Engineering Analysis of the 1907 Cornu Helicopter

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Abstract

Paul Cornu (1881–1944), a Frenchman from Lisieux, along with his father Jules and brother Jacques, pioneered the development of three rotating-wing aircraft concepts from 1906 to 1908. Their work encompassed the development of flying models, attempts at flying a larger, piloted helicopter concept, and the design of a hybrid or convertiplane concept. Their aeronautical patents included a method of flight control using differentially activated shuttered louvers, as well as cyclic blade pitch using a form of swashplate mechanism. Paul Cornu claimed that he first flew their twin-rotor helicopter concept for the first time in November of 1907. However, the engineering analysis of his concepts conducted in this paper shows that Paul Cornu's claim to successful piloted flight with a helicopter, free of the ground and under positive control, is extremely dubious. Although the Cornus were apparently successful in building and flying models of a helicopter concept, what they lacked was the necessary understanding of rotor aerodynamics, helicopter performance, and effective methods of flight control to scale their flying models to the size needed to carry a pilot free of the ground. This paper describes a chronology and a critical engineering analysis of the Cornus' helicopter concepts, from their flying model in 1906, to the more well-known 1907 piloted helicopter, and finally to their "Helicoplane" hybrid concept of 1908.

Introduction

Until the 1930s, aviation had witnessed a long series of unsuccessful attempts at building a helicopter that could take off and hover free of the ground under positive control of the pilot. Many engineers and inventors had experimented with different types of rotor systems and engines, but the various helicopter contraptions were generally underpowered, unstable, and incapable of sustaining themselves in the air for more than just a few seconds. Control systems were also woefully insufficient to give the pilot sufficient authority over the aircraft to overcome their inherent instability. Although it could be argued that each machine represented some modest step forward in helicopter design, none of them could be considered "successful" in that they never achieved a flight that was sustained free from the ground, or a flight that was fully directed by the pilot under positive control. These capabilities, as well as forward flight and autorotational capability in the event of engine failure, were not to be achieved with a helicopter until the mid-1930s.*

Shortly after the Wright Brothers' first successful powered flights with fixed-wing airplanes in 1903, two wealthy French industrialists by the names of Henry Deutch de la Meurthe and Viscount Earnest d'Archdeacon offered a prize of 50,000 French francs † to the first pilot who could fly an aircraft around a one kilometer closed circuit course. A fierce competition began for the Deutch–Archdeacon *Grand Prix d'Aviation* or *Grand Prix Prize of Aviation*. The innovative aircraft designs that ensued, which were mostly all fixed-wing airplanes, contributed greatly to the development of European aviation.

A rotating-wing aircraft that was specifically designed to compete in the Deutch–Archdeacon competition was built by a Frenchman named Paul Cornu (1881–1944), with the help of his father, Jules Cornu, and later with his younger brother, Jacques Cornu. During the period 1906–07, the Cornus constructed a helicopter concept that has been claimed to have carried a human off the ground for the very first time in a controlled flight. Nearly every book and article written on the history of the helicopter makes this claim (e.g., Refs. 1–4), although photographs of the feat have never been produced, and few seem to have ever questioned the claims, even with the sketchy evidence.

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Presented at the 64th Annual Forum of the American Helicopter Society, Montréal, Canada.

*The Breguet *Gyroplane No. 1* and the Focke-Wulf Fw-61 both have legitimate claims to being the first successful helicopters with the capabilities to meet these basic requirements.

†In today's money, this would be the equivalent of about US$150,000.

The present paper describes a chronology and engineering analysis of the Cornus' work on their rotating-wing aircraft concepts, which ranges from 1906 through to about 1908. One of first forms of documentation for the Paul Cornu's claims of successful helicopter flight date back to a 1908 issue of the *L´Aerophile*, in an article (Ref. 5) written by Paul Cornu himself, where he claims his first attempts at flight took place in November of 1907, with a first hop free of the ground on December 6. Based on the engineering analysis described in the present article, however, it is shown that it is very dubious that Paul Cornu could have successfully flown his machine free of the ground in sustained flight and under positive control. Although, like several other primitive helicopter concepts of the era, brief hops into the air might still have been possible.

Although the Cornus seem to have been successful in building and flying smaller models of their helicopter concept, it is clear that what they lacked was the necessary understanding of rotor aerodynamics and helicopter performance to build a larger and successful piloted concept. However, the engineering analysis also shows that the Cornus were certainly on the right track. Perhaps with a better knowledge of aerodynamics to build more efficient rotors, and an understanding of how to scale up their tests with free-flying models to a bigger machine with sufficient power, they might have had somewhat better success. But to have been truly successful in carrying a pilot off the ground in a helicopter for the first time in history, as it has been frequently claimed, the Cornus would have needed a much more powerful engine and/or a larger rotor with lower disk loading and higher efficiency, and certainly a better method than a belt drive for power transmission.

Before the Helicopter

Born on June 15th 1881 in Glos la Ferrière, France, to Jules and Louise Cornu (née Lecouturier), Paul Cornu was the eldest of thirteen children. The Cornu family was to settle in Lisieux in northern France, near Normandy. Paul's father, Jules Cornu, was an accomplished mechanic and machinist, and owned a removal and haulage company (Cornu & Sons) with a small workshop to support the business (Ref. 6). It was here that Paul Cornu learned his trade from his father, and he was also to become a competent draftsman. Jules Cornu was very interested in the emerging field of aviation, and had at one point designed (but not built) a dirigible.

By the late 1890s, Cornu & Sons began to progressively specialize in manufacturing bicycles, small engines, pumps, and also motorcycles and an automobile—see Figs 1 and 2. Their business was apparently beginning to thrive (Fig. 3), and at one point they received an order for ten automobiles from Russia. It was an order, however, that they were unable to fulfill (Ref. 6).

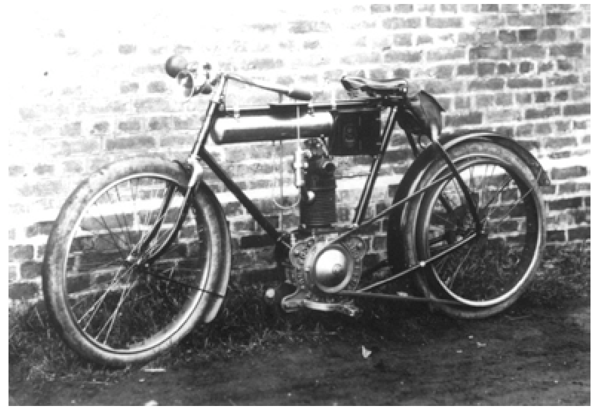

Figure 1: An early motorcycle, circa 1900, built in Lisieux by the company of Cornu & Sons.

Figure 2: An early automobile, circa 1900, built in Lisieux by the company of Cornu & Sons.

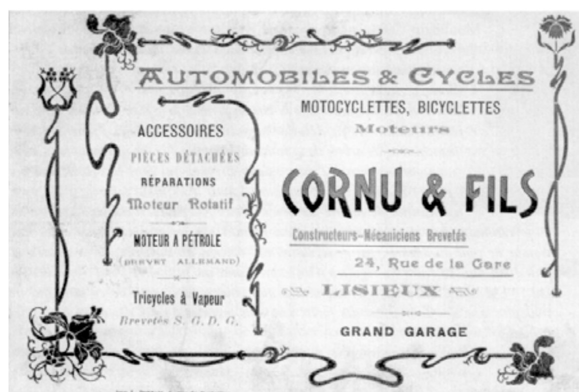

Figure 3: A newspaper advertisement for Cornu & Sons, who were operating out of the "Grand Garage" on Rue de la Gare in Lisieux.

Jules and Paul Cornu were to make several claimed improvements to engines and pumps, some of which were patented. Figure 4 shows one example of their patented

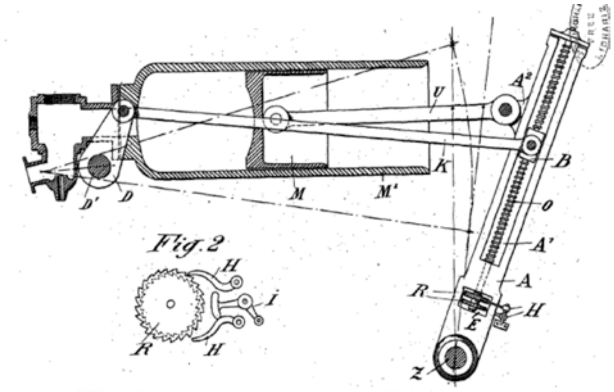

Figure 4: A sketch from a Cornu patent showing an internal combustion engine with a continuously variable stroke. (From Swiss Patent No. 22,208, June 4, 1900 and British Patent No. 18,728, November 24, 1900.)

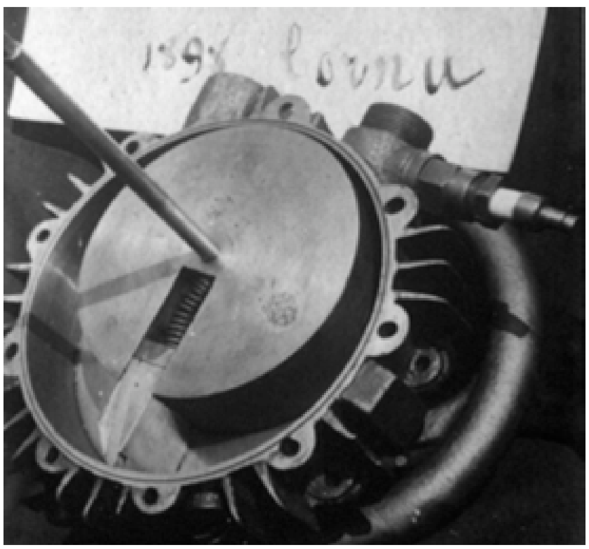

Figure 5: The Cornus' rotary internal combustion engine worked fine, except under load!

engineering work, which is an internal combustion engine with a continuously variable stroke (Refs. 7, 8). It was apparently designed to power an automobile, the variable stoke capability being used in leu of a gearbox.

The Cornus particularly enjoyed the challenges of designing and building intricate machinery, or in improving upon their existing capabilities. They were also to design a form of rotary internal combustion engine (Fig. 5); the rotary engine apparently worked fine without a load, but it unfortunately stopped immediately when it was asked to produce any power (Ref. 6).

The Cornus were also to design much more unusual machinery, including a type of "thermal" clock. This was based on the principle of Franklin's boiler,[‡] in which the

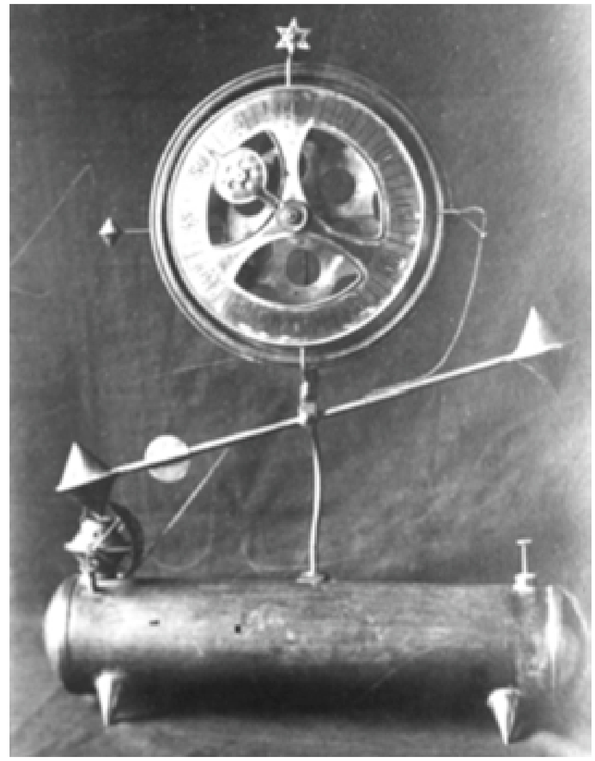

Figure 6: The Cornus' steam powered clock, which was based on the principle of Franklin's boiler.

rapid vaporization of a liquid (ether or alcohol) in an evacuated ampule modifies the equilibrium of the horizontal arm from heat produced in the boiler below, as shown in Fig. 6. The regularity of the process is such as to keep reasonably good time. However, the design was really not very practical.

A Testbed for a Helicopter

In 1903, the *Aero Club de France* offered a modest prize of 1,500 French francs [§] to the first person to fly 100 m (330 feet). In the same year, two wealthy industrialists, Henry Deutsch and Earnest Archdeacon, combined forces to establish the *Grand Prix d'Aviation* or *Grand Prix Prize of Aviation*, a more significant prize of 50,000 francs for the first person to fly around a one kilometer closed course. By 1905, the prize remained unclaimed (even though the Wright Brothers at this point had made a flight of over 30 km in the United States) so Paul Cornu

[‡] In its original form, "Franklin's boiler" has a pair of glass ampoules linked to one another through a tube. Ether or alcohol is introduced into the ampoules and brought to a boil to displace the air, and the tube is then sealed and the ampules cooled. In this condition, the liquid inside bears only its own vapor pressure, which is very low. The heat of one's hand is then sufficient to boil the liquid and transfer it over to the other ampoule.

[§] In today's money, this would be the equivalent of about US$4,500.

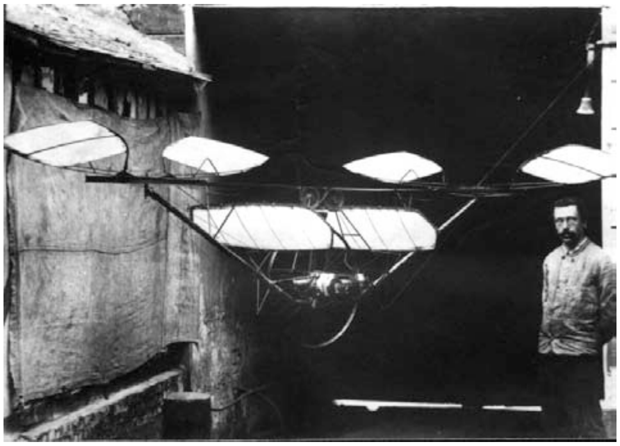

Figure 7: The Cornus' rotating-wing testbed for the helicopter concept.

set out with his father and brother to design an aircraft, and a helicopter at that, in an attempt to win the Deutsch–Archdeacon prize.

Like all good engineers, the Cornus began with tests on a model of their concept, which comprised two separate but counter-rotating rotors—see Fig. 7. Their testbed was similar in form to one made by Colonel Charles Renard in 1904 (Fig. 8). While Renard's rotor concept was unsuccessful, his aeronautical work was still viewed as credible within the aviation community. The Cornus used a Buchet Model 190, a one-cylinder engine that delivered up to about 2 hp at its shaft. A large spoked, bicycle-like wheel was used as a flywheel. By redesigning some parts of the engine, Paul Cornu was able to cut its weight in half from 14 kg to 7 kg. This engine drove the two rotors, each 2.25 meters in diameter, through a flexible belt transmission. The rotors rotated in opposite (counter-rotating) directions, a necessary requirement to cancel the torque reaction. The blades had a frame of welded tubular steel, covered with stretched silk. The final testbed weighed 13 kg, and Cornu reported that it was easily able to lift a net weight of up to 16 kg (Ref. 9).

Paul Cornu seemed to understand the basics of making a "propeller" (rotor) produce thrust with good efficiency in the hover state. He even said (Ref. 10): "The first quality of a lifting propeller is a small pitch. The smaller the better. Since all the work is absorbed by the slip, the latter will have to be reduced as much as possible." He is basically alluding to the fact that normal propellers, with their typically high blade pitch and twist, would be unsuitable for maximizing aerodynamic efficiency in the static thrust (hovering) condition. This is important, and it shows that he had some understanding of basic propeller principles. See also Paul Cornu's article in *L'Aerophile* (Ref. 11).

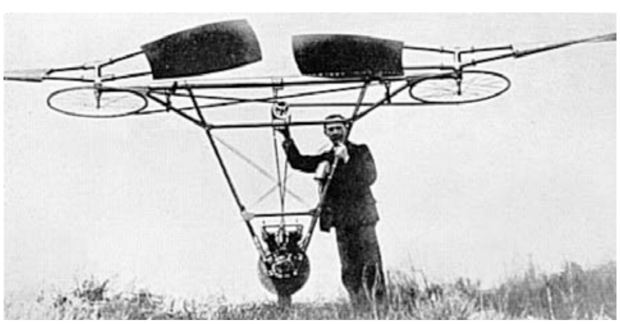

Figure 8: Charles Renard built this machine in 1904, which had two rotors of 2.5 m diameter. It did not fly successfully.

Cornu goes on further to say (Ref. 10) that: "The way this is achieved is by taking a propeller with a larger diameter." In effect, he is concluding that a larger diameter rotor is needed to compensate for the low thrust that would be produced by blades of low pitch (but higher efficiency). Indirectly, of course, Cornu is saying that a low disk loading is needed for good hovering efficiency, a fact well-known today. It is not clear, however, if he really understood the significance of disk loading and its fundamental role in defining the aerodynamic performance of a hovering rotor. Bearing in mind that rotor theory *per se*[¶] was not to become more widespread until the 1920s, it seems highly unlikely that the Cornus knew of any type of rotor theory in 1906.

Notice from Fig. 7 that the actual "Renard" type blades that the Cornus built were short and of low aspect ratio, with no twist or real airfoil shape, and with large root cut-outs. Therefore, with engineering hindsight they were probably not that aerodynamically efficient. This was something that even Paul Cornu was to admit: "This remarkable result, given the small dimension of the propellers, we attribute to our transmission which we patented." But a belt drive is not all that efficient in transmitting power, although it was a system commonly used in machine shops of the day, and the Cornus certainly had experience in using such belt-driven transmissions on both their motorcycle (Fig. 1) and automobile (Fig. 2). A photograph detailing the Buchet engine and belt drive transmission as used on the Cornus' testbed is shown in Fig. 9.

The testbed was to fly for the first time in May 1906. Paul Cornu's notebooks were to record the date exactly: "May 1st, 1906, the prototype lifted 13.5 kilograms with one third advance to ignition, which means it can fly on its own since it only weighs 13.3 kilograms."

On October 4, 1906, public experiments of the Cornus' testbed took place at Lisieux. They had built a test fixture consisting of an offset articulated arm to which the testbed was tethered, limiting its movement to a height of no more than 3 m and forcing it to travel around in a circular path of some 25 m in diameter. Paul Cornu was

[¶]Which was developed from the fundamental propeller theories of Rankine and Froude.

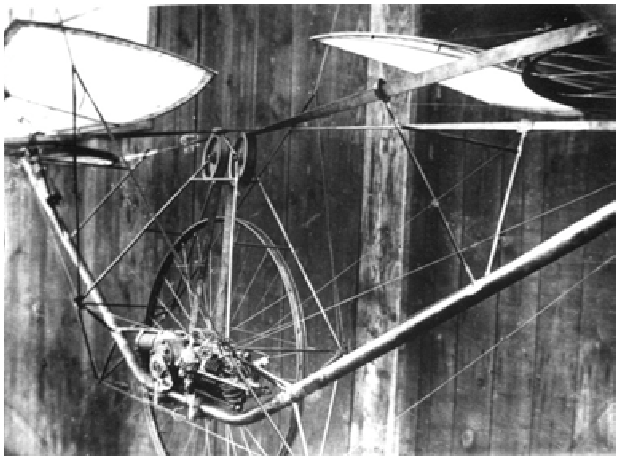

Figure 9: Another view of Cornus' testbed showing the installation of the engine and belt drive system.

also to get signatures from people and news reporters who were witnesses to these flights, a partial list of names being published in Ref. 12. The signed document said: "The undersigned ascertained that there were two tests...that the prototype elevated itself vertically when the engine was started, then that the vehicle gained elevation one more time and started moving horizontally when the deflecting wings were rotated so as to receive part of the air flow produced by the rotors."

These tests with their testbed received some publicity in the press, especially with the primitive state of aviation at this time. Just three weeks later, on October 23, 1906, Santos Dumont was to make the first successful flight of any aircraft in Europe, covering a distance of just over 50 m (150 ft) at Bagatelle outside Paris.

Performance Analysis of the Testbed

Based on elementary rotor theory, we can show that the Cornus' claims of flight with their models are probably legitimate. The power for flight can be readily estimated using the "momentum theory," which formally embodies the conservation laws of mass, momentum and energy for the air flowing through a rotor. The minimum (or "ideal") power required to drive a rotor of disk area A carrying a thrust of T is

$$P_{\text{ideal}} = \frac{T^{3/2}}{\sqrt{2\rho A}} \tag{1}$$

where ρ is the density of the air (sea level can be assumed). Applied to the Cornus' testbed, we can assume that each of the rotors carried half of the total weight of the rig, W. In this case, the ideal power required for one rotor would be

$$P_{\text{ideal}} = \frac{(W/2)^{3/2}}{\sqrt{2\rho A}} \tag{2}$$

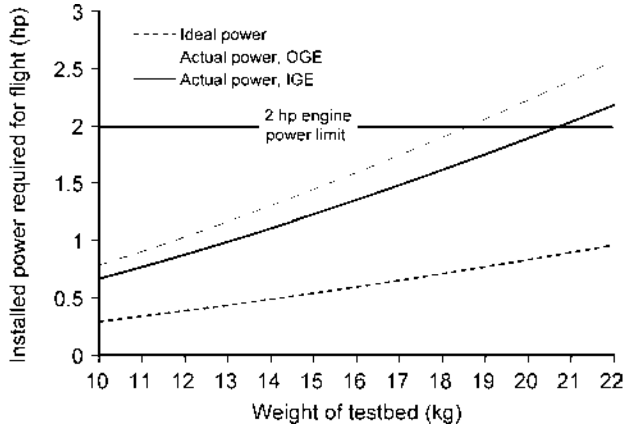

Figure 10: A simple engineering analysis of the Cornus' testbed shows that it had sufficient power to fly.

and the ideal power for both rotors is simply

$$P_{\text{ideal}} = \frac{2\,(W/2)^{3/2}}{\sqrt{2\rho A}} \tag{3}$$

Now, we need to modify this equation slightly to take into account the aerodynamic efficiency‖ of the rotors, for which we use the figure of merit FM. This means that the aerodynamic power for both rotors would be

$$P_{\text{aero}} = \frac{1}{FM}\frac{2\,(W/2)^{3/2}}{\sqrt{2\rho A}} \tag{4}$$

Factoring in a mechanical efficiency of the drive system, η, then the actual (shaft) power required for flight would be

$$P_{\text{actual}} = \frac{1}{FM\,\eta}\frac{2\,(W/2)^{3/2}}{\sqrt{2\rho A}} \tag{5}$$

As the results in Fig. 10 show, even with a relatively low expected rotor efficiency of 50% ($FM = 0.5$) for such stubby low aspect ratio blades, and a transmission efficiency of $\eta = 0.75$ (a belt transmission is never as efficient as a geared transmission because of a certain amount of slippage), the testbed could easily have lifted 13 kg out of ground effect (OGE). We have also assumed here for convenience that the flight took place at standard sea level conditions.

If some benefit of in ground effect (IGE) operation is factored in, then we can write the actual power as

$$P_{\text{actual}} = \frac{k_g}{FM\,\eta}\frac{2\,(W/2)^{3/2}}{\sqrt{2\rho A}} \tag{6}$$

where k_g is less than unity, and typically 0.85 for a reasonably close distance between the rotors and the ground. Figure 10 shows results for the required power for hovering flight, which confirms that the Cornus' claims of successful flights with their testbed are entirely plausible.

‖This is always less than unity, which represents the ideal 100% aerodynamic efficiency.

Propulsion and Control Issues

Supplying sufficient power for flight is only part of the problem of developing a successful helicopter, and the need to control the machine in flight is also fundamental. This was obvious to the Cornus. It is also necessary to give the machine some rudimentary level of stability, although this was perhaps a more subtle concept for the Cornus to understand. Notice in Figs. 7 and 11 that there is evidence that the Cornus had begun to explore methods of controlling the machine with the use of adjustable wings or vanes placed in the slipstream below the rotors. This is significant, because their contemporaries were not quite at this stage of sophistication in addressing control issues, with primary efforts still focused more on getting their machines just to lift off the ground. For example, another Frenchman, Louis Breguet, was to experiment with a large quad-rotor concept in 1907, but this machine had no means of flight control and was stabilized by several men on the ground. Breguet's machine was unsuccessful, something even Breguet was to admit to.

In 1906, Paul Cornu and his father were to patent (Ref. 13) a propulsion and control device (Fig. 12) showing a system of vanes mounted below sets of spinning rotors. These vanes could be tilted collectively and differentially to provide propulsion and also some form of aircraft pitch control when the test rig moved forward. A version of this system was tested on their model twin-rotor rotor testbed—see previously in Fig. 11. Paul Cornu was to say: “...we installed only 14 surfaces, weighing, including their mounts and the inclination system, 400 grams; they made it possible to obtain a horizontal traction of 1,500 grams, enough to move our helicopter.”

Referring to Fig. 12, Paul Cornu explains the principle of the control concept in his own words: “The propulsion surfaces “c” are mounted between two rods. The latter are connected via small moving parts “e” that are attached around fixed hinges “f.” A lever “g” mounted in the same line as the central part “e” makes it possible to give the surfaces a varying inclination. Hence, by a simple action of the lever “g” it is possible to make the machine move forward or backward at a speed that will depend on the inclination of the surfaces. To obtain this forward or backward motion it is absolutely unnecessary to vary the speed of the lifting propellers.”

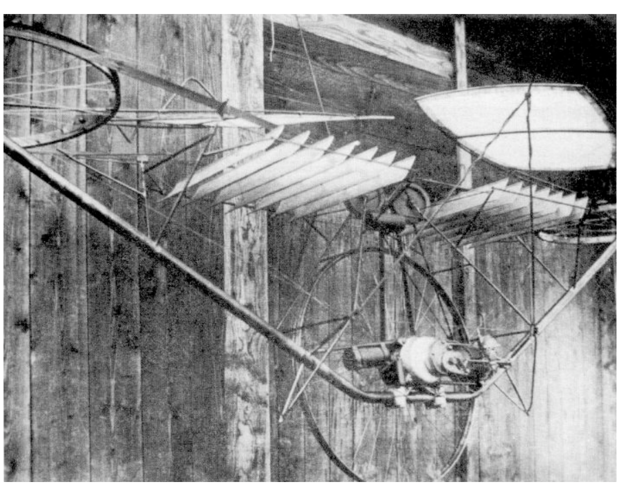

Figure 11: The Cornus' testbed fitted out with the shuttered control vanes.

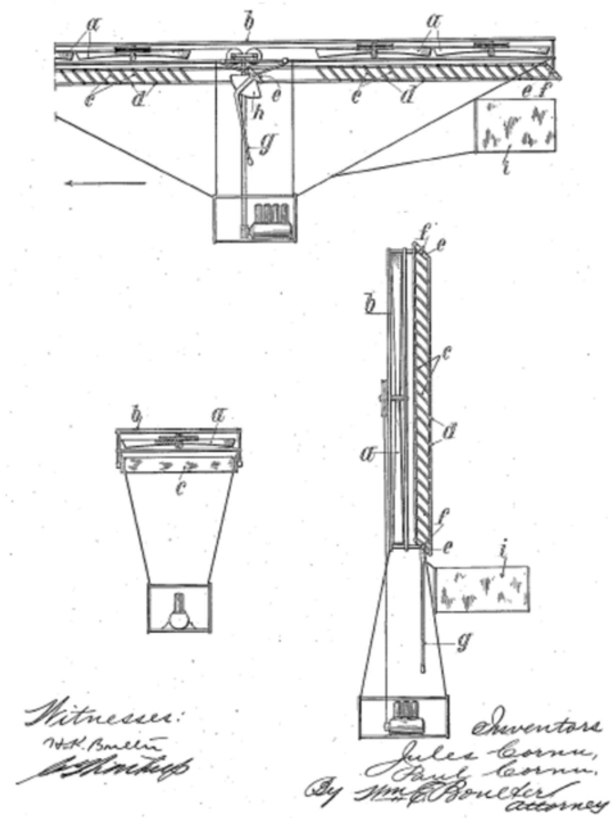

Figure 12: A sketch from a Cornu patent showing a device that might be used for controlling a helicopter in its flight by placing vanes in the slipstream of the rotors. (From British Patent No. 19,259, May 30, 1907) Notice the signatures at the lower right.

It is not clear, however, if Cornu understood how the aerodynamics of the control surfaces would be modified by the forward flight motion of the testbed; in forward flight the expected changes in the aerodynamics of both the rotor flows and the free-stream onset flow would likely have altered the control effectiveness and the overall flight response of the machine. It is not clear exactly what happened when the tests were conducted, but there were probably a few surprises.

However, Paul Cornu alludes to the fact that his rotor testbed was able to demonstrate some forward flight capability. Cornu was to say: “The practical speed is a little less due to the slippage; however the machine moves easily at a speed of 15 to 20 km/hour.” He goes on further to state: “The machine is not equipped with a rudder since it is suspended by a special beam which provides guidance during the ascension.” Presumably Cornu is referring here to the tethering system, which restrained the flights so that they followed a circular path. The patent in Fig. 12, however, clearly shows the concept of a rudder (“i”) for steering the craft through the air.

Patented Helicopter Concept

On the basis of the relatively successful hovering experiments with the model rotors, it appears that the Cornus were off to a decent start. The next issue, however, was to scale the concept up to the size that could lift a pilot. A piloted “flying machine” was patented (Ref. 14) by Jules and Paul Cornu in 1906 based on an application submitted in 1905. The patent basically details the mechanical details of the rotor system for the piloted machine, as well as the method of flight control and the belt-driven transmission.

Figure 13 shows details of the transmission, which was one long “endless” flexible belt. By means of several guide pulleys, the power was transmitted from the engine shaft to the rotors. By a special arrangement of crossover pulleys, the rotors could be driven in opposite (i.e., counter-rotating) directions with a steady speed (rpm), despite any slight belt slippage.

Figure 14 shows how the drive system was to be integrated into the rotor system. The crossover pattern of the paths of the drive belt and their tensioner guides can be seen. The belts wrap around large pulley wheels on the rotor shafts.

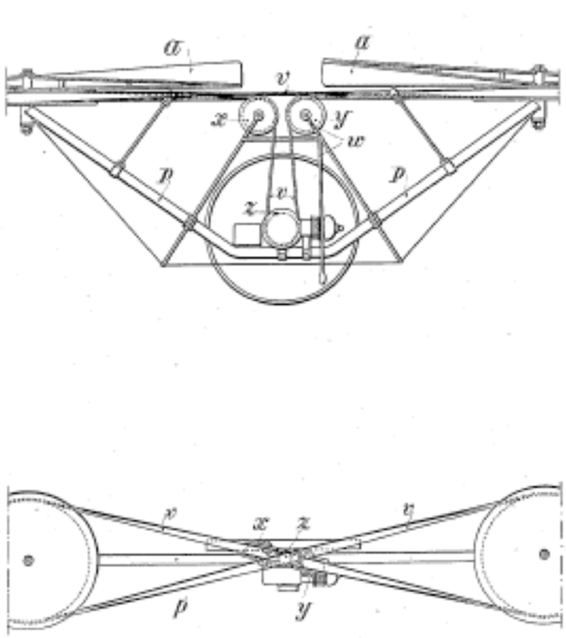

Figure 13: The patented belt-driven transmission on Paul Cornu’s helicopter. (From United States Patent 902,859, November 3, 1906.)

The airframe is basically a U-shaped keel beam, with the rotors placed at each end. In the patent, the two-bladed rotors had blades that tapered rapidly in chord toward their roots, although we know now that this is not such an aerodynamically efficient blade design.

Of interest again is the proposed flight control system, which comprises a series of louvered vanes or “pivoted blades” in a more sophisticated arrangement to that shown previously in Fig. 12. By inclining most of the vanes all in one direction, the intent was to provide a propulsive force. By differentially inclining the vanes as shown in Fig. 15, this would give the machine pitch control. Furthermore, by swiveling the vanes away from the longitudinal axis, “turning” control could be obtained. These control inputs were to be applied by the “aeronauts” (i.e., pilots) through the use of various levers or other “suitable devices.”

Of significance is that the Cornus even thought about including a stability enhancing device on their helicopter. This was done by using the two vertically hanging pendulums (“o”); as intended, these pendulums are connected via chains to the shuttered wings. If the machine tilted, the pendulums would swing so as to remain vertical relative to the ground. The intent is that the movement of the pendulum pulls the chains to activate the appropriate shutters to change their angle of attack in the rotor downwash, and so create compensating forces and moments to return the machine to its undisturbed condition. This was their theory, but there are many factors that would determine the practical success of such a concept. Yet, it does not seem that the Cornus actually constructed this type of device on their prototype helicopter.

Fabrication of the Cornu Helicopter

Construction of the Cornu helicopter started in the middle of 1906. A fundraising campaign led to 120 people subscribing 100 francs toward the project.[**] This allowed the Cornus to purchase a much more powerful Levavasseur 24 hp *Antoinette* engine, which was to cost about half of the money raised. The Levavasseur *Antoinette* was a water-cooled and fuel injected engine, with eight-cylinders arranged in a “V” about the crankshaft.[††] While Paul Cornu initially considered a different rotor configuration with “smaller and more rapidly rotating blades” for

[**]In today’s money, 12,000 francs would be the equivalent of a total of about US$36,000.

[††]Later models of the *Antoinette* were to power a variety of airplanes, and were to be developed into more powerful 16-cylinder versions that produced in excess of 50 hp.

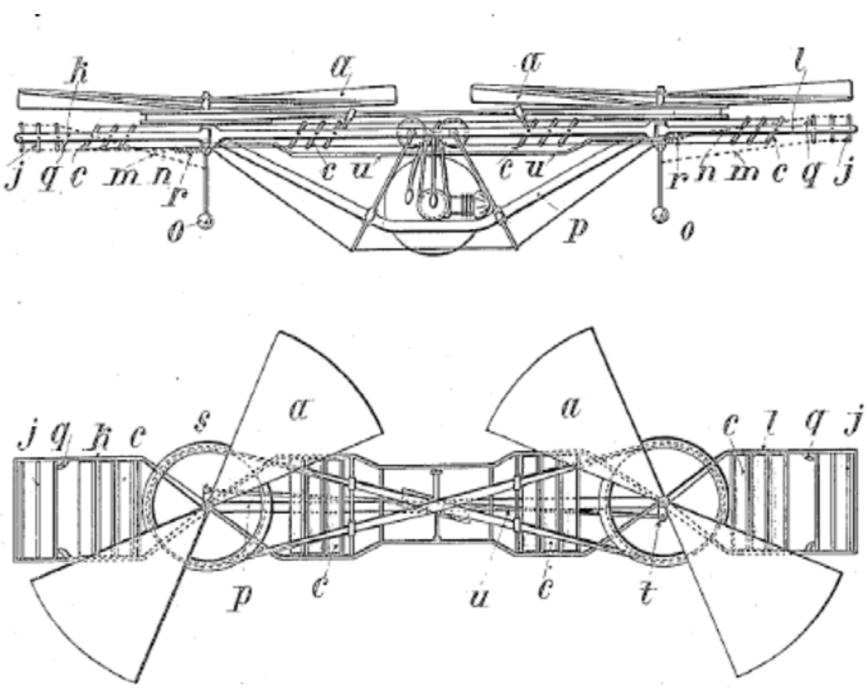

Figure 14: One image from the Cornus' patent of their helicopter. (From U.S. Patent 902,859, November 3, 1906.)

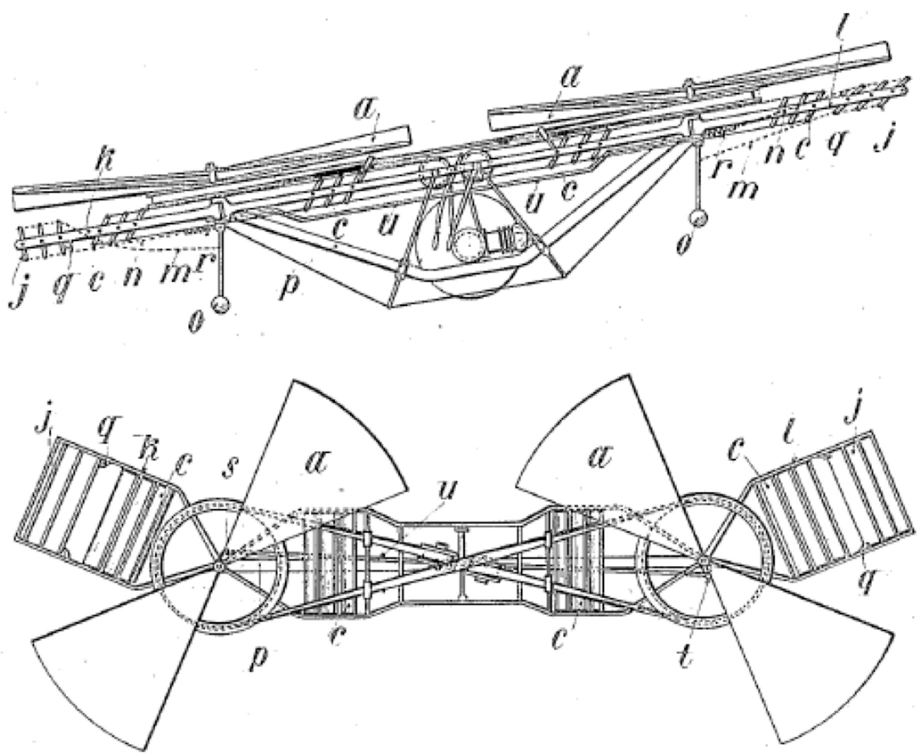

Figure 15: Another image of the Cornus' patented helicopter showing the anticipated effects of control activation. (From U.S. Patent 902,859, November 3, 1906.)

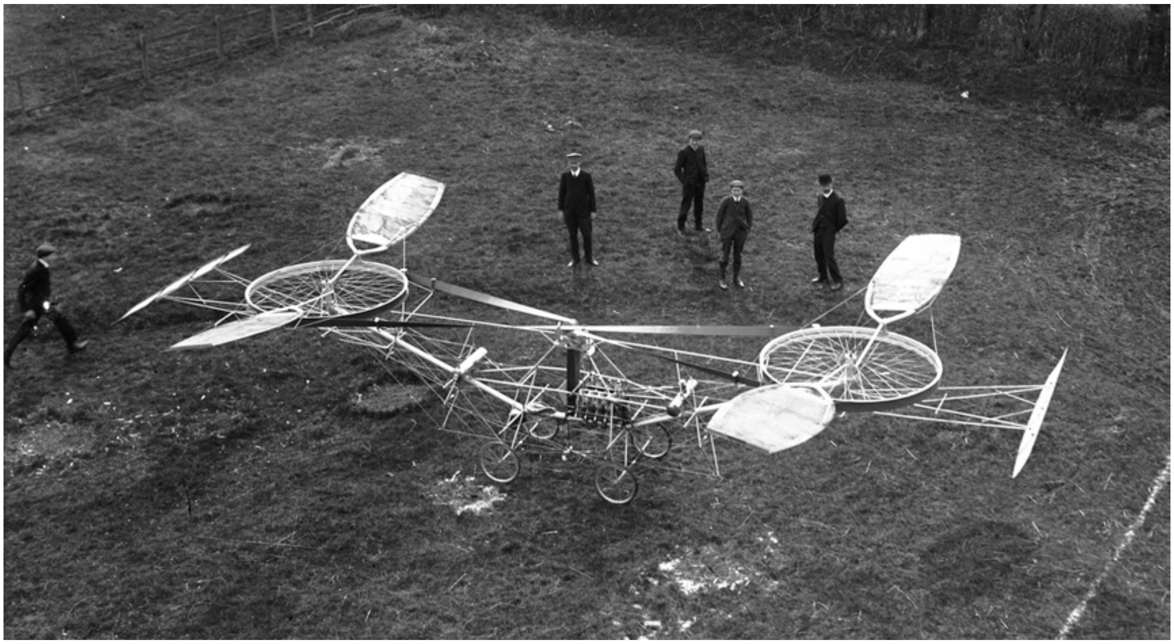

Figure 16: A good overall view of Paul Cornu's helicopter, as constructed in mid-1907.

his bigger piloted machine, he eventually decided that it would be wise to stay with the general (and successful) configuration used on his testbed.

The fabrication of the Cornu helicopter was undertaken in a small machine shop on the Rue Gaudien in Lisieux, which was to take nearly a year. The photographs of the Cornu machine (Fig. 16) show that it closely resembled the testbed and the patented design. It had a skeletal airframe of very simple construction and of relatively light weight, being constructed of a steel beam bent into a wide U-shaped keel, with six "star" frames all held together with tensioned "Bowden" cables. This way, the Cornus were able to get a relatively stiff, minimal weight airframe structure; the airframe itself was to weigh only about 110 lbs (50 kg). The total length of the airframe was 6.2 m (20.34 feet), so the machine was really not that large.

The 24 hp *Antoinette* engine was mounted at the lower part of the U-shaped beam (Fig. 17). Copper cooling water and fuel tanks were placed symmetrically at the front and back third of the structure, respectively, which can be clearly seen in the photograph in Fig. 17. The water tank had a capacity of 12 liters, with a circulation enabled by thermo-siphon; the fuel tank had a capacity of up to 7 liters. The pilot's station was immediately behind the engine. On the right of the pilot was an ignition advance lever to control engine power.

A two-bladed rotor was mounted at each end of the main structural beam. Power was supplied to these rotors through a belt and pulley transmission, essentially similar to that used on their rotor testbed. But a transmission system at this scale seems to have caused Paul

Figure 17: A close up view of the *Antoinette* 8-cylinder engine, and the pilot's station with the flight control levers.

Cornu many problems and much frustration. To help prevent belt slippage, Cornu added belt tensioners and finally added leather to the surfaces of the small pulleys, as well as rubber to the large pulleys. But even then the problem of drive belt slippage was not solved. The inner hub part of each rotor looked like large bicycle wheels. These spoked wheels were 1.8 m in diameter, and had an outer steel flange that was 10 cm in width—see Fig. 18.

At the periphery of these inner wheels were mounted two very light, wide chord, silk-covered blades, similar in shape and form to those used on his models (Fig. 19). The blades were attached to a tubular spar that ran all the way

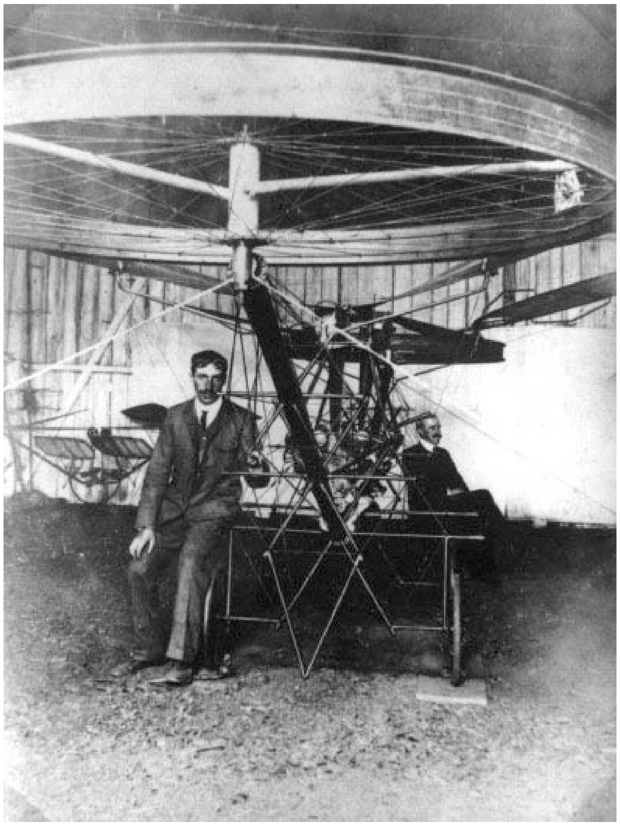

Figure 18: Detail of the spoked inner part of the rotors without the blades attached. (Notice the original rotor testbed in the background.)

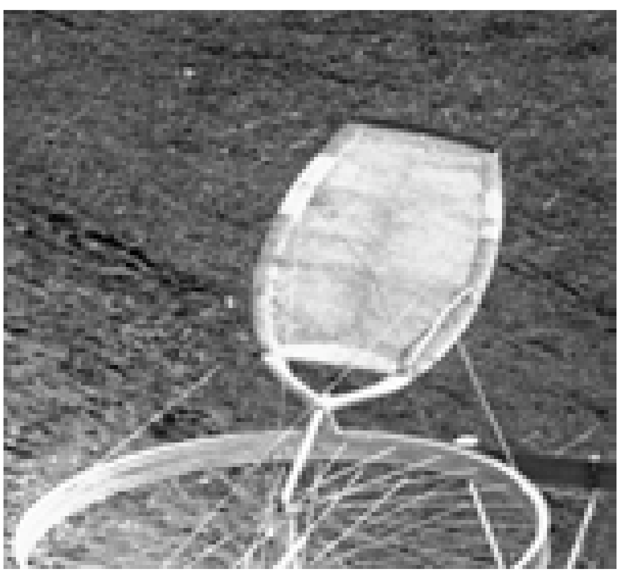

Figure 19: The relatively short, stubby blades were made of a light steel framework, covered with silk and sealed with a rubber-like material. The cables to vary the blade pitch can also be seen here.

to the rotor shaft axis. The blade length was 1.8 m and had a chord of 0.9 m at their maximum point near mid-span. This means that the total rotor radius was 0.9 m (radius of inner spoked hub) plus 1.8 m (blade length) to give 2.7 m (8.86 feet).[‡‡] The tubular steel framed blades were "flattened toward their extremities," meaning that they were tapered in thickness moving toward the blade tips. As a result, the thin blades were not really stiff enough in bending to carry the aerodynamic lift loads without deforming, so Cornu added lead weights starting out at 2/3 span, taking advantage of centrifugal forces to help minimize bending moments. The blades were also flat (no proper airfoil section) and untwisted, both chordwise and along their span. The weight of each rotor system was 24.5 kg (54 lbs).

It is of some significance that Cornu designed the blades to have variable pitch capability; this is something not widely known about his machine. The blades were attached to pulleys using an aluminum plate. These blades were able to pitch, their roots extending through a shaft to the rotor hub, where they were attached to an eccentric cam. The blades were then pitched by cables that were fixed on one end to a pulley and the other end was connected to the blade at its 2/3-span. In Paul Cornu's words: "With this setup, the blade is pulled as a whole and the tension of the cables, combined with the rotation in the attachment, enables the variation of the pitch."

As with his model tests, Cornu tried to provide propulsion and "steering" control by placing two vanes in the slipstream below each of the rotors; the inclination and force on the these wings was controlled by the pilot with two hand operated levers. The vanes were supported on arms, which could be swung laterally, left or right, to help steer the machine. These aerodynamic surfaces were basically the same as the main blades; they were made of a tubular steel frame 2.5 m in length and 0.6 m at their maximum width, flattened, and covered with the same rubberized silk as the main lifting blades.

Paul Cornu explains their functionality: "These surfaces can move about a horizontal axis running through their center and are attached on two articulated supports around an extension of the propellers axis. The inclination of these surfaces (propulsion) and their lateral displacement (direction) are adjusted via two levers placed left and right in proximity of the aviator. The air reaction produced by the propellers on the surfaces provides the propulsion the speed of which depends on their inclination. Their lateral displacement provides steering." The weight of the propulsion and steering system was 9 kg (19.8 lbs).

[‡‡]By some accounts, however, the rotor radius was reported to be as much 3.0 m.

Figure 20: The completed Cornu helicopter in 1907, with pilot on board, apparently ready to fly.

Testing the Cornu Helicopter

It is reported that construction of the Cornu machine was competed in late August of 1907, and actual ground testing started soon afterwards. But, nearby in Douai, Louis Bréguet's helicopter, a quadrotor, was to take off momentarily on August 24th, but it was a tethered flight and also made a crash landing. It was not a true flight, something even Bréguet was to admit to, and Cornu was to proceed with his own flight tests. These tests were conducted in the grounds of the former *la Goulafire* factory owned by a Mr. Duchesne–Fournet.

For this first set of flight tests, the rotors were spinning at 70 rpm with a [helicoidal] pitch of 2.7 m. Cornu found that to avoid vibrations, the rotors had to be perfectly balanced: "It was established that it was sufficient to place a weight of 55 g at the extremity of one blade and of 75 g on the other to make the entire system [balance] perfectly well." The engine operated only at 750 rpm. For this test, a 50 kg (110 lb) sand bag was placed on the pilot's seat, which was simply a saddle from a bicycle. Because of drive belt slippage, the diameter of the driving pulley was changed again, which apparently reduced the extent of the problem but did not solve it.

Including ballast, the machine at this point weighed in at 235 kg or 518 lbs (185 kg or 408 lbs empty), and it was reported to have nearly lifted completely off the ground on September 27, 1907. For this attempt, the engine was rotating at 850 rpm and the rotors were spinning at 85 rpm with their pitch set to 3 m.

After some experiments in adjusting the driving pulley and the pitch angles of the blades, Cornu reported that his machine (but without a pilot) lifted off by itself (but still tethered) for the first time on November 13, 1907. Cornu was to record the details of this event in his logbook (Ref. 9): "November 13th, 1907. In the afternoon, the second attempts. The machine rises with a 55 kg sandbag. We want to keep it but I find myself lifted up and carried away, Jacques is almost too. It takes little to escape us. Finally I jumped on one of the handles of the device, and me with one hand clinging to the undercarriage, I manage with the other to reduce the spark advance and the aircraft finishes on the ground without any damage."

Until this point, the Cornus' machine consisted only of the main frame, engine, and rotors. The control surfaces were then added. A few days later, the machine, which now weighed about 203 kg (447.6 lbs) without the pilot, was ready for its first piloted flight (Fig. 20). The pilot was Paul Cornu himself (who weighed 57 kg or 125.7 lbs), giving a net takeoff weight of 260 kg (573 lbs). At this point the machine apparently did not take off because of drive belt slippage. But replacing the rubber surface on the small drive wheel helped alleviate (but not cure) the problem, and the tests continued. On December 6, 1907, Paul Cornu was to report (Ref. 9): "I climbed for the first time in the aircraft and on the second attempt, with very little advance, all off, but there is still slipping on the big pulleys."

Paul Cornu goes on to say: "From December 7 to 27, I tried different ways to get a better grip on the pulleys.

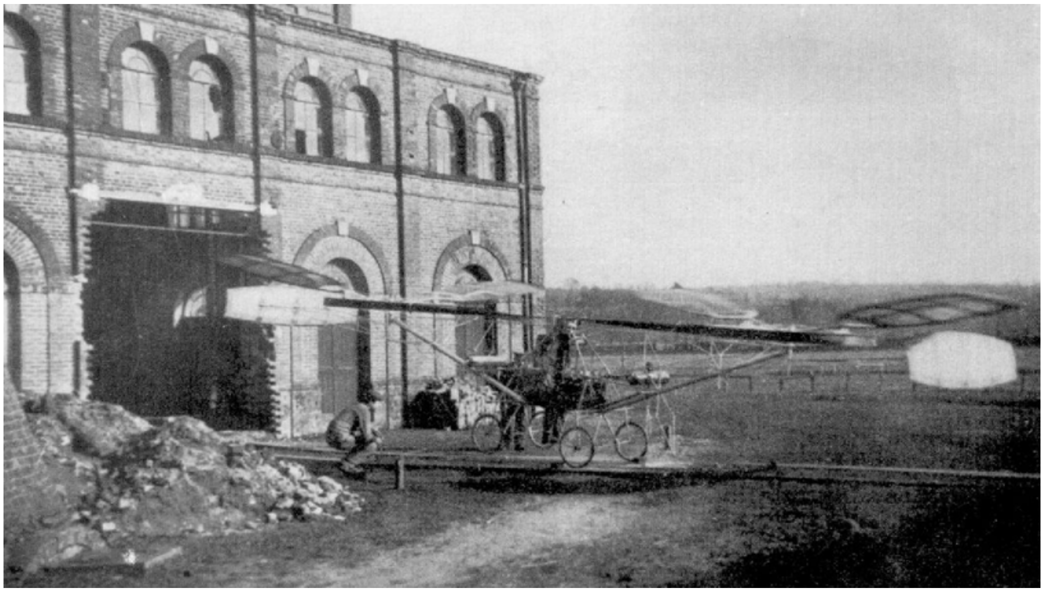

Figure 21: Perhaps the only photo that exists of one of the hops into the air, taken in early 1908, which suggests at least that the two rear wheels of the Cornu machine were free of the ground.

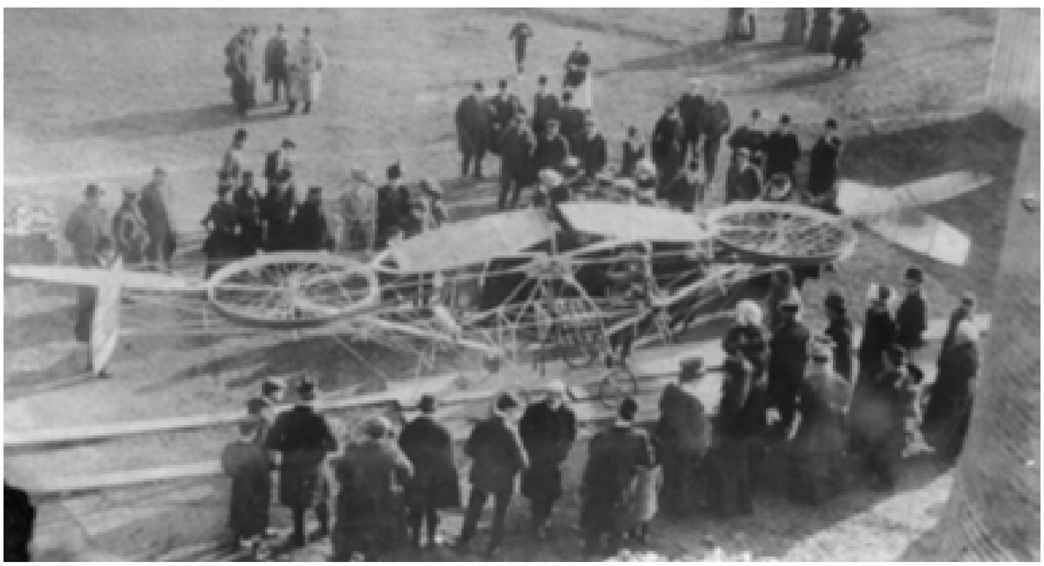

Figure 22: Crowds of onlookers examine the Cornus' helicopter, circa early 1908.

Glued first several layers of paper without effect; then place inside the pulleys paper tape in order to make a flat surface without it being curved as before, and then pasted strips on it. The result is better but still not perfect. Finally Jacques idea is to place a very hot iron on the rubber belt, which has the effect of melting and plugging the hollows. The grip, instantly, is perfect!" Cornu also talks about the blades: "During these experiments, we have tried every possible change to the propellers." By December 28 the problems with the large pulleys has been repaired. Cornu says (Ref. 9): "But, having put talc on it to prevent the belt getting twisted, talc spreads over the small pulley which has the effect of drag, and the result is not better, and this just as the slipping on the big pulleys was cured. We used a hot iron on the small pulley and let dry one full day."

On December 29, 1907 Paul Cornu was to summarize the outcome of preceding months and reaches a profound conclusion (Ref. 9). He is of the opinion that the future helicopter will not resemble those already developed by himself or Breguet: "Based on the tests that I have done so far, here are the main provisions and dimensions that a helicopter should be able to lift one man, and whose weights with the aviator would be about 300 kg: engine 30 hp operating with a transmission gear two propellers made of metal superimposed on the same axis [coaxially] and rotating in opposite directions, with a diameter of 3 meters, turning at 1,000 revolutions per minute. Under the lower propeller will be placed two adjustable planes for propulsion; these planes may also rotate from right to left for direction. Immediately below will be fixed on the chassis, formed as part of a steel tube, containing the motor, clutch and pilot. The crucial point is to use rotors of small diameter rotating at a very high speed. Because of this high speed, the propellers must be made of metal, to avoid the thickness and so the resistance to penetration."

But the prize for the first flight around the 1 km closed course was soon to be won. On January 13, 1908, Henry Farman, took off on a flight with his Voisin-Farman HF-1 airplane, and covered the prescribed circuit in a brief 28 seconds, winning outright the Deutch–Archdeacon *Grand Prix Prize of Aviation*. Paul Cornu seemed impressed, but also disaapointed: "Everyone is willing to recognize as a tour de force the extraordinary feat of Farman. But since Mr. Farman is not the inventor or the manufacturer of the aircraft, his tour de force is charged with driving an airplane for one kilometer."

The last hop made with Cornu's machine seems to have occurred on January 14, 2008. Cornu says: In the tests, the aircraft raised two wheels to 40 cm, but the drive belt breaks, and the machine falls but without damage. About this time, the photo in Fig. 21 was made. While perhaps open to a certain amount of interpretation, it would seem on close inspection that there is indeed some daylight under the rear wheels.

After then, there were more mechanical failures than successes. Cornu tries to make flights by attaining some forward speed, which we know should have reduced the power requirements for flight. On March 18, Cornu says (Ref. 9): Propulsion test very successful. The aircraft complete with the aviator lifts up regularly from the back, but we can do better although the engine develops 12 hp instead of 24 hp. He goes on: But the fear of further accidents, and have sufficient knowledge of the various causes of malfunction present, we have decided not to continue and to present the aircraft as it is. The lift we got easily when the aircraft was new would still be achieved with 12 hp maximum if the propellers were more rigid."

Early in 1908, Paul Cornu was again reported to have flown his helicopter, this time at Coquainvilliers, near Pont Levêque in Normandy. Again, a series of hops were reportedly made. Cornu seems to have well understood the need for witnesses (see Ref. 12), but apparently there were no witnesses to corroborate the flights. On this occasion the wind was reported to be quite strong. On one attempt at flight the machine reportedly started to tip over, and Paul Cornu's brother, Jacques, grabbed hold of the machine, which momentarily lifted them both into the air (total weight estimated to be 328 kg or 723 lbs). However, it seems that fully controlled flights were not made.

Cornu made no secret of his helicopter work, and later crowds of people came to see his macine (Fig. 22). His helicopter was reportedly last shown to the public on March 26, 1908. By that point, it was showing signs of mechanical failures because of its lightweight construction, was becoming very difficult to maintain (Ref. 9). He invited 115 of his original "shareholders" who put up money to build the machine, and about 30 of his friends. Of the 115, only 21 people responded to the invitation. But 250 people actually turned up to see the machine! It did not fly, obviously a huge disappointment for Cornu. But by that point, the machine was worn out and parts were breaking as quickly as they could be repaired. Cornu says: Also, after the tests at 5 o'clock, we heard some comments that are not always very kind

Engineering Evaluation of Power Required for Flight

It is these various claims from 1907 and 1908 that have given Paul Cornu credit (Refs. 15–17) for the very first flights of a piloted helicopter, the implication being that the vehicle left the ground vertically under its own power and sustained itself in hovering flight. Yet we have no photographs of this event. This is surprising because the aircraft was so thoroughly photographed on the ground. There is perhaps only one photo (Fig. 21) that hints that at least a short hop into the air was made.

Of course, had their concept been as successful as Paul Cornu had claimed and others had expounded, then it would seem almost certain that they would have found some financial backing to develop their machine further. The fact that they apparently did not is perhaps rather significant. Nevertheless, the claims of successful flight have been perpetuated now for an entire century. We must, however, look at this claim a bit more carefully, and in the same vein as that done previously for his smaller engineering testbed.

It is fundamentally important to address the issues of power required for the hovering flight of the Cornus' piloted helicopter concept, which can be done very simply. Assuming each rotor lifted half of the total aircraft weight, then using the momentum theory (previously outlined) taking into account the expected aerodynamic efficiency of the rotors (50%), and with a conservative estimate of transmission losses (75%), then the power predictions as a function of aircraft weight are shown in Fig. 23.

At first, the assumption of an aerodynamic efficiency of only 50% may seem low, but we must remember that even the best helicopter rotors that were to follow in the 1940s and 1950s had efficiencies of only 60% (i.e., figures of merit, FM, of 0.6), and this was using low solidity rotors with high aspect ratio blades–see Fig. 24. Cornu's stubby (low aspect ratio) blades could not be expected to be aero-

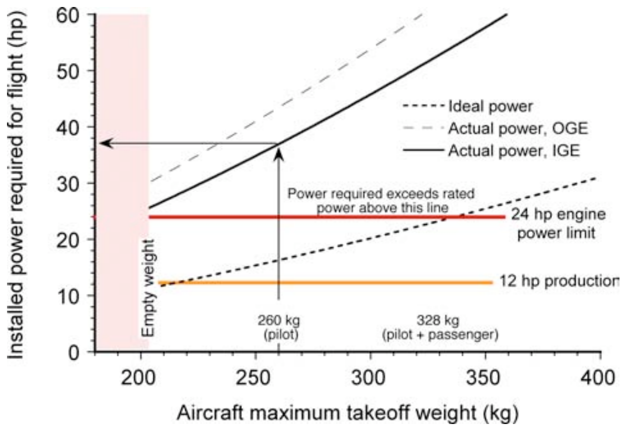

Figure 23: An engineering analysis of the Cornus' helicopter shows that it did not have sufficient power to fly in sustained flight, even in ground effect.

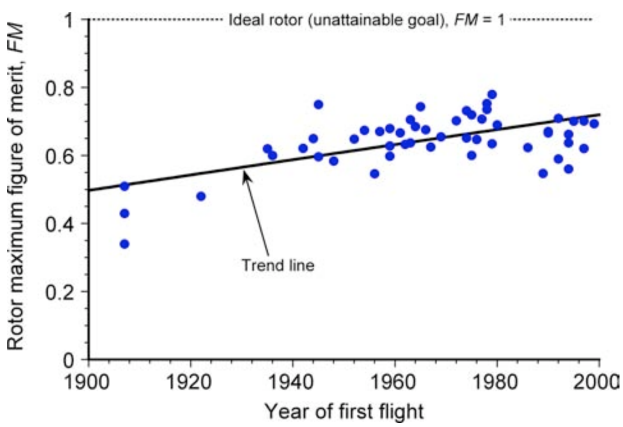

Figure 24: Historical trends of rotor efficiency (figure of merit) suggests that in 1907 the state-of-the-art in rotor design was relatively poor.

dynamically efficient, so the assumption of an FM of 0.5 is reasonable although still probably rather generous.

For Paul Cornu to hover his machine free of the ground at the stated weights (between 260 kg and 328 kg, or 573–723 lbs) the results in Fig. 23 show that the installed power required would have needed to be about 40 hp. Even the "ideal" power required for flight (which assumes no aerodynamic losses and $FM = 1.0$) and with 100% mechanical efficiency was close to 16 hp!

With an expected 15–20% reduction in the power required to hover in ground effect relative to the power required for flight out of ground effect, the actual power required would still have been over 30 hp. Therefore, the installed engine power required to lift Cornu and his machine and sustain flight free of the ground, even by just a few feet, would still have been much more that the 24 hp *Antoinette* engine could have provided.

The problem is worse than this, because on the topic of power production, Paul Cornu is reported to have said: "The engine power was observed from its speed which never exceeded 900 rpm. At this speed, Mr. Leon Levavasseur [the designer of the engine] indicates that his *Antoinette* engine cannot produce more than 12 to 14 hp under the best of conditions." The engine may have only reached this low rpm because of the high load on the engine from the rotors, which as mentioned previously could not have been that aerodynamically efficient by a modern assessment. Therefore, it seems unlikely that the engine used by the Cornus achieved anywhere near enough power to enable his machine to hover free of the ground, even with the performance benefits of ground effect.

This does not mean that Cornu did not see any daylight under the wheels of his machine, as the photo in Fig. 21 suggests, but any flight could have only been momentary, perhaps aided by brief transient overspeeds of the rotors or a gust of wind. There seems little doubt that Cornu made the attempt at flight, but it could not have been a proper free-flight, and so technically could not qualify as a "successful" flight of a helicopter.

Further Analysis of Needed Power Requirements

Driving the power requirements for flight is the need to achieve a sufficiently high value of power loading, PL, which is the ratio of thrust to power (T/P) for the rotors. Again, using simple momentum theory gives the power loading in terms of the rotor disk loading DL (ratio of thrust carried per unit area of the rotor disk) as

$$PL = \frac{\sqrt{2\rho}\, FM}{\sqrt{DL}} \tag{7}$$

It is apparent from Eq. 7 that the power loading (and hence overall rotor efficiency) improves with an increase in FM and a reduction in disk loading. Clearly the key to improved hovering efficiency (best power loading) is to operate at a low disk loading and at as high a figure of merit as possible at that disk loading.

Testbed

We can first evaluate the disk loading for the Cornus' testbed; the weight carried by each rotor was 6.5 kg (14.33 lbs), the rotor radius was 1.125 m (3.69 ft), and the rotor disk area (we ignore the root cut out, even though it is large) was 3.98 m^2 (42.79 ft^2). This gives a low disk loading of only 0.335 lb/ft^2.

Assuming sea level conditions, Eq. 7 would give an ideal power loading for the two rotors as a system (i.e., the theoretically lowest power required and best efficiency) of 65.53 lb/hp, and an actual power loading (assuming FM = 0.5) of 32.77 lb/hp. This means that each hp available could theoretically lift 32.77 lb (14.86 kg). In practical terms, this also means that with an engine with a power available, P_{avail} of 2 hp and $\eta = 0.75$, then Cornu would have been able to lift a maximum weight OGE of over 18 kg and nearly 21 kg when IGE. No wonder he was impressed with the performance of his testbed with only a 2 hp engine!

Piloted Concept

But the problem is more interesting for the Cornus piloted helicopter concept, which had a weight, W, of 260 kg (573.3 lb) in its lightest flight condition. Assuming the aircraft could have flown, then the weight carried by each rotor would have been 130 kg (286.65 lbs). The rotor radius in this case was 2.7 m (8.86 ft), and the rotor disk area (again, ignoring the root cut out) was 22.9 m^2 (246.61 ft^2). This gives a disk loading of 1.16 lb/ft^2, which is about four times the disk loading of his testbed.

Assuming sea level conditions, Eq. 7 would give an ideal power loading for the system of 35.2 lb/hp, and an actual power loading (assuming FM = 0.5) of 17.61 lb/hp at this lower flight weight. This means that if the flying feat was accomplished, then the power needed for his piloted machine would have been 573.3/17.61/0.75 = 43.41 hp, which is clearly well beyond what was available from the Cornus' 24 hp *Antoinette* engine, and especially at the 750–900 rpm it was apparently able to achieve. Even if Cornu was able to make a rotor with higher aerodynamic efficiency, the power required would still have been more than he had available.

We can also determine the blade loading coefficient of the Cornus' machine in its claimed flight condition, which helps us better understand the potential aerodynamic operating state of the rotors. Each blade had an area of only about 14.4 ft^2. This gives a solidity per rotor σ (ratio of total blade area to disk area) of 28.4/246.61 = 0.115, which incidentally is not an unreasonable value for a modern helicopter rotor.

A determination of the thrust coefficient, C_T, requires the rotor tip speed, V_{tip}, which was only 78.85 ft/s at 85 rpm on the Cornu machine. This means that that the C_T for the rotor becomes

$$\begin{aligned} C_T &= \frac{T}{\rho A V_{\text{tip}}^2} \\ &= \frac{286.65}{0.002378 \times 246.61 \times 78.85^2} = 0.0786 \quad (8) \end{aligned}$$

which is a very high value for a helicopter rotor. This means that the blade loading coefficient C_T/σ would be 0.0786/0.115 = 0.684, which is extremely high! The corresponding mean lift coefficient of the rotor then would be $\bar{C}_L$= 6 (C_T/σ) which is over 3, and clearly impossible! Typically, a blade loading coefficient for a rotor system would be below 0.15 with a mean lift coefficient of less than 0.6 and usually lower than this to avoid operating the blades too close to stall.

For the Cornus' machine, it would seem that the blade area would have been far too low at these rotor speeds (85 rpm) for the blades to produce and sustain the needed lift without stalling. If the blades operated with stall, then this would only have driven the power requirements for flight even higher! It is perhaps reasonable to conclude that the high aerodynamic drag of the stalled blades during the startup phase was probably one reason that prevented the engine from reaching its full power of 24 hp.

Alternative Design Options?

It would seem from this relatively simple engineering analysis that Cornu seriously underestimated the power requirements for flight and the expected aerodynamic operating state of the rotors at the intended flight condition. A proper free flight of his piloted helicopter concept would have then defied the laws of physics! Is it perhaps not so surprising then that we have never seen a photograph of his machine in hovering flight free of the ground?

The analysis conducted here suggests that perhaps Cornu became over-confident with the success of his testbed, and did not fully understand the engineering principles needed to scale-up his concept with the relatively underpowered 24 hp engine that was available to him.

To bring the in-flight power requirements down to the theoretically available value of 24 hp, then the rotor disk loading can be solved for using

$$DL = \frac{T}{A} = 2\rho \left(\frac{FM\, \eta\, P_{\text{avail}}}{W} \right)^2 \quad (9)$$

Inserting P_{avail} = 24 hp, η = 0.75, FM = 0.5, and W = 573.3 lbs leads to a disk loading of 0.356 lb/ft^2. Solving for the rotor radius is then performed using

$$R = \sqrt{\frac{W}{2\pi\, DL}} \quad (10)$$

To reach this target disk loading, Paul Cornu would have need a rotor radius of some 16 feet or 4.89 m—see Fig. 25; this was about twice the radius of the rotor systems that he actually used. He would have also needed to use a higher rotor rpm, perhaps 20–30% higher, to get the needed thrust, and also to get the blade loading coefficients on his blades down to the values that they could operate below stall. This may have also allowed the engine to generate more rpm, and hence produce more torque to the rotor system.

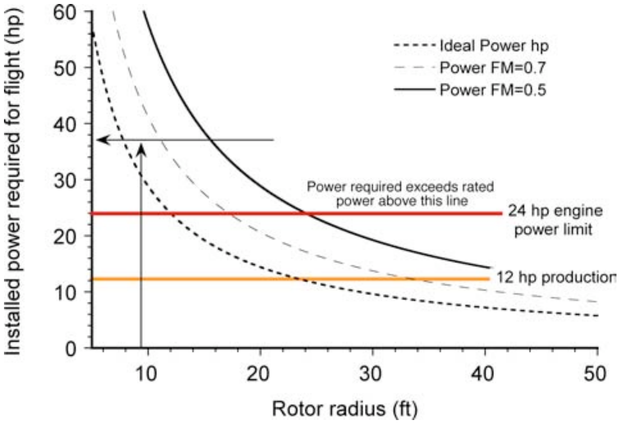

Figure 25: To bring the power requirements down to the levels available, the rotor on Cornu's machine needed to be much bigger.

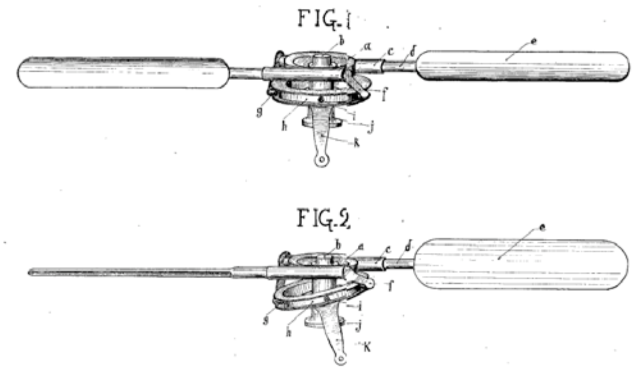

Figure 26: In 1908, Cornu was to patent the idea of a rotor system with continuously variable cyclic pitch. (From French Patent No. 398,545, June 7, 1909.)

Cyclic Pitch

Paul Cornu was clearly unsatisfied with the performance demonstrated by his helicopter, but he was not to abandon the helicopter entirely. Cornu remained active in aviation circles for many years. He read and contributed to the journal *L´Aerophile*, and clearly had a longer term goal of devising an improved helicopter concept. He was to propose the concept of a coaxial rotor system and a "Helicoplane," both of which used a cyclic pitch variation mechanism on their rotors. Like most early pioneers he had lots of good ideas, but what he lacked was enough sustained funding to pursue his ideas and bring them to conception.

Paul Cornu was aware of the issues associated with moving a rotor in forward (edgewise) flight. he was to say at one point: "Helicopters have a serious defect: the air flow during the horizontal motion of the machine has an unfavorable influence on the efficiency of the lifting propellers; it has even a destabilizing effect." He goes on further to say: "At faster speeds the equilibrium would certainly be affected by the violent air flow which would certainly act on the propeller blades.

In April of 1908, Cornu was to outline an idea for a shrouded rotor or what he called a "helicopter lens." His idea was to contain rotor rotors (propellers) in a shroud or duct to protect them from the relative airflow from forward flight. Cornu was to say "In addition to the propeller, it [the shroud] would contain the the engine the aviator. In this way the propellers would be insulated from the air currents produced by the propulsion, and the entire envelope would facilitate forward penetration."

Paul Cornu's next idea was to use cyclic pitch to compensate for the "serious defect" of the forward flight motion on the rotor. The basis of his cyclic pitch concept is shown in Fig. 26, which is taken from his patent (Ref. 18). Basically the functionality of the concept is similar to a conventional swashplate system for blade pitch control. The blades marked as "e" spin around the shaft, and the end "g" of a pitch horn "f" follows a circular disk "h" with a groove in it. This disk is suspended on a spindle "i." The orientation of the disk is changed using the lever "k" which is connected to some form of control system linkage activated by the pilot. Changing the orientation of the disk causes a displacement of the end of the pitch horn. The blades had the ability to feather in pitch inside a sleeve, so a displacement of the pitch horn increases or decreases the pitch of the blades as they spin around the shaft. When the disk is horizontal, the pitch on the blades are the same; when the disk is tilted the blades follow a once-per-revolution variation in their pitch. While it is clear that the concept had some applicability to achieving flight control of helicopters, interestingly Cornu's patent focuses more on its possible application to controlling the flight of balloons and dirigibles.

Paul Cornu's ideas of rotating-wing aircraft that could use this type of blade pitch control device were presented at the first ever International Air Transport Exhibition (the *Salon Aeronautique*) in Paris at the end of 1908. This was an aircraft exhibition (a predecessor to the now famous Paris Airshow) held as part of the 2nd Paris Automobile Show at the Grand-Palais near the Champs-Élysées in central Paris. Louis Bréguet was also to display a model of one of his helicopter concepts at the same exhibit, and of course it was Bréguet that was to go on to become a famous aircraft manufacturer, and one of the first to develop a fully-functional helicopter in 1935.

Cornu's Coaxial Rotor Rig

One of Cornu's ideas is shown in Fig. 27 as a coaxial rotor system. The coaxial concept had a box-like rectangular frame, with the engine at the front and the pilot at the back. As intended, the engine drove, via a clutch, two bevel

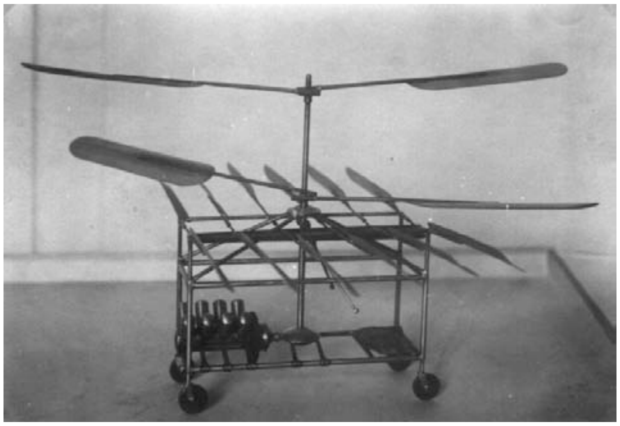

Figure 27: A model of Paul Cornu's proposed coaxial helicopter system, circa 1908.

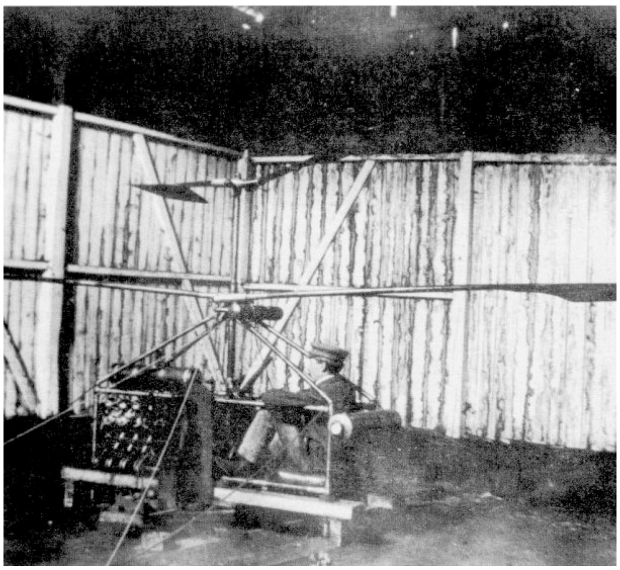

Figure 28: A photograph of Paul Cornu's coaxial helicopter rig, circa 1908.

gears enclosed in a central housing, with two concentric output shafts that ran in opposite directions. Two rotors, with their rotational planes 0.7 m apart, were mounted to the respective output shafts. Notice the similarity of the blade shape in the model to that shown in Cornu's patent (Fig. 26).

Again, Cornu's ideas of using shuttered vanes for flight control and to enable forward propulsion is evident here. These vanes were installed as two sets of six surfaces each; one on the right and the other on the left of the main frame. The vanes were intended to be controlled by the pilot using two independent levers.

A photograph of Cornu's coaxial rotor rig, as constructed, is shown in Fig. 28. Cornu was concerned, and legitimately so, about the aerodynamic efficiency of the coaxial rotor system. Cornu was to state: "The experiments demonstrated that there is a loss in speed of 50% on the theoretical speed of the air moved by the lower propeller." It is not clear, however, what "theoretical" basis he was using because the theoretical analysis of rotor systems were not to be widely understood and used until the 1920s. Despite its apparent aerodynamic "loss," Cornu was nevertheless convinced the coaxial rotor system offered a mechanical simplicity over his previous tandem rotor concept; clearly the elimination of the inefficient and problematic belt drive system must have been viewed as a positive step!

Paul Cornu was to conduct many experiments with this coaxial rig, and demonstrated that to lift a weight of 400 kg with a coaxial rotor system of 4 m in diameter, a power of some 70 hp was required. This result is reasonably consistent with coaxial rotor theory, which predicts power levels required in the range of 50–60 hp excluding mechanical losses. Apparently more than two-hundred tests of the coaxial rotor system were conducted, using rotor diameters that varied up to as much as 6 m. His coaxial rotor concept, however, remained as a testbed.

The Helicoplane

Cornu was aware of the issues with rotors operating in forward flight, and sought a solution in another type of aircraft. Cornu's "Helicoplane" is shown in Figs. 29 (from Ref. 19) and 30, which was a hybrid concept comprising rotors for vertical takeoff and landing, and a fixed-wing to sustain forward flight. See also Ref. (Ref. 20) for details of his concept. The rotors were intended to be 6 m in diameter, with a blade area of 4 m^2. The rotor planes were apparently tiltable, by using his swashplate mechanism, to propel the aircraft forward. The main wing had a span of 12 m (39.37 ft) and a chord of 1 m (3.28 ft). The concept also had a canard with a conventional tail. Cornu projected the aircraft to have a maximum speed of 100 km/hr (64 mph) when using a 80 hp engine.

Cornu was unable to find an investor for his concepts at the 1908 *Salon Aeronautique* to support the construction of his proposed machines. Issues such as the availability and power of suitable engines in 1908 were also factors that he was to have to consider. Even the best engines available at the time were either underpowered, or were too heavy to be suitable for application to a helicopter or other such vertical lift aircraft concept.

After Helicopters

Cornu's rotating-wing concepts were soon to fade from the aeronautical limelight, although they had received much publicity in their time, with extensive coverage in

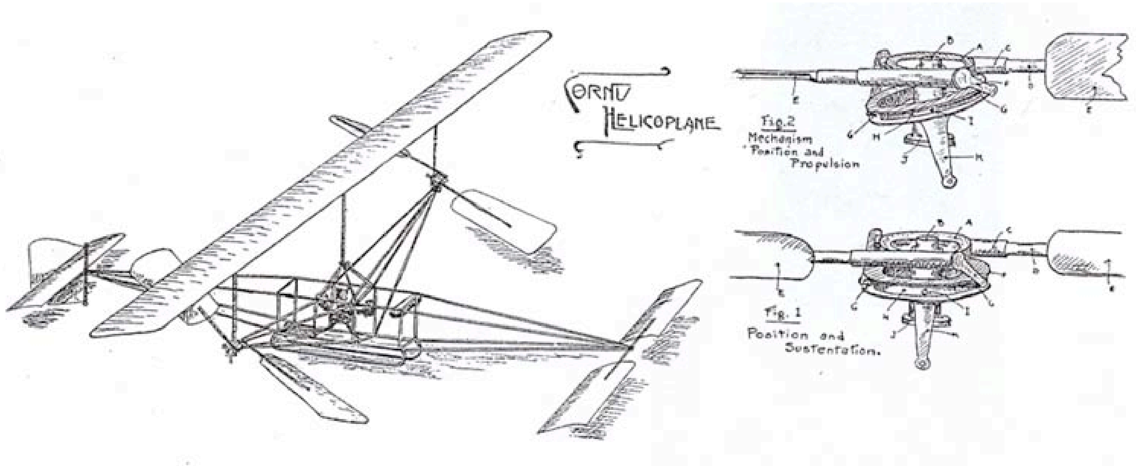

Figure 29: A sketch of Paul Cornu's proposed "Helicoplane," which incorporated two rotors with cyclic pitch capability.

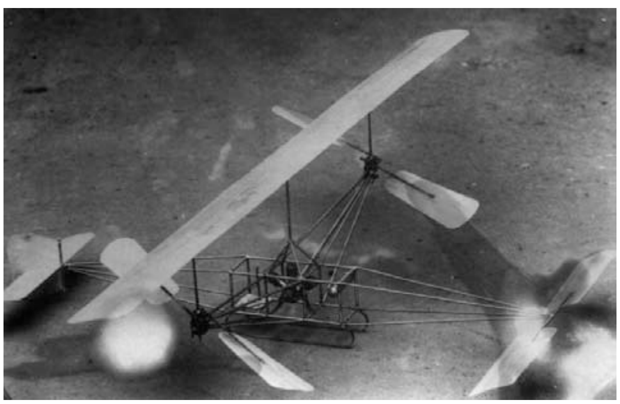

Figure 30: A model of Cornu's proposed "Helicoplane," circa 1908.

European publications such as *L'Aerophile* and *La Review de L´Aviation*, and in the United States in *Scientific American*. It would seem that the press exaggerated the claims of flight, but this is perhaps not so surprising. In fact, it is clear that many major newspapers were reporting aviation "successes" long before the flights made by the Wright Brothers or Santos Dumont!

The outbreak of World War I in Europe in 1914 saw Paul Cornu being drafted into the French Army, in which he served as a medical orderly. He still maintained his business and workshop, and after the war he started a new business making wireless telegraphy sets for the military. Cornu was to serve on the city council in Lisieux, in which he seems to have taken a lead role, following in his father's footsteps. For many years, Paul Cornu received many accolades for this pioneering work with the helicopter, and was recognized along with other French pioneers in aviation.

In 1938, when he was 58 years old, Paul Cornu was called up to work as a machinist in an arms factory in

Figure 31: An announcement for an Aviation Ball in 1931 in honor of Paul Cornu.

Vire. In his later years, he suffered progressively from poor health. He remained unmarried and had no children. Paul Cornu was not to see the end of World War II and the liberation of France. Tragically, he was killed on June

Figure 32: Paul Cornu (1881–1944) sits proudly in the pilot's seat of his 1907 helicopter.

6, 1944, at the age of 63, along with several members of his family, during the allied bombing raids on northern France at the start of the Normandy landings. Many of the original photographs of his helicopter were destroyed, but Paul Cornu's logbook still survives, documenting his pioneering attempts at helicopter flight.

Conclusions

Paul Cornu and his father Jules made some innovative attempts at building and flying a helicopter, and in 1906 they were certainly ahead of others working in the field. But by using an engine with a maximum power output of less than 24 hp, it is highly unlikely that the Cornus' 1907 helicopter ever flew in sustained flight, free of the ground, even accounting for the benefits of ground effect, and discounting the known loss in efficiency with the slippage of his belt driven rotor transmission. Although the Cornus conducted some successful experiments with small rotor models, they lacked the necessary theoretical and practical understanding of rotor performance to enable these results to be properly scaled to a full-size helicopter. The relatively low power output of their engine was probably compounded by its inability to make sufficiently high rotor speed because of the low aerodynamic efficiency of the rotor system.

At best, like other vertical flight machines of the era, the Cornus' machine likely made brief, uncontrolled bouncing hops into the air, possibly aided by momentary overshoots of rotor speed or gusts of wind. The "success" of their flights was probably exaggerated by the press, who were obviously keen to report any modest successes in the aviation world. However, the Cornus were on the right track to success, and perhaps with a better knowledge of rotor aerodynamics, a more powerful engine, a better transmission, and with the use of lighter materials rather than steel airframe components, the outcome of the tests would have been more successful. Therefore, although technically Paul Cornu could not have flown his helicopter in sustained free flight in 1907, he and his father Jules must still be correctly recognized as pioneers in the ultimate development of the helicopter. For this, the name of Cornu will be remembered whenever the history of the helicopter is told.

Acknowledgments

There have been many people who have contributed to this article, both directly and indirectly. The authors would first like to thank Bernard Mettler, who translated the article by Bracke from the original in French, and Carlos Cruz, who translated the biography of Cornu by Francois Cornu. A special thanks also to Francois Cornu for providing a detailed transcript of Paul Cornu's logbook and for the many engaging discussions on Paul Cornu and his accomplishments. Mike Hirschberg read the early drafts of this paper and suggested several improvements. Our thanks also to Roger Connor at the National Air and Space Museum for finding the early articles on Cornu from *L´Aerophile* and other sources, and for his encouragement and support throughout this work.

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