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EVOLUTION OF THE HELICOPTER.

By Karl Balaban.

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In the former monarchy of Austria-Hungary, much work was done, during the war, on the problem of the helicopter. Thus far but little has been published concerning this work, aside from the short article in No. 24 of this magazine (Zeitschrift für Flugtechnik und Motorluftschiffahrt) for 1921.

The writer of the present article enjoyed the privilege of assisting on the problem and will give here the history of the evolution of the helicopter and the preliminary work, as likewise an account of a series of propeller experiments, for the express purpose of the helicopter, concerning which nothing has yet been published, although the whole helicopter problem is intimately connected with the solution of the propeller question.

In 1916, the Austrian Daimler Motor Company in Vienna, built a high speed electric motor for use on giant airplanes. Each propeller was to derive its power from a directly-coupled electric motor, driven by a dynamo which, in turn, was to be driven by a powerful gasoline engine. The motor, especially designed for this purpose, was to be driven by a 600-volt direct current, giving 300 HP and 6000 R.P.M. and weighing 250 kg. (550 lbs.) including the gearing, which was to reduce the R.P.M. to 1000. It was based on the broad experience of the Daimler Company in building aviation engines of the finest materials. Their expectations were in fact realized later, excepting that, in giving 300 HP, the driving gear became too hot, so that the

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output had to be reduced to 250 HP.

In 1916, Major v. Petroczy, then officially detailed to the Vienna Aviation Officers School, entered the service of the Austrian Airplane Company in Vienna, so that the latter could work out a plan in common with the Daimler Company. This plan, which was partially developed at the coffee house table, was considered new at that time, but was, in reality, very old, as I learned much later. Major Petroczy planned to replace captive balloons by captive helicopters. On the history of the latter, Mr. Zurovec, in "Bestrebungen zur Lösung der Aufgabe des senkrechten Aufstieges" (Attempts to Solve the Problem of Vertical Ascent), Z.F.M. 1921, No. 24, p. 354, has given the most important points in Nimfuhr's "Leitfaden der Luftschiffahrt und Flugtechnik," second edition, p. 214, so that there remains to be described in the present article only the actual work on said project. Everything will be related here, even the failures, with the knowledge that the latter are often more instructive than the simple account of the achievements.

Major v. Petroczy planned to install the above-mentioned electric motor as power plant on the helicopter and supply it with electric current through the mooring cable. This current could then be generated in a sheltered place on the ground which would naturally be of great advantage.

At the first conference, which was attended, on behalf of the Daimler Company, by its Director, Dr. Porsche, Chief Engineer Köhler of the Construction Bureau and Electrical Engineer Zadnik, and, on behalf of the Austrian Airplane Company, by Director Ockermüller and the writer, Major v. Petroczy presented the following arguments:

A captive balloon is let up behind the lines as near as possible to the enemy positions and offers, from a great height, a good view of these positions. Its operation and upkeep require a large number of men on the field for letting it up, protecting it, keeping it supplied with gas (for which purpose trains of trucks have to be constantly on the road), etc. Moreover, gas must be generated in the interior of the country and shipped by rail, in case there is no portable gas generator available. Men are also required for operating the winch truck for letting up and hauling down the balloon. Altogether, a large and expensive plant is required for each balloon. There was also the argument that a captive balloon, on account of the great scarcity of rubber, represented a large capital and, what was still more important, it was very difficult to replace within a short time. A large "sausage" balloon near the enemy lines offered a fine target for artillery and was often attacked by aviators. It then had to be quickly hauled down, since otherwise it was sure to be shot down. It was practically impossible for the balloonist to drive away attacking airplanes, because the basket was under the balloon, so that he could not shoot up. If the balloon was set on fire, the observer had to descend by parachute, in order to avoid being buried by the burning balloon.

Hence a captive balloon did not offer an ideal observation station and it was only natural to seek something better to take its place. Major v. Petroczy proposed to replace it with a captive helicopter.

Petroczy figured that, with a specific lift of 4 kg (8.8 lbs) per HP, using the 300 HP electric motor, it would be possible to raise a helicopter having a total weight of 1200 kg (2645 lbs).

Later, his proposal, figured out even to details, proved to be only a hindrance to the successful solution of the problem. Instead of leaving us a free hand for inventing, he had prescribed for us only one way, that of putting a particular theory into practice. We have no thought of reproaching Petroczy, since he was led only by the best motives. Moreover, his ideas seemed very practical and at that time, on account of the newness of the subject, no one could have known that there were better, simpler and cheaper solutions.

On the basis of the plan presented by him, it was first considered as to whether a 1200 kg propeller lift would be sufficient. It was taken for granted that a lift of 4 kg per HP could be obtained, because it had been obtained with ordinary airplane propellers on the stand, though with a propeller of about 2.9 m. diameter, driven with a load of about 120 HP, while 300 HP had been adopted for the helicopter propeller. It was implicitly assumed, however, that the required lift could be obtained by means of specially constructed propellers.

It was required of the captive helicopter that it, with an observer, should be able to ascend from 500 to 1000 meters (1102 to 2205 ft) in a wind of about 8 m/sec (26 ft/sec), and that the observer should take along a parachute, a telephone and a machine gun. (Here a fundamental error was made. Instead of determining first whether the helicopter would fly at all, it was required to be a military airplane.)

The following weights were tentatively suggested:

	kg	lbs.
Propeller	50	110
Motor with driving gear	250	551
7.2 mm cable for 1000 m	150	331
Parachute and landing gear	200	441
Observer	80	176
Vertical component of wind pressure on cable	230	507
Total	960	2116
So that a lifting power of	1200	2645
would give a surplus of	240	529

for covering the weight of the machine gun and telephone.

I have purposely given the figures just as they were first proposed at the conference, although even during the conference the weight of the motor with driving gear was raised to 300 kg (661 lbs), tereby reducing the reserve lifting power by 50 kg (110 lbs).

That this motor was not particularly suited for the purpose, as it seemed at first thought, follows from the following consideration:

In addition to the motor, the cable had to be lifted to the height of 600 meters (1968.5 ft), so that its weight would have to be added to the weight of the motor. Furthermore, there had to be added the vertical component of the wind pressure (for a wind of 8 m/sec (26 ft/sec)), which amounted to 230 kg (507 lbs) necessitating a 7.2 mm (.024 in) steel cable. The electric conductor, as was immediately apparent, would better be an aluminum cable, because an iron cable, on account of its high electrical resistance, would have required a very large cross-section and consequently would have been much too heavy. (For 300 HP at 600 volts would produce 368 amperes, which the small steel wire could not carry.)

The choice of this motor, apparently so favorable, proved a great obstacle to the solution of the whole problem. It was not discovered till much later that a less powerful motor, on account of its smaller weight, is decidedly preferable to the more powerful one. We were given at that time, however, a problem with the essential details already worked out for us, namely: electric motor drive and conduction of electricity through the mooring cable. Our task was to find out whether this plan was feasible and, if so, to determine the best practical method of construction. This restriction of the problem, which, dictated with the best intentions, was expected to lead to a quicker solution, really hindered it, and it was not until much later that we succeeded in freeing ourselves from it.

As landing gear, v. Petroczy suggested supporting surfaces like those employed by Parseval in 1908 (V.D.I., 1909, p.899).

A parachute was already at hand in utilizable form. It was opened by a kind of "Nuremberg shears" which encircled the whole parachute and worked perfectly, so that it was possible to jump safely from a height of only 20 meters (65 feet), as had been repeatedly done. It weighed only 8 kg (17.6 lbs) and occupied only a little space.

The general plan of construction was likewise briefly sketched at the first conference. A simple frame, for supporting the motor M and the propeller P, carried the aforesaid airbags L. The cable was to pass over the end of an outrigger and the free turning moment was to be offset "in some manner or other," (Fig. 1).

In order to render said moment harmless, various suggestions were made (Fig. 2). In addition to the propeller P, carried by the frame, there are arranged axially under it three, or even more, guiding surfaces F, for offsetting the turning moment.

Fig. 3 shows another device, with which a slight turning was allowed. It was suggested to place one or more resistance surfaces on lateral arms, while the cable was to be attached to another such arm or outrigger.

Even at that time, the problem of the propeller was recognized as of supreme importance, whose solution must be first sought. The advantage of a small revolution speed for helicopter propellers was, of course, known and hence experimental propellers were ordered for 400, 600 and 800 R.P.M. at 300 HP, of which the last two were specially intended for use on the captive helicopter, in order to make the gearing correspondingly light.

Various propeller companies were asked whether they were prepared to make propellers up to a maximum diameter of 6 meters (nearly 20 feet) with a thrust of at least 1200 kg (2645 lbs) at 300 HP. Only the Austria-Hungary Integral Propeller Works in Vienna announced themselves ready to make such a propeller. A blower firm offered to make a blower instead of a propeller, in which, at our suggestion, the blades were to be made of plywood. The project was dropped, however, because the computed weight was too great. In the meantime, the testing stand had to be built, in order to be able to test the propellers.

The completion of the electric motor could not be expected for a long time, so that there was no chance of being able to use it for testing the propeller. The ratio of the propeller thrust to the required power had first to be determined. The Daimler Company now provided a shunt motor of 100 HP which offered a convenient regulation of the R.P.M. This motor, however, did not weigh less than 3500 kg (7716 lbs). By means of toothed gears, its revolution speed was reduced to 600 R.P.M. and a special water resistance was provided for regulating the shunt.

The output was determined from the energy absorbed by the electric motor, which was measured by well damped volt and ampere meters. The efficiency of the motor was known for various loads. With the intermediate spur-wheel drive, according to the statement of the Daimler Company, an efficiency of 96% could be obtained.

The measurement of the pull was much more difficult. This required the greatest possible accuracy, together with the simplest possible construction of the test stand, which, for the sake of keeping the whole matter secret, as well as for saving time, was to be built in the airplane factory. After much discussion of the pros and cons, the following arrangement was adopted:

The electric motor M, with attached gearing ü, was firmly mounted on a strongly built wooden stand (Fig. 4). The stand rested on wheels with ball bearings and stood on perfectly level square iron rails. The stand was held stationary by the interposition of a lever H, to the middle of which was attached a spring balance on which the pull could be read directly. In this manner a moment ratio of 2 : 1 was obtained and, by using two balances in tandem and taking the mean of their readings as the pull, any inaccuracies of the balances were more readily noted. The friction of rest was naturally considerable but the whole stand was constantly in vibration, so that this friction was much diminished. Fogure 4 shows diagrams of the testing stand, which was made of strong timbers, 15 x 15 cm (about 6 in. square), stiffened at the joints by strong sheet-iron plates. There were also volt and ampere meters on the stand, while the rheostat was separately installed, with current conduction through a flexible cable.

The revolution speed of the motor shaft was measured by hand with a Horn revolution counter and then that of the propeller was computed, the conversion ratio of the driving gear being known.

As regards the attainable accuracy of the measurements, the computation of the output from the voltage and amperage, on the basis of efficiency, is, naturally, not free from objections. The efficiency of the gearing was estimated at 96% on the basis of tests made with other similar gearings. The friction between the stand and the rails was so small as to be negligible in comparison with errors due to the use of spring balances. It may safely be assumed, however, that a thrust of 450 kg (992 lbs) was accurate to within 50 kg (110 lbs) (11%).

The first tests were made with a propeller furnished by the Austria-Hungary Integral Propeller Works. This ash propeller had the following measurements: diameter D 6 m (19.7 ft); pitch p 3 m (9.8 ft); width of blade c 45 cm (1.48 ft); weight W 150 kg (331 lbs). At $P = 100$ HP and $N = 600$ RPM, it gave a thrust of $T = 450$ kg (992 lbs) or 4.5 (9.9 lbs) per HP.

For judging this result, we may use Bendemann's formula, according to which the theoretically attainable thrust (T_{th}) is given by

$$T_{th} = \sqrt[3]{2 \frac{\gamma}{g} F L^2}$$

or approximately (with $\gamma/g = 1/8$ for the mass of the air and $L = 75$ P) by

$$T_{th} = \sqrt[3]{1100 D^2 L^2}$$

On the basis of this expression, the maximum thrust with a propeller of 6 m (19.7 ft) diameter and 100 HP, would be $T_{th} = 735$ kg, so that the propeller efficiency (the ratio of the actual to the theoretical thrust) would be $\eta = 61.2\%$ a very small value, whereby it should, however, be remembered that the propeller absorbed only 100 HP, instead of 300.

The poor results of this first experiment were very discouraging. At that time the writer left the Austrian Airplane Company and joined the Austrio-Hungary Aviation Arsenal, which had installed an extensive plant in Fischamend near Vienna for the manufacture of airplanes. There was a special section for making propellers, the director of which, Lieutenant v. Asboth, was assigned the task of experimenting with helicopter propellers, for which purpose a modern testing plant was completed early in 1917 and placed at his disposal. The plant has already been described in this magazine, so that a detailed description of it now is unnecessary. (In carrying out the provisions of the peace treaty, this plant had to be turned over to the Entente and is now installed in Rome.)

He had already obtained fairly good results with ordinary propellers with a patented cross-section (D.R.P. No. 326431 of December 20, 1916). These propellers, however, offered very little foundation for the designing of helicopter propellers, which, with 300 HP and a diameter of 6 m., were expected to exert a force of 4 kg/HP, for at that time we only figured on the use of a single propeller.

The methodical testing of propellers was then begun in Fischamend, with the purpose of attaining an efficiency as near 100% as possible, while Prof. v. Karman was given the task of discovering the constructive solution of the problem. Naturally, however, he could not begin his work, so long as he did not know how many propellers were to be considered, and in what arrangement.

Several ordinary propellers, of like diameters but different pitches, were first tested and graphs made, which greatly influenced subsequent experiments. There seemed, for instance, to be a connection between the diameter and pitch, of such a kind that, for each diameter, the maximum efficiency could be obtained by only one definite pitch, if a given HP were to be absorbed. In order to investigate this connection, one of these components was continually modified. Hence, propellers with like diameters but different pitches were made and then tested on the stand at 500 to 2000 R.P.M., for thrust and torque and output and the results were shown by graphs. The diameter was then varied (100 mm at a time), while the pitch and width of blade remained the same, and new graphs were made.

In like manner, the influence of the width of the blade was determined, by narrowing it 5 mm at a time, without diminishing its thickness. Its trailing edge was left thicker by the narrowing (Fig. 5), but the shape of the cross-section was also modified to correspond to its width.

The experiments showed, first of all, that the result was affected by a number of scarcely noticed circumstances, e.g.; curve on either side, its elasticity, etc. Experiments were also tried with blades bent strongly backward (Fig. 6), which when driven, assumed a position perpendicular to their axis of rotation, under the influence of thrust and centrifugal force.

Figs. 7 and 8 show the results obtained with two very similar ash propellers differing only in the amount they were bent back. The difference in their power absorption and efficiency is quite noticeable. With the same R.P.M. of 1300, we obtained, e.g.,

Record 76	Record 77
T = 390 kg	T = 350 kg
P = 124 HP	P = 89 HP
η = 78.5%	η = 87%

For reducing the weight as much as possible, propellers were made of spruce, which indeed proved very light, but not strong enough. Figs. 9 and 10 depict the results obtained with a spruce propeller 2.8 meters diameter. Here it is interesting to note that, with small revolution speeds of 550 and 600 R.P.M. corresponding to about 3.5 and 5 HP, values of 108 and 104% were obtained for η; a fact also confirmed on other propeller types and which is contrary to every theory. It is, of course, possible that, with such small powers, the thrust and output could not be accurately enough determined and wrong numbers were obtained. Of interest here is also the course of the η curve in records 25 and 32, since the latter represents the same propeller, in which only the width of the blade was made a little narrower. In the former case, a falling; in the latter case, an almost horizontal efficiency line.

For the first tests with four propellers, some made of mahogany were used, which had the characteristics:

N =	800 R.P.M. and	800 R.P.M.
D =	3.5 m.	3.5 m.
W =	9.75 kg.	20 kg.

The prescribed, relatively high, revolution speed with small output (P = 50 or 100) gave an unfavorable η, which, however, in the interval from 650 to 850 R.P.M. remained almost constant. One of the main objects of the experiments was to be able to predetermine methodically the course of η and to give the propellers corresponding dimensions.

The best material for light propellers was found to be mahogany, but only of the best quality. (In testing the "PKZ" Asboth propellers, the ones furnished by the "Elma" company in Budapest broke, because they were made of a poorer quality of mahogany.

In order to study the influence of the cross-section, propellers were made with a pitch of zero and were tested on a small stand built by us. A direct-current motor was mounted on a small plate and balanced on a knife-edge, in order to make it possible to determine the torque. This plate was suspended so it could turn about a point, so that the thrust could also be determined. In this manner, favorable cross-sections were determined and small propellers tested. Streamlines over the cross-section were also obtained: The blades were coated with oil and very fine soot was blown into the air stream. The soot adhered to the oil and thus formed wonderfully fine streamlines.

Parallel with these propeller experiments, investigations were now carried on concerning the construction of a helicopter. First of all, it was recognized that, with such large engine powers, it was better to employ several propellers. This decision and the following brought about entirely new arrangements. Provision had to be made for protecting the occupant, in case the helicopter should fall, due to stoppage of the motor or other cause. The possible loss of the helicopter in such an event had been accepted from the first, but the pilot was supposed to save himself by parachute. Such a course was, however, practically impossible, if the pilot had to free himself from the framework of the aircraft. At that time the only solution of this difficulty seemed to be to place the pilot in a kind of tower open at the top, so that, in the event of the helicopter's falling, it would fall, to a certain degree, away from him. The construction of propellers for utilizing this tower as a hub was rather unsafe and this circumstance favored the designing of a helicopter with several propellers.

Thus was evolved the project shown in Fig. 11. One motor drove four propellers of about 3-meter diameter, which were arranged symmetrically in pairs. They were driven by ball-bearing gears, by means of which the revolution speed could also be reduced. The space remaining between these four propellers was occupied by the pilot, who, in case of necessity, could jump out of the top and escape with a parachute. This aircraft was also designed as a captive helicopter. For this purpose there was a universal suspension frame, also shown in Fig. 11.

The Fischamend group of experimenters, led by Prof. v. Karman was also, at the behest of the "Fliegerarsenal," occupied with the same problem, although only with respect to construction details.

In order to take advantage of the greater efficiency of small propellers with a smaller weight per HP, Prof. v. Karman, at that time, planned to build a helicopter with a considerable number (10-12) of propellers arranged in a circle, the space left in the middle to be occupied by the pilot. It was soon found, however, that the combined weight of all the shafts, gears and bearings would be too great, aside from the resulting uncertainty of drive. It was decided, however, that the plan of four propellers, with the minimum number of gears, etc., was the best, since the torque could be fully offset and lateral stability attained, so that all considerations seemed to confirm the correctness of our first design.

In order, however, to investigate other possibilities, Prof. v. Karman and Ensign Zurowetz designed the project shown in Fig. 12, in which there was a tower for the observer. The four propellers were arranged in a row, enabling escape through the bottom, although not in every direction, on account of the three mooring points.

The arrangement of the propellers necessitated this manner of mooring. The four propellers, whose axes all lay in the same plane, could only give stability with reference to the plane perpendicular to them, through the middle of the helicopter, and it was immediately recognized that this three-point mooring involved quite a complication. At that time, however, we knew of no other equally promising plan and consequently kept on with this project.

A small compressed-air engine and a model of the helicopter were built, which rose while attached at the three points. On the basis of this result, it was planned to make a similar full-sized helicopter. In my opinion, however, this experiment could offer no enlightenment regarding the results with a full-sized helicopter. First of all, the weight relations of the model and of the full-sized helicopter did not correspond and were hardly comparable. Consequently, experiments with the model could hardly give any correct idea and we had to await the results of experiments with the full-sized helicopter.

Another problem then arose. In order to make two helicopters, another motor was required, since only one had been built and there was no way to operate our latest project. As already mentioned, our calculations showed that the electric motor offered no advantage over the ordinary airplane engine when, in addition to the weight of the motor, the weight of the current conductor was taken into account. The wind pressure would also be greater than on a small steel cable, just strong enough for mooring and hauling down. The four propellers tested for our project enabled us to use the regular six-cylinder airplane engine made by the Austrian firm of Warchalowsky, Eisler and Co., known as the "Hiero" engine series 34000, with a brake-horsepower of 250 at 1400 R.P.M., and arranged for drive at both ends, which would have greatly facilitated the disposition of the driving gears for the four propellers. Consequently, we figured further only on the internal combustion engine, which weighed 335 kg (738.5 lbs).

The work now suffered an interruption through the transfer of the writer to the Hungarian Airplane Works, where an entirely different line of work left very little time for continuing with the helicopter.

In the meanwhile, both projects were continued by Prof. v. Karman, who gave a brief account of them in the article already mentioned (Z.F.M. 1921, No. 24). In both helicopters, the center of gravity is over the plane of suspension and stability is attainable, only when the mooring cables are kept taut by sufficient excess lifting force.

Von Asboth, when afterwards Director of the Hungarian Propeller Factory in Budapest, caused a helicopter to be built like Fig. 11, which was, however, greatly damaged by a fire. The drawing plainly shows the tower with the swinging frame for the mooring cable, as also the four arms for the propellers. The engine is installed at the bottom, with the fuel tank above it.

In all previous helicopter types, the only plan considered for saving the pilot, in the event of engine trouble or a propeller break, was by means of a parachute. The expensive helicopter was sure to fall and be completely destroyed. This was also liable to occur, if the propeller thrust diminished and the mooring cable became slack. It was therefore planned to haul down the helicopter by means of a winch, until it touched the ground, with the engine running at full speed.

The sacrifice of the aircraft, in the event of injuries, is an extremely crude means for saving the pilot. Our endeavors were now chiefly devoted to the invention of a helicopter that could descend slowly and land or change its altitude at will without being drawn in by the cable. Experiments with this object in view, were carried on in common with Director Bloudek of the Construction Bureau of the "Ufag" without further support from the "Fliegerarsenal," which was then occupied with the two Karman projects.

We indeed requested instructions and financial support and received, August 8, 1917, from the "Fliegerarsenal" the following specifications for the construction of a captive helicopter.

"Specifications for the construction of an experimental captive helicopter:

1. Engine.- As motive power, a 230 HP Hiero engine shall be used. A fuel supply for two hours shall be carried;

2. Mooring.- The mooring cable shall be able to withstand a stress of 3500 kg (1716 lbs);

3. Useful load and altitude.- 180 kg (about 397 lbs) shall be carried as useful load. With this load and a full supply of fuel, the captive helicopter shall be able to attain an altitude of 1200 meters (3937 feet) and still have sufficient reserve lifting power to insure its stability;

4. Driving gear.- This shall be able to run continuously for 10 hours under full load without excessive heating or wearing;

5. Armament.- This shall consist of a machine gun and 1000 cartridges. The machine gun shall be mounted on the ring in such manner as to be able to cover as wide a range as possible;

6. Visibility.- This shall be given special attention. Only the space directly under the helicopter can be excluded from the field of vision;

7. Stability.- The helicopter shall remain still enough in a moderate wind, up to about 15 meters (49 feet) per second, to enable continuous observation with a spy-glass;

8. Safety measures.- Provision shall be made for enabling the observer to save himself by means of a parachute, in case the engine stops. It is also greatly desired that the descending speed, with engine entirely stopped, be diminished enough to prevent the destruction of the helicopter."

On August 27, 1917, we replied in full to the above communication and explained our objections to the specifications, as follows:

"Due to the lack of any practical experience and the uncertainty of all theoretical considerations, we suggest that for the experimental helicopter, only the following stipulations be made:

1. That it shall fly;

2. That it shall be stable;

3. That it shall give at least as good visibility as a captive balloon.

"We ask to be freed from all other restrictions, until we have acquired the necessary experience from the first experimental helicopter, to be made as quickly and cheaply as possible. Such restrictions would only complicate the work and render its success doubtful. Moreover, certain specifications are of no consequence for the first helicopter. Under this head falls, first of all, the question of armament. No more protection from airplane attacks needs to be required for a helicopter than for a captive balloon. Simultaneous defense from above and below is still impossible and the protection would therefore be very imperfect, even though it were possible to shoot upward. Had it been required to make airplanes immediately available for military purposes, their development would certainly have been much retarded.

"The choice of the vertical engine is just as unpractical. Its horizontal shaft requires a series of driving gears, which are not only unreliable, wasteful of power and expensive, but also require a long time for their manufacture. Moreover, the whole power plant is heavy and the dead weight considerable. Such a powerful engine (230 HP Hiero) is not necessary, since it is possible to fly with much less power, if the dead weight is only small enough. For the first helicopter, one hour's fuel supply is sufficient, especially as this would considerably reduce its weight and dimensions. It would then be possible to transport two small helicopters instead of one large cumbersome one, thereby gaining the great advantage, in case one should prove defective, of having another at hand. Moreover, the cost of production would be considerably reduced, as likewise the cost of operation. Consequently, more such helicopters could be used and fewer vehicles and men would be required for their transportation. All these advantages are obtainable by the adoption of an engine smaller than the one specified, and indeed of a rotary engine, as will be more fully explained further on.

"Likewise, thestipulation of the breaking strength of the mooring cable is only of limited value. It depends on the maximum attainable lift of the particular helicopter and only needs to be great enough to haul down the helicopter while the engine is running with throttle wide open. A safety factor of 1.5 to 2 is sufficient, inasmuch as a helicopter would seldom need to be hauled down when running under full power and any increase in the size of the cable would also increase its weight and the pressure of the wind against it, which in turn would necessitate a disproportionate increase in lifting power. The mooring cable can therefore be adapted to the particular helicopter and its choice left entirely to the constructor.

"The useful load, without armament, may, of course, be smaller than 180 kg (397 lbs). For the first captive helicopter, 120 kg (264 lbs) would suffice:

1 observer	75 kg	(165 lbs)
Spy-glass, radio, etc.	45 "	(99 ")
Useful load	120 kg	(264 lbs)

"As regards safety measures, it may be said that, if a helicopter can be made as safe an an airplane (that is, if it can land safely by gliding, in case of injury), no more can be required of it. The rescue of the observer by means of a parachute is even undesirable, in the sense that he should abandon the helicopter to its fate at the first intimation of the possibility of a fall. Provision should therefore be made that, in case of engine failure, the helicopter may land as softly as possible. In the event of being set on fire by incendiary bullets, there is no rescue even for an airplane, so that for the first helicopter, the possibility of safe gliding flight should be entirely satisfactory.

"The above may be summed up briefly, by saying that, in such a new problem, no restrictions should be set, but free play should be left to the inventor. We will now take the liberty to give in detail the results of our investigations and to describe the process of evolution.

"The first helicopter had four propellers arranged around a central observation space. The visibility was good and the space beneath could be readily observed, since the propellers were supported only by a light framework of triangular pyramids (Fig. 11).

"This arrangement was adopted for the electric motor. The firing field was free above, while it was partially obstructed by the framework below. In case of engine failure, the helicopter was expected to fall away from the observer, while he saved himself by means of a parachute. The propeller torque was eliminated by balancing the propellers in pairs against each other. Stabilizing surfaces had to be provided, which, if situated above the propellers, would naturally have restricted the firing field. The total weight would have been 1200 - 1400 kg (2646 to 3086 lbs) and would have necessitated about 300 HP. There was no possibility of protecting the helicopter against being smashed or at least seriously damaged, in the event of a fall. Moreover, there was no certainty that it could be sufficiently stabilized by the stabilizing surfaces.

"We therefore turned to other solutions and were first influenced by the following considerations. The dead weight consists chiefly of the weight of the engine, radiator, fuel tank and fuel, gearing and shafts, as follows:

230 HP Hiero engine	335 kg (739 lbs)
Radiator	30 " (66 ")
Water	37 " (81 ")
Total	402 kg (886 lbs)

"To the above must be added the weight of the driving gear, which, with the crosswise position of the engine with gears at both ends, consists of bevel gears, requiring much space. With the weight of the engine, the weight of the whole structure must be increased and, consequently, the necessary lifting power of the propellers. The increase of the lifting power is not proportional, so that better results can be secured with weaker and lighter engines than with stronger and heavier ones, especially when their revolution speed is slower and the torque correspondingly greater. It follows logically from this consideration that, especially for helicopters, the air-cooled rotary engine is the most promising. In fact, even the 100 HP Gnome engine weighs only 100 kg (220 lbs), so that two of them, with an output of about 200 HP, weigh 160 kg (353 lbs) less than the vertical engine. This method gives better results, in spite of the greater fuel consumption, since the propellers are coupled direct and still revolve at only 1200 R.P.M. They are thus more readily installed and the friction of the gears is eliminated. At the same time, the torque is large, on account of the low speed, but serves a purpose to be explained later.

"Furthermore, the stability problem is solved by the facts that the center of gravity is below the attachment of the mooring cable and that the propellers revolve about their axes, while the whole frame revolves about the vertical axis of the aircraft. This arrangement has various advantages, which can be explained in connection with a second project with two propellers and two wings (Fig. 13).

"About the central tower K there are placed symmetrically two propellers, each driven directly by a rotary engine. Each propeller supplies about 100 HP at 1200 R.P.M. and has a torque of $Q_d = 716 \frac{100}{1200} = 60$ kg-m (434 ft-lb). If only one propeller is revolving, e.g. the propeller S_1, the helicopter will rotate in the opposite direction. This can be avoided by causing the second propeller S_2 to revolve in the opposite direction from the first.

"With both propellers revolving in the same direction, there is considerable uncompensated torque which, with a lever arm of 2.5 m (8.2 ft), exerts a force of

$$F = 60/2.5 = 24 \text{ kg } (52.9 \text{ lbs}).$$

Unless, with the same lever arm, a force of 24 kg is opposed to this, the rotation will be continuously accelerated. A uniform speed of rotation may, however, be readily obtained by means of the wings F_1 and F_2, which are made of such dimensions that their centers of pressure are just 2.5 m from the center of rotation Z and their head resistance is 24 kg. With a ratio of 1/10 between lift and head resistance (or drag), each wing exerts a lift of 240 kg (529 lbs). The maximum lift is therefore:

2 propellers, diameter 2.8 m, 100 HP, each 430 kg		= 860 kg
2 wings, each 240 kg		= 480 "
Total	(2954 lb)	1340 kg.

Here the so-called "parasite" torque is obviously very advantageously utilized, the stabilization being effected by the gyroscopic action in conjunction with the low position of the center of gravity. The central observation tower is free to rotate and is held either by two cables sufficiently divergent to overcome the friction of the shafts around which the propellers and wings revolve, or by a small pedal drive operated by the observer and with which he can change his position at any time.

"The principle just enunciated has therefore very great advantages, although even here difficulties present themselves. For instance, it must be possible to vary, at will, the angle of attack of the revolving wings, in order to change to gliding flight. Since the head resistance of the wings is already prescribed, the wing loading is very high in gliding flight, which is quite a disadvantage. The necessary dimensions of the whole helicopter are rather large, 8 to 9 meters (29.5 feet) diameter, and the location of the observation tower, in the center of the whole system of revolving propellers and wings, is very complicated.

"The exit at the top is unobstructed and it is possible to use a parachute. If, therefore, the observer saves himself, in case of engine failure, by resorting to the parachute, the wing loading is slightly reduced, but since there is no one left to adjust the wings, the helicopter, nevertheless plunges to the ground.

"A greater gliding ability is obtainable by means of one propeller and revolving wings. This arrangement, however, removes the possibility of escape at the top, besides bringing the center of gravity too high. Otherwise, the observer could be seated above the middle of the propeller and have an open field for firing upward (Fig. 14).

"From these devices to the use of revolving wings is only a step further. In this connection, we thought of the arrangement long since proposed by Prof. Wellner, namely: wings, whose revolutions are produced by means of propellers. This project is especially attractive. Very great lift, with maximum gliding ability and great stability, is thus attainable. By the use of small engines and a peripheral velocity of about 100 km (62 miles) per hour of the center of pressure, a lift of about 200 kg (441 lb) would be attainable with 100 HP, which, with a lever arm of 2.5 m (8.2 ft) corresponds to a torque of 500 kg-m (3616 ft-lb). This project, however, has many disadvantages. By placing the pilot over or under the revolving wings, his view is cut off in one direction or the other, the center of gravity is rather high, the cage suspension is quite complicated and the functioning of the engines still more so. In the use of rotary engines, troublesome gyroscopic phenomena are produced by the rotation about the center of the helicopter. The same holds true regarding the propellers, which do not function so well on account of the cycloidal paths of their blades.

"Finally, a project was thought out, which consists of wings revolving in opposite directions (Fig. 15). A low-lying rotary engine is coupled directly with a pair of wings and its housing with a second pair situated under the first pair. Consequently, they revolve in opposite directions, with a speed corresponding to about half the revolution speed of the engine. Outside the outer shaft is placed the seat S, which is attached to the suspension. The latter consists of the outriggers A which carry the cables K, which combine to form the mooring cable. In order to prevent the seat from being carried around by friction, it is made so it c can be turned by means of a pedal and be brought into any desired position. For obtaining the required torque, it would be necessary to have gears, which would be difficult to install. The shifting of the wings is difficult to accomplish. Moreover, the wings exert too great an influence on each other, but the center of gravity is low.

"For the execution of this project, we make the following suggestions. On the basis of experiments with free-flying models, we learned that a helicopter can be steered in a very simple manner. Two steering surfaces, symmetrically arranged and turning in opposite directions, make steering possible, so that there is no real need of a mooring cable. No propeller is required and the weight of the helicopter is reduced by the amount of the weight of the mooring cable and the pressure of the wind against the cable. The following suggestions apply, however, to both free and captive helicopters.

"The rotary engine is coupled directly with a propeller of about 3 m (9.8 ft) diameter and gives, at 1200 R.P.M. and 100 HP,

$$Q_d = 716.2 \frac{100}{1200} = 59.7 \text{ kg-m.}$$

This would cause the helicopter to rotate, so that wings would need to be used, as already described. Since the total weight of the helicopter does not exceed 500 kg (1102 lbs), a wing area of about 15 sq.m (161.46 sq.ft) at 30 kg/m² (6.14 lbs/ft²) wing load, is sufficient. A directly coupled vertical propeller exerts a lift, at 100 HP, of at least 440 kg (970 lbs) (amount obtained with a 100 HP Mercedes engine and airplane propeller), so that only 60 kg (132.3 lbs) more lift is required for the wings. The wings thus have a load of only about 4 kg/m² (0.82 lb/ft²), can be used with a very small angle of attack, offer very little head resistance and, on account of their higher revolution speed, exert a very favorable influence on the stability.

"When the engine is throttled, the angle of attack of the wings is changed and the aircraft automatically passes into the gliding position. The engine may also be regulated by contact breaking.

"The seat is attached to the tripod forming the landing gear and connected with the steering surfaces. When the latter are rotated toward each other, the rotation of the seat is completely prevented. This requires very little force, since only the friction of the ball-bearings at the suspension point of the landing gear must be overcome (Fig. 16).

"If the steering surfaces are both turned in the same direction, the helicopter flies horizontally. The steering surfaces are shifted by a kind of cross-head control, on which there is also the contact for the ignition. By means of the low-lying seat and the location of the engine under the wings, the center of gravity is brought below the wings, which fully suffices for the stabilization, as demonstrated by experiments with models, since the gyroscopic action of the revolving wings exerts a great influence. The landing gear has three freely moving, automatically adjusting, elastic wheels, which enable landing on any ground and with the wind in any direction.

"The fuel tank is above the engine, so that the fuel flows to the engine under the influence of gravity. In case of fire, the fuel burns upward, because of the downward motion of the helicopter. The whole structure is made of steel tubing, so that the danger of fire is reduced to a minimum. Only the wings are covered with fabric.

"When the engine is started, the helicopter remains on the ground, since the propeller exerts a lift of only about 440 kg (970 lbs). The wings are held stationary for awhile. Then they are allowed to revolve slowly until the torque is equalized. The throttle is then thrown wide open, the lift increases with the increasing peripheral velocity and the aircraft rises from the ground, since it now has nearly 150 kg (330.7 lbs) of excess lifting power, the total weight consisting of the following items:

Rotary engine, 100 HP	120 kg	264.6 lbs.
Propeller	12 "	26.5 "
Engine supports	8 "	17.6 "
Fuel tanks	4 "	8.8 "
Fuel and oil for one hour	50 "	110.2 "
Planking around engine	4 "	8.8 "
Wings, 6 complete	60 "	132.3 "
Gears for wings	10 "	22.0 "
Rudders	10 "	22.1 "
Suspension	6 "	13.2 "
Landing gear	15 "	33.1 "
3 wheels	12 "	26.4 "
Total dead weight	311 kg	685.6 lbs.
Useful load	120 "	264.6 "
Total weight to be lifted	431 kg	950.2 lbs.

A 100 HP propeller, with a diameter of 3 m (9.8 ft) and about 1000 R.P.M. and with the wings revolving at 200 R.P.M., can lift at least 400 kg (882 lbs). The wings lift, with 60 kg-m free torque and 3 m lever arm to center of pressure, about 200 kg (441 lbs) thus giving about 150 kg (330.7 lbs) excess.

"The wings can be shifted by the observer without leaving his seat. At the start they may be given a negative angle of attack, which can then be gradually changed to positive and thus enable a very gentle take-off.

"In order to descend, the engine is throttled and the wings are given a negative angle of attack, so that they may be allowed to revolve during the descent and thus give a stable gliding flight. Just before landing, it is not necessary to speed up the engine, but only to give a positive angle of attack to the wings which produce the effect of a brake and also causes them to exert a greater lift, thus enabling a gentle landing.

"There are three steering surfaces, which, by rotating toward one another, prevent the shifting of the seat from friction. Moreover, the seat can be shifted by means of them and, lastly, the whole aircraft can be steered sidewise, forward or backward. The steering is done by a control stick similar to the one used on airplanes, so that the mooring cable is rendered entirely superfluous.

"The noise from the engine is considerably lessened by its being inclosed. The ease of removing the wings facilitates transportation. Landing gear, wings and propeller can be transported separately. Thus disassembled, the helicopter occupies no more space than an airplane fuselage without landing gear.

"Were this project to be carried out, we could deliver the helicopter within four weeks from the date of receiving the engine."

The "Fliegerarsenal" then explained that it would not hold us to the original specifications for the first experimental helicopter, but must do so for quantity production. At the same time, doubt was expressed as to whether the weights given for the free helicopter were correct, that is, as to whether such an aircraft could be built. The weights were verified, however, by computation on the basis of the finished drawings.

Furthermore, it was claimed that we had had no experience in steering a free helicopter, which was a defect in our arguments against the captive helicopter. It could be rightly claimed, however, that a mooring cable could offer no help against a fall and that just as little was known regarding the steering of a captive helicopter as of a free one. As regards the stability, we based hopes on the strong gyroscopic effect and the low position of the center of gravity. As for the rest, the "Fliegerarsenal" could, of course, make no mathematically or scientifically justified objection and sentimental objections were not convincing enough. No further support was given us, however, and, unfortunately, the plans, completed even to the detailed drawings, had to remain idle. "Unfortunately," because, whether successful or not, it meant a long step forward toward the solution of this problem.* We will therefore illustrate a few of the structural details with drawings.

The manner of shifting the wings is shown in Fig. 17. Handle G imparts a vertical motion to rod A and ring B, with which rod A is connected. Ring B is held loosely by the sleeve C, which revolves with and can slide along the shaft D. Ring B serves to impart a vertical motion to sleeve C but does not revolve. Another rod E connects sleeve C with the lever F which rotates the wing spar. Thus the angle of attack may be changed at

* It is, of course, now clear to me that the plans according to Figs. 1-3 and 15 would not have given sufficient stability, but these plans brought us logically to the plan shown in Fig. 16.

will, for either ascending, descending, or horizontal flight. All six wings are acted upon simultaneously in the same way, since there are six rods (one for each wing) attached to sleeve C. The throttle is also connected with the handle in such a way that the wings are automatically thrown into the position for gliding flight whenever the engine is throttled.

Steering (Fig. 18).- There are three surfaces F_1, F_2 and F_3, so arranged that F_2 is opposite the seat S. Thus F_1 and F_3 are located symmetrically with reference to the seat, whereas F_2 is in the same vertical plane as the seat. These surfaces each have an area of 400 x 900 mm (15.75 x 35.43 in) and a spar of 40 x 0.8 mm (1.58 x .03 in) steel tubing, which fits over an axle O made of tubing 38 x 1 mm (1.5 x .04 in) (Fig. 19). Over the end of this axle O there is slipped a cap K, which is connected with the wing by means of a tube running parallel to the axle. Hence, by rotating the cap K about the axle O, the surface is also rotated and its angle of attack is changed.

Fig. 18 illustrates the principle of the steering mechanism. The control stick (the lower end of which is held in a ball-and-socket joint G) is connected with the caps K by means of pairs of levers H_1 H_1', H_2 H_2', H_3 H_3' (the last pair being omitted in Fig. 18). In the actual design these levers are situated in the same horizontal plane, but in Fig. 18 they are shown at different heights for the sake of clearness. H_1', H_2' and H_3' are hinged to the control stick so they swing about horizontal axes. H_1, H_2 and H_3 are hinged to the caps in the same way. One of the latter levers (H_1) is shown in Fig. 20. It is fashioned out of sheet metal and has an eye at its lower end for hinging to the fork-shaped end of the counter-lever. If the control stick is pushed forward, no effect is produced on the opposite surface F_2, since H_2 and H_2' only turn about their horizontal axes. H_1', however, turns the lever H_1, so that the symmetrically situated steering surfaces F_1 and F_3 are rotated, thereby imparting an inclined position and a forward motion to the whole aircraft. When the control stick is twisted, all the steering surfaces are rotated alike and the whole aircraft is turned in the same direction as the control stick. As regards other details (landing gear, wings, etc.), there is nothing that calls for special mention.

According to experiments with a model of about 1.5 m (4' 11') blade diameter, the descending speed is considerably lessened (in case the engine stops) by the continued rotation of the suitably adjusted wings, so that the possibility of thus avoiding a crash appears at least probable. The results of experiments with models are, however, only partially applicable to full-sized aircraft.

The subject of stability is, of course, very important. As stated in my article "Zur Stabilität des Hubschraubers" (On the Stability of Helicopters) in No.15 of Z.F.M., it is very probable that the aircraft would be stable, as a consequence of the gyroscopic action and the low position of the center of gravity.

Translated by National Advisory Committee for Aeronautics.

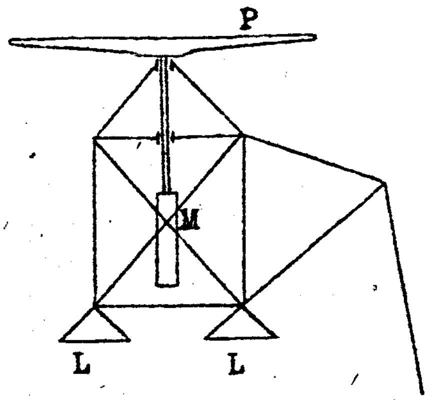


Fig.1

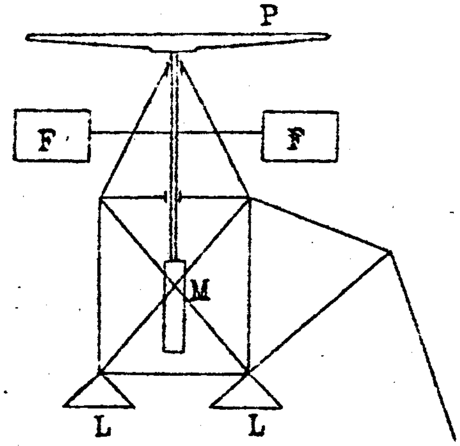


Fig.2

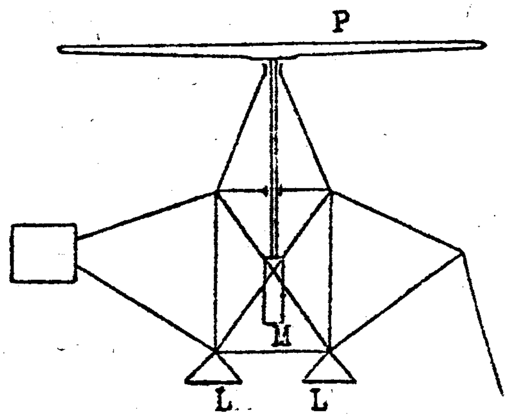


Fig.3

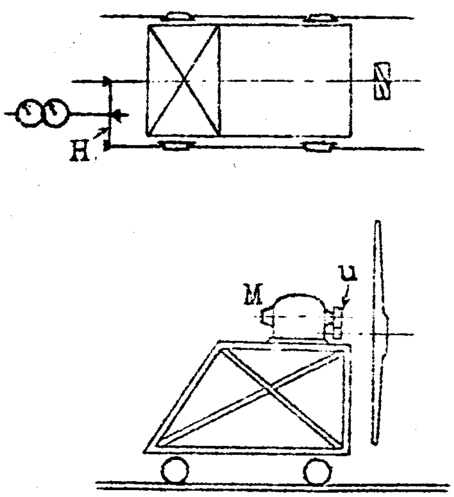


Fig.4

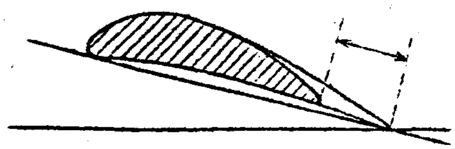


Fig.5

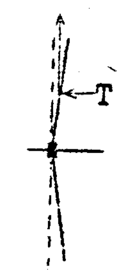


Fig.6

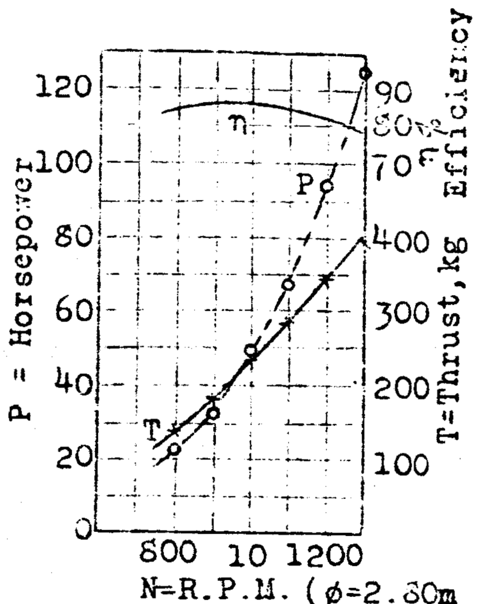


Fig.7. Record No.76 Type:A16b

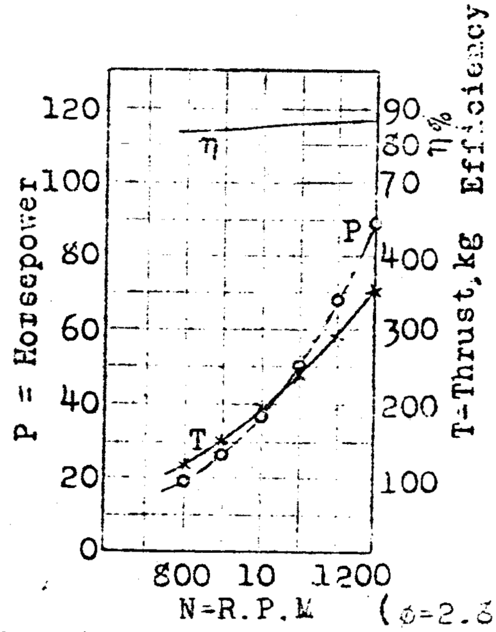


Fig.8. Record No.77 Type:A16a

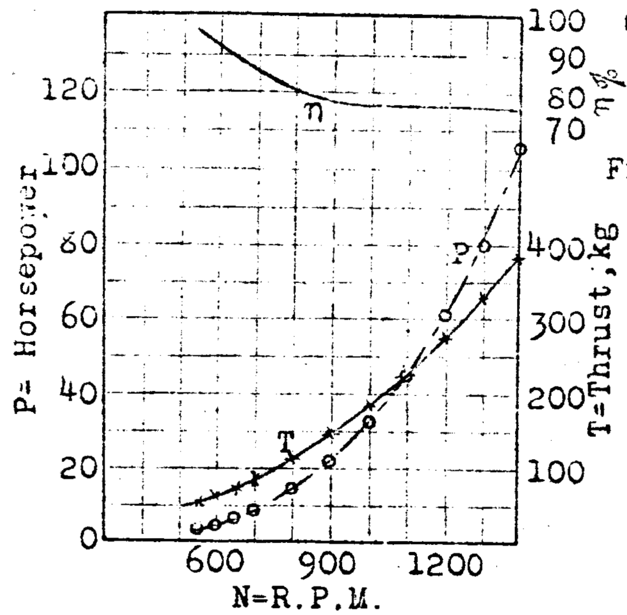


Fig.9. Record No.25 Type:A207 spruce
ø=2.80m

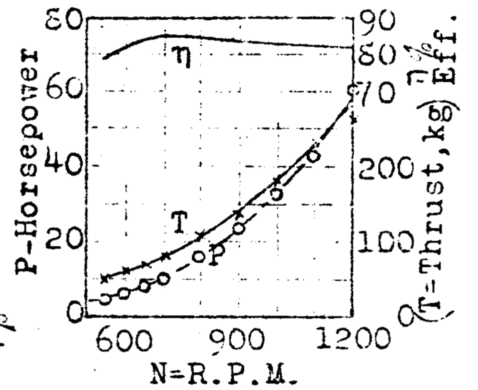


Fig.10. Record No.32 Type:A207 spruce
ø=2.80m

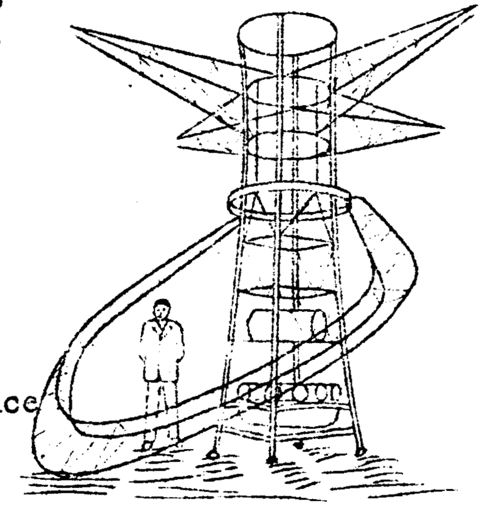


Fig.11. First design.

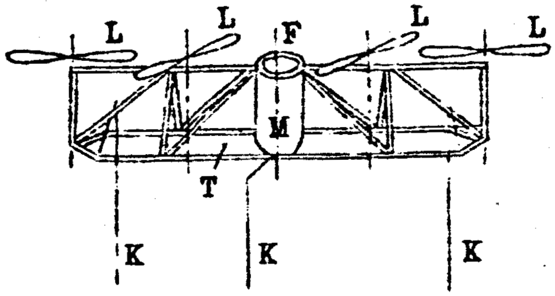


Fig. 12

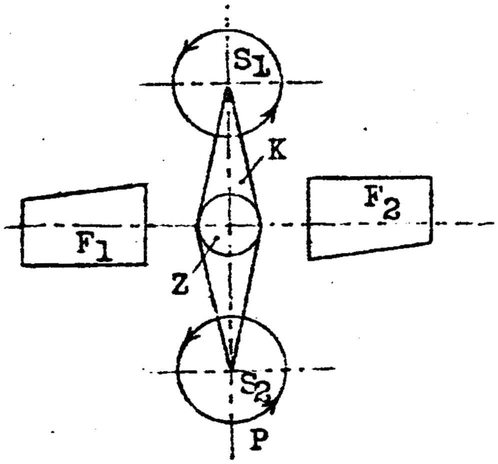


Fig. 13

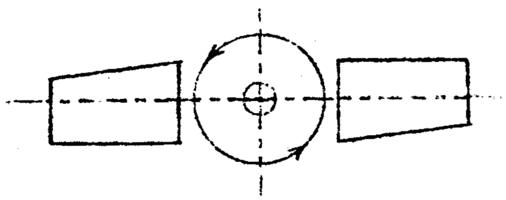


Fig. 14

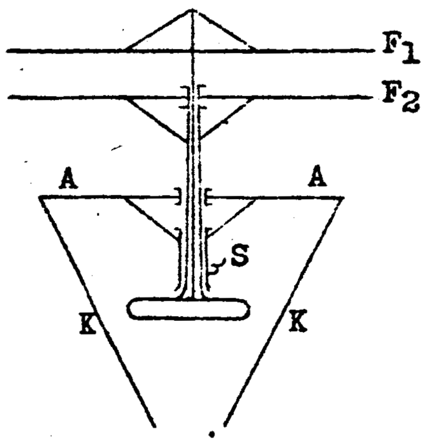


Fig. 15

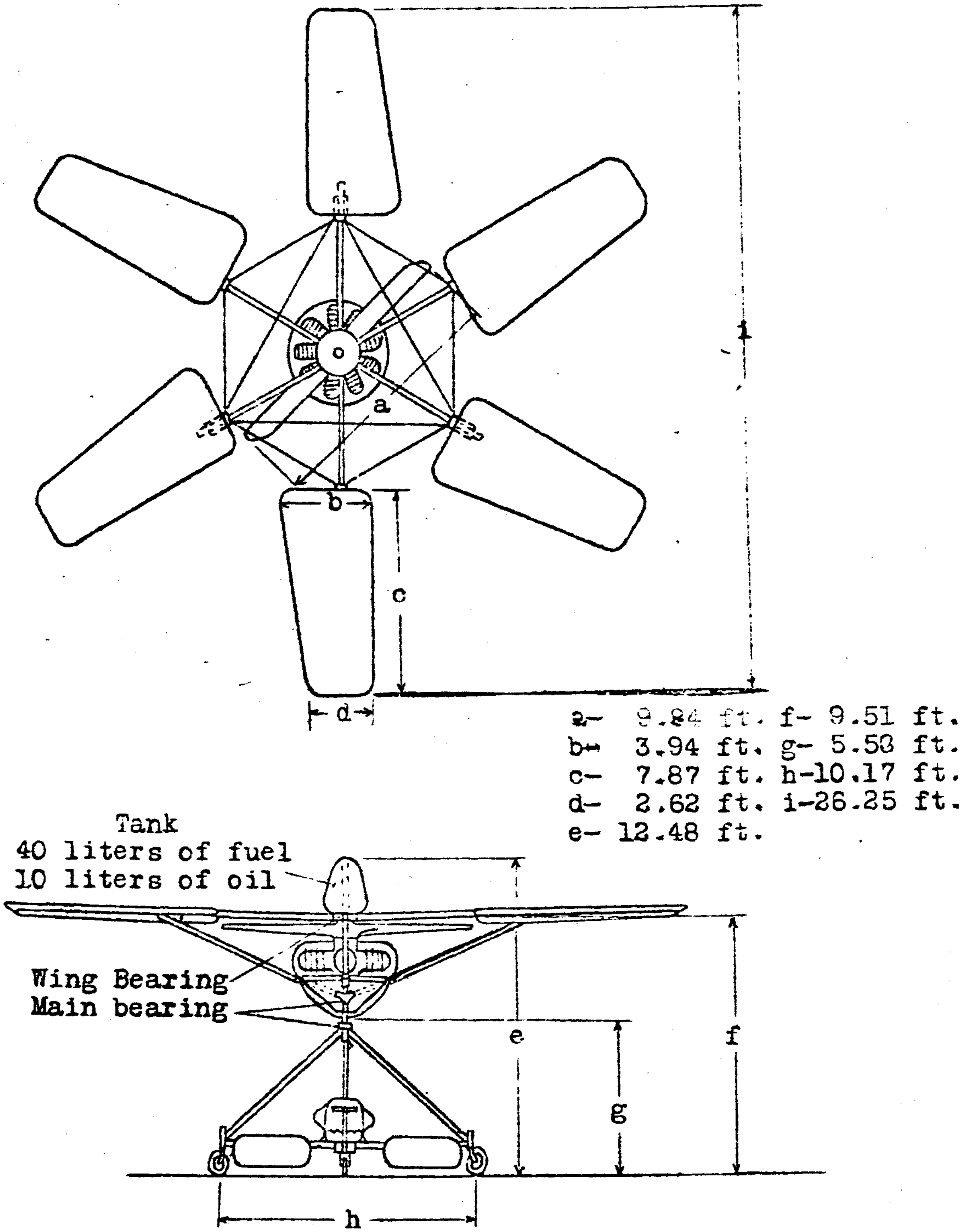

a
b
c
d
i
a- 9.84 ft. f- 9.51 ft.
b- 3.94 ft. g- 5.58 ft.
c- 7.87 ft. h-10.17 ft.
d- 2.62 ft. i-26.25 ft.
e- 12.48 ft.
Tank
40 liters of fuel
10 liters of oil
Wing Bearing
Main bearing
e
f
g
h

Fig. 16

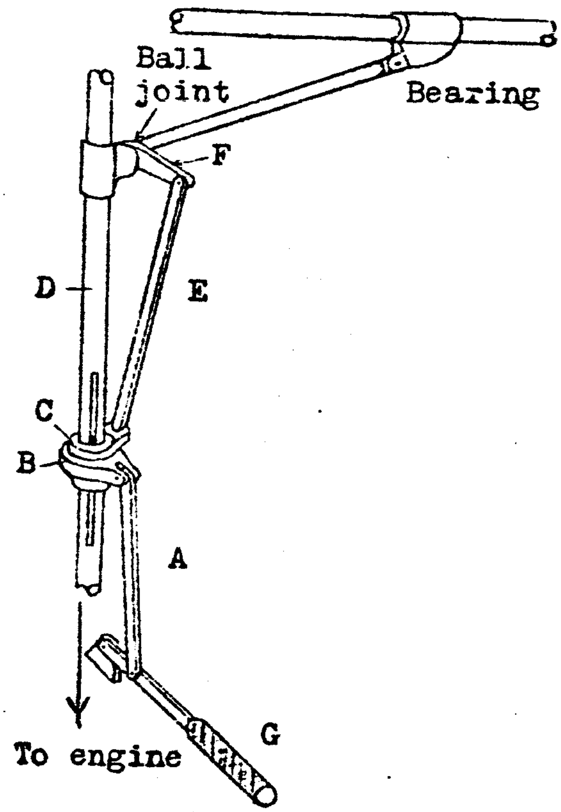

Ball
joint
Bearing
F
D
E
C
B
A
To engine
G

Fig. 17

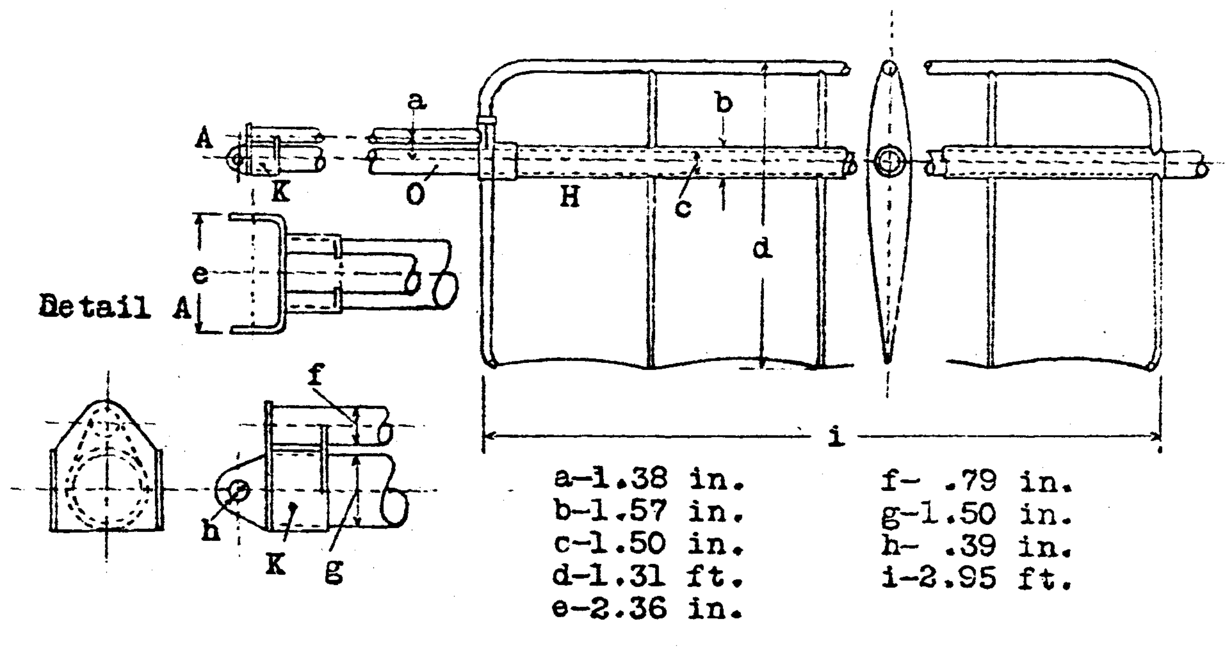

A
K
a
O
H
b
c
d
e
Detail A
f
h
K
g
i
a-1.38 in.
b-1.57 in.
c-1.50 in.
d-1.31 ft.
e-2.36 in.
f- .79 in.
g-1.50 in.
h- .39 in.
i-2.95 ft.

Fig. 19

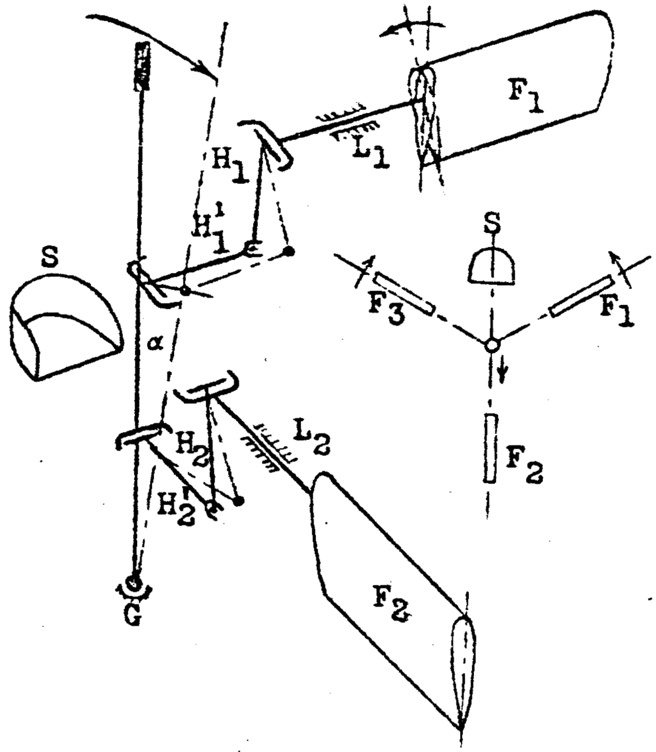
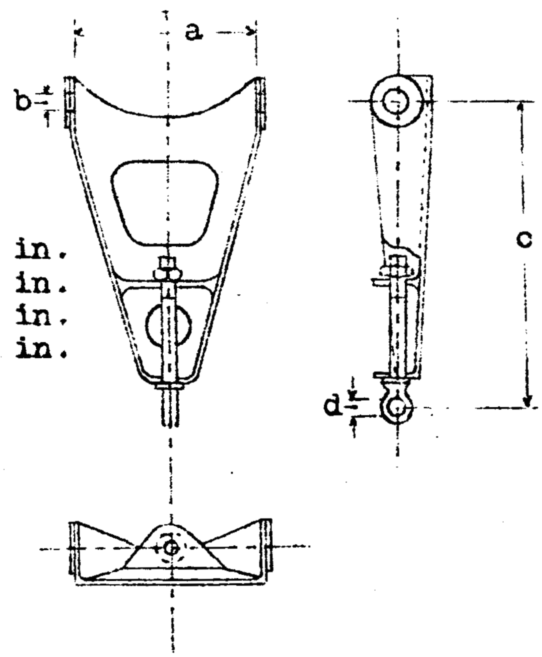


Fig. 18



a-2.36 in.
b- .31 in.
c-3.94 in.
d- .20 in.

Fig. 20

Figs. 18 & 20