22 prototype in Torrance, California, in 1975. In 1979, Robinson received a type certificate, and the R22 began production. Although the cost was less than a third of turbine engine helicopters, acceptance of the helicopter was initially slow. By the late 1980s, however, the R22 was setting sales records. The latest model, the R22 Beta II was introduced in 1996. It weighs 855 lb empty and can carry a useful load of 515 lb. It is powered by a larger 131 hp 4-cylinder Lycoming engine. The four seat R44 was certificated in 1992 and now outsells the R22. The 1,442 lb (empty) R44 Raven has a 225 hp Lycoming 6-cylinder engine and has a useful load of 958 lb. Over 250 total R22 and R44 helicopters are sold per year, making them the best selling helicopters for 10 of the past 11 years. Both helicopters are also offered in float versions. Total revenues, including overhauls, are over $80M. [30,31]

Figure 101. The Robinson R22 Mariner II (left) and the R44 Raven (right).

Conclusion

Early attempts to develop a practical helicopter were beset by two main problems: sufficient thrust to weight and adequate controllability. The increasingly improved performance of the aviation piston engine, as well as increased understanding of rotor dynamics, allowed the helicopter to eventually become a practical vertical flight aircraft. Once the controllability issues with the helicopter had been solved, dozens of helicopter companies were developing designs by the early 1950s. Nearly all of the companies (or their descendents) that reached production in the US during this time are still active today. Over 60,000 American helicopters have been produced, roughly half of the worldwide total.

The environments of the combat in Korea and Vietnam did much to spur rapid development of vertical flight aircraft. Helicopters were first used for troop and equipment transport, medical evacuation, and later, for attack. The introduction of the turboshaft engine greatly improved the power to weight, reliability, speed and payload (although at increased fuel consumption and expense) of the helicopter and led to further developments. [3]

By 1960, the US helicopter industry had become an important part of the transportation sector, with over $2.5B in sales – 20% of which were for civil applications – and over 7,000 helicopters produced. [5]

Today, the helicopter is nearly as much a necessary part of society as the fixed wing aircraft. Over 3 million lives have been saved by helicopters in both peacetime and wartime operations since the first person was rescued from the sea in 1944. There are currently more than 15,000 civil and 30,000 military helicopters operating in more than 150 countries around the world. [2]

Helicopter developments in the US have resulted in a robust industry competing for future commercial and military production. Worldwide civil production demands are expected to stabilize around 800 units per year, but climb to a value of over $2B per year. Military production requirements are expected to be around 400 units per year worth nearly $6B annually. In addition, nearly 2/3 of the helicopters now sold worldwide – approximately 800 annually – are American helicopters. Major modification programs are also underway, spiking to over $15B in the next few years. These requirements ensure a healthy future for US helicopter companies in the 21st Century. [38]

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Appendices

Table 1. Characteristics of representative vertical flight machines (1900-1945).

Designer	Country	Vehicle Name	First Flight	Engine	Power (hp)	Gross Wt (lb)	Empty Wt (lb)	Rotor Qty + Blades	Rotor Dia (ft)
Louis Breguet	France	Gyroplane No.1	24 Aug 07	Antoinette (inline 8)	45	1,274	1,102	4 4-blade biplane	26.1
Paul Cornu	France	-	13 Nov 07	Antoinette	24	573	419	2 2-blade	19.7
Berliner/Williams	USA	-	1908	2 x Adams-Farwell rotary	36 each	610	460	2 2-blade	18.7
J. Newton Williams	USA	-	May 08	Curtiss	40			2 2-blade	
Igor Sikorsky	Russia	Helicopter-1	Jun 09 (*)	Anzani	25	595	401	2 2-blade	16
Igor Sikorsky	Russia	Helicopter-2	Feb 10 (**)	Anzani	25	551	357	2 3-blade	
Boris Yuriev	Russia	-	1912 (***)	Anzani	25		445	1 2-blade	28.2
Jacob Ellehammer	Denmark	-	1912	Ellehammer (radial 6)	36			2 6-blade + 1 prop	24.5
von Karman/Zurovec	Austria	PKZ 1	Mar 18	Austro-Daimler electric	190	1,433		4 2-blade	13.8
Wilhelm Zurovec	Austria	PKZ 2	2 Apr 18	3 x Le Rhône rotary	120 each	3,087		2 2-blade	19.7
Emile and Henry Berliner	USA	-	Jun 19		80		617	2 2-blade	13
Marquis Pescara	Spain	No. 1	1919	Hispano	45		1,323	2 6-blade biplane	21
Marquis Pescara	France	No. 2	May 21	Le Rhône rotary	170			2 6-blade biplane	21
Henry Berliner	USA	-	Jun 22	Le Rhône rotary	110	1,350	1,250	2 2-blade	14.8
George de Bothezat	USA	-	Oct 22	Bentley BR-2 rotary	200	3,700	3,400	4 6-blade + 2 props	26.5
Etienne Oehmichen	France	No. 2	11 Nov 22	Gnome rotary	120		1,764	4 2-blade + 8 props	(2) 24.9 + (2) 21
Louis Brennan	England	-	May 23	Bentley BR-2 rotary	230		3,000	1 2-blade	60
Marquis Pescara	France	No. 3	Jan 24	Hispano-Suiza (Vee)	180		1,874	2 4-blade biplane	23.6
A.G. von Baumhauer	Netherlands	-	Jun 25	Bentley + 80 hp tail engine	200	2,860	2,000	1 2-blade	50
TsAGI (Boris Yuriev)	USSR	1-EA	Aug 30	2 x M-2 rotary	120	2,525	2,160	1 4-blade	36.1
Corridion D'Ascanio	Italy	-	Oct 30	Fiat A 50	95	1,760		2 2-blade	43
Oscar von Asboth	Hungary	AH-4	1931	Clerget rotary	110	1,080		2 2-blade	14.1
Nicolas Florine	Belgium	-	Apr 33	Hispano-Suiza	200	2,100		2 4-blade	23.6
TsAGI (Boris Yuriev)	USSR	3-EA	1933	2 x M-2 rotary	120	2,525	2,160	1 4-blade	36.1
TsAGI (Ivan Bratukhin)	USSR	5-EA	1933	2 x M-2 rotary	120	2,667	2,308	1 6-blade	3 x 39.3 + 3 x 25.5

Louis Breguet/ René Dorand	France	Gyroplane Laboratoire	26 Jun 35	Hispano 9Q (radial)	350	4,475	3,153	2 4-blade	52.5
Heinrich Focke	Germany	Fw 61	26 Jun 36	BMW Bramo Sh 14A	160	2,090	1,716	2 3-blade	23
TsAGI (Ivan Bratukhin)	USSR	11-EA	1936	Curtiss Conqueror	630	5,732		1 6-blade + 2 prop	3 x 50.5 + 3 x 30.2
Anton Flettner	Germany	Fl 185	1936	BMW Bramo Sh 14A	140	1,984		1 3-blade + 2 prop	39.4
TsAGI (Ivan Bratukhin)	USSR	11-EA PV	1939	Curtiss Conqueror	630	4,960		1 6-blade + 4 prop	3 x 50.5 + 3 x 30.2
Anton Flettner	Germany	Fl 265	May 39	BMW Bramo Sh 14A	140	2,205	1,764	2 2-blade intermesh	40.4
Igor Sikorsky	USA	VS-300	13 May 40	Lycoming 4 cylinder	65	1,092		1 3-blade	28
Heinrich Focke	Germany	Fa 223 Drache	Aug 40	BMW Bramo 323Q3 Fafnir	1000	11,020	7,000	2 3-blade	39
Igor Sikorsky	USA	VS-300A	1941	Franklin 4AC-199	100	1,325	1,044	1 3-blade	36
Platt LePage	USA	XR-1	May 41	P&W R-985-2	440	4,730		2 3-blade	30.5
TsAGI (Ivan Bratukhin)	USSR	Omega I	Aug 41	2 x MV-6 radial	220	4,519	3,800	2 3-blade	23
Anton Flettner	Germany	Fl 282 Kolibri	late 1941	BMW Bramo Sh 14A	150	2,205	1,675	2 2-blade intermesh	39.2
Igor Sikorsky	USA	XR-4	14 Jan 42	Warner R-500-3	165	2,540	2,010	1 3-blade	28
Bell (Arthur Young)	USA	Model 30	Dec 42	Franklin	160	2,300		1 2-blade	32
Frank Piasecki	USA	PV-2	11 Apr 43	Franklin 4 cylinder	90	1,000		1 3-blade	22
Friedrich Doblhoff	Austria	WNF 342 V1	Spring 43	Walter Mikron II	60	990	500	1 3-blade	29.5
Friedrich Doblhoff	Austria	WNF 342 V2	1943	Walter Mikron II	90	1,014	740	1 3-blade	29.5
Igor Sikorsky	USA	XR-5	18 Aug 43	P&W R-985-AN-5	450	4,896	3,781	1 3-blade	49
Igor Sikorsky	USA	XR-6	15 Oct 43	Lycoming 0-435-7	225	2,596	2,034	1 3-blade	38
Friedrich Doblhoff	Austria	WNF 342 V3	1944	BMW Bramo Sh 14A	140	1,208		1 3-blade	32
Stanley Hiller	USA	XH-44	Jul 44	Franklin 4 cylinder	90	1,400		2 2-blade	
Kellet	USA	XR-8	Aug 44	Franklin O-405-9	245	2,975	2,320	2 3-blade	36
TsAGI (Ivan Bratukhin)	USSR	Omega II	Sep 44	2 x MG-41F radial	350	5,071	4,145	2 3-blade	23
Fred Landgraf	USA	H-2	Nov 44	Popjoy R	85	850	636	2 2-blade	
Frank Piasecki	USA	PV-3/XHRP-X	7 Mar 45	Warner R-975	450	5,000		2 3-blade	41
TsAGI (Ivan Bratukhin)	USSR	Omega G-3	1945	2 x PW 985-AN-1 radial	450	5,732	4,839	2 3-blade	23
Friedrich Doblhoff	Austria	WNF 342 V4	1945	BMW Bramo Sh 14A	140	1,411	950	1 3-blade + 1 prop	32.8
Bell (Arthur Young)	USA	Model 47/YR-13	8 Dec 45	Franklin O-335-1	165	2,300		1 2-blade	32

(*) Unmanned; did not leave the ground;(**) Unmanned;(***) Did not leave the ground.

Table 2. Characteristics of representative autogyros.

Designer	Country	Vehicle	Date	Engine	Power (hp)	Gross Wt (lb)	Altitude (ft)	Distance (mi)	Speed (mph)
Cierva	Spain	C.4	1923	Le Rhône 9JA	110		100	2.5	
Cierva	Spain	C.6A	1924	Le Rhône 9JA	110		655	7.5	68
Cierva	Spain	C.8L Mk II	1928	Armstrong-Siddeley Lynx IVc	200	2,470	4,000	255	100
Pitcairn	USA	PCA-1	1930	Wright R-760-4	240	2,750			105
Pitcairn	USA	PCA-2	1931	Wright R-760-4	240	3,000		290	110
Pitcairn	USA	PCA-3	1931	Wright R-975/E	300	3,063			120
Pitcairn	USA	PA-19	1931	Wright R-975/E2	420	4,640	18,400		120
Yuriev	USSR	2-EA	1931	Gnome-LeRhone	230	2,275	13,775		99
Kellett	USA	K-2	1932	Continental R-670	160	2,200			100
Kellett	USA	K-3	1933	Kinner C-5	210	2,300			110
Kuznetsov	USSR	A-6	1933	Shvetsov M-11	100	1,800	6,560		33
Yuriev	USSR	A-4	1934	Shvetsov M-26	300	3,000	13,448	115	109
Kamov	USSR	A-7bis	1934	Shvetsov M-22	480	5,070	15,421	370	120
Kuznetsov	USSR	A-13	1934	Shvetsov M-11	100	1,768	9,840		28
Kellett	USA	KD-1	1935	Jacobs L4MA7	225	2,050			120
Kellett	USA	YG-1A	1936	Jacobs L4MA7	225	2,205			128
Pitcairn	USA	PA-33	1936	Wright R-975/E2	420	3,300			140
Shrzhinksy	USSR	A-12	1936	Wright Cyclone	670	3,720	18,270		152
Kuznetsov	USSR	A-15	1937	Shvetsov M-25B	730	5,644	21,000		161
Kellett	USA	YG-1B	1937	Jacobs L4MA7	225	2,400		360	128
Pitcairn	USA	PA-34	1937	Wright R-975/E2	420	3,300			140
Kellett	USA	KD-1B	1939	Jacobs L4MA7	225	2,295	14,000	200	125
Cierva	Spain	C.30A	1944	Armstrong-Siddeley Genet Major	140	1,900	8,000	250	110