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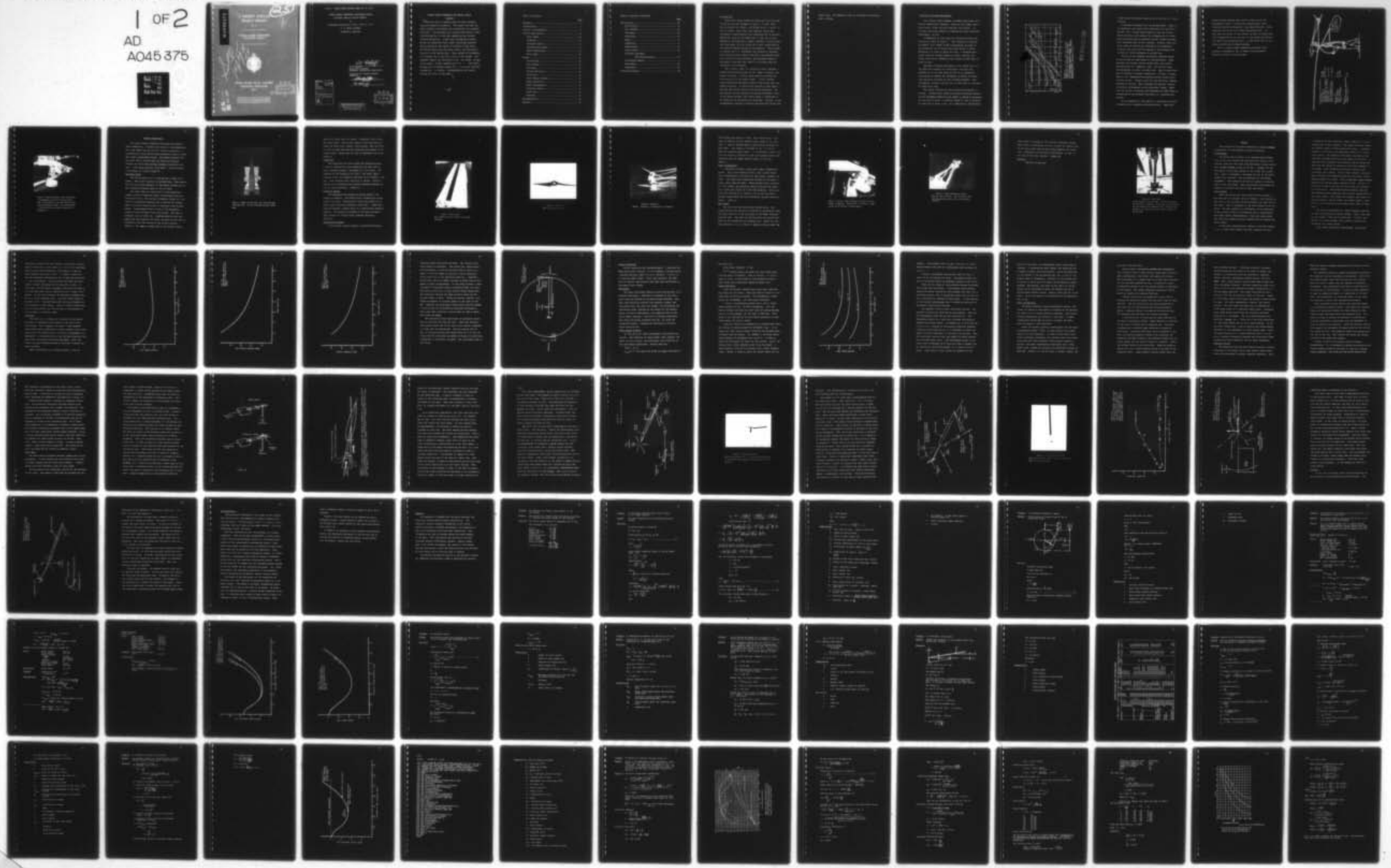

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A TRIDENT SCHOLAR PROJECT REPORT

NO. 87

"SINGLE BLADED TORQUELESS HELICOPTER DESIGN"

See 1473

UNITED STATES NAVAL ACADEMY
ANNAPOLIS, MARYLAND
1977

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SINGLE BLADED TORQUELESS HELICOPTER DESIGN

A Trident Scholar Project Report

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SINGLE BLADED TORQUELESS HELICOPTER DESIGN

ABSTRACT

There has been a standing need for small portable strap-on backpack helicopters. This paper describes the steps leading to the design and construction of a working prototype. The prototype has a single rotor blade 12 feet long balanced by a 4 foot spar supporting two counter rotating propellers. A belt power transmission system drives the propellers from a small two-stroke gasoline engine located at the center of rotation of the rotor. The device straps onto the pilot's back, and the pilot's legs act as the landing gear. Empty weight of the machine is 75 pounds and it can lift a total of 270 pounds. Performance figures are calculated to be: Top speed - 48 mph, cruise speed - 38 mph, maximum rate of climb - 420 ft/min., minimum rate of descent (power off) - 9.4 ft/sec, and fuel consumption - 1.5 gal/hr. Recommendations for future designs are given in the paper.

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Introduction

Ever since Icarus donned his wings and flew too close to the sun, man has dreamed of flying. In 1903, with their aircraft the 'Flyer', the Wright brothers opened the age of flying. Since that time, however, flying has increased in sophistication and complexity and is now well beyond the reach of the common man in cost and utility. Therefore, the dream for a simple, portable, strap-on back-pack helicopter is still alive and is well exemplified by the numerous designs listed in the Appendix. The millions of dollars the U. S. Government has invested in portable man-carrying devices such as the Bell's Jet-powered flying belt, Hiller's Flying platform, and Aerospace General's minicopter illustrate that there is a military need for individual flying machine.

This project, then, is a design of such a machine; a machine which would be easy to fly, cheap to operate, and simple in design - a device which would be portable and could strap on to the pilot's back. I felt a single-bladed torqueless helicopter design would be the most successful approach. In the utility section of this paper, I describe the factors which influenced by selection. The description section explains the working prototype I built. In the design section, the factors which I considered in the design of my helicopter are discussed. Finally, in the recommendation section, I indicate the direction future work should take. The Appendix lists all the major calculations used in design.

Utility of Backpack Helicopters

Four factors affect whether a backpack helicopter will will be commercially feasible. They are trip times, operating costs, flight training required, and comfort. In military operations comfort is replaced by a more important requirement, utility.

A comparison of trip times for various distances and vehicles is shown in Figure 1. This indicates a backpack helicopter (roof copter in the illustration) is equal to the automobile and is better than other forms of transportation to a range of about 20 miles. A backpack helicopter would be further favored in urban, mountain and forest areas where automobiles may average no more than 30 miles an hour.

Although a backpack helicopter is as complex and is in the same size catagory as a motorcycle, its cost will probably be in the same range as that of an automobile. Low production numbers and redundancy in design to ensure safe operation accounts for the increased expense. Fuel consumption, however, will be low, in the order of 2 gallons of gasoline an hour.

The flight training for the torqueless helicopter is minimal. Students have soloed torqueless helicopter designs such as Aerospace General's mini copter or Benson's Gyrocopter in less than 10 hours. A similar amount of time is required to learn how to drive a car. As a comparison, a conventional

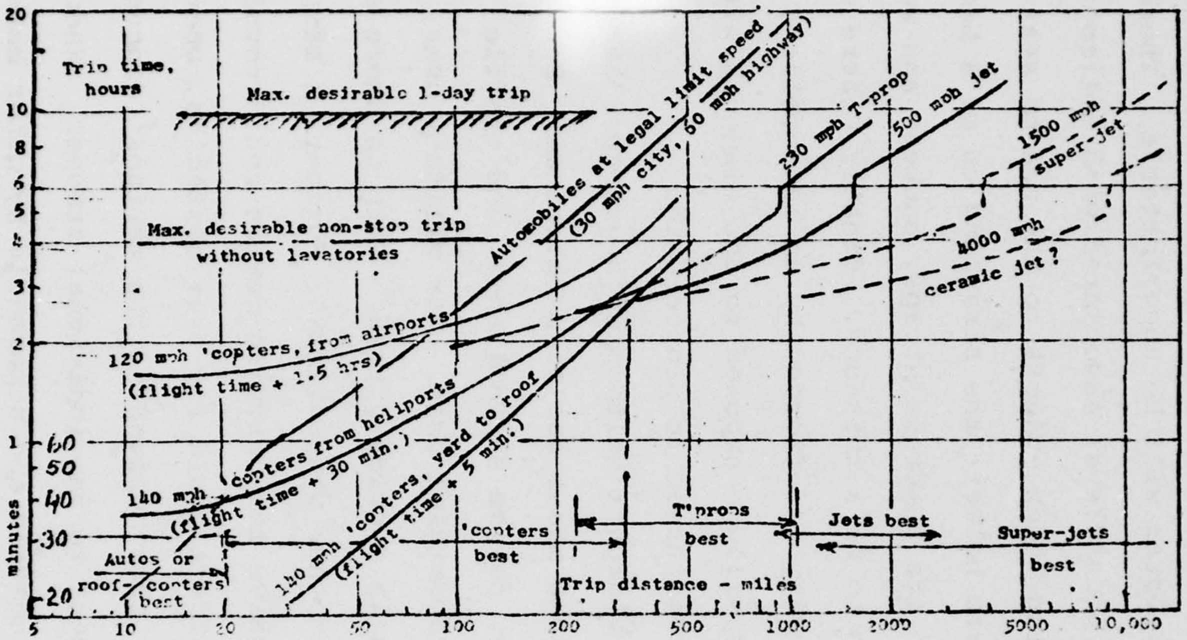


Figure 1
Comparison of trip times for various distances and vehicles. (reprinted from Aerospace Vehicle Design, Vol I. Aircraft Design by K. O. Wood; Johnson Publishing Co., Colorado; P. 64)

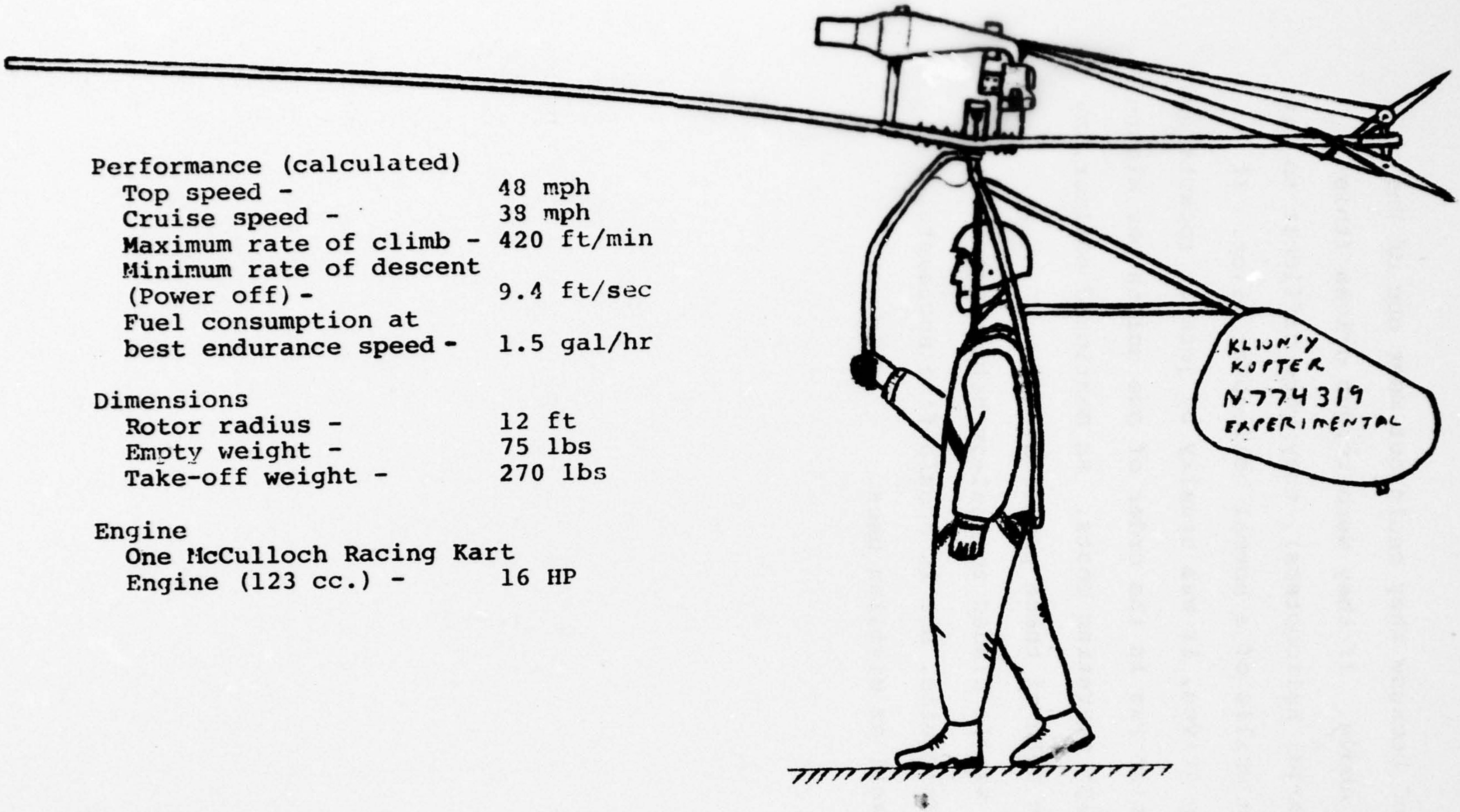
torque driven helicopter requires up to 200 hours of flight training.

A backpack helicopter will be uncomfortable. There is an inherently high noise level associated with helicopters. Further, for a nation which objects to the use of seat belts and motor cycle helmets, the strapping on of a backpack helicopter with its numerous straps, buckets and webs will certainly seem to be a nuisance. Finally, there will be no sense of security as afforded by an automobile's interior, the pilot will be exposed to the elements with no shell or fixed references to protect him.

Utility is the backpack helicopter's greatest asset. It can be used as cheap means for reconnaissance. Power and pipe line survey, police surveillance, and traffic monitoring are all commercial uses. For military uses, reconnaissance is again a primary task. Ship to shore movement of Marines is another possibility. Further, a simple, easy to fly, inexpensive man-carrying device could revolutionize warfare. Solders could fly over obstacles, whether man-made or natural, thus, expanding the marines' concept of vertical envelopment to the individual trooper. Wherever the terrain is hostile and unpassable by other means of transportation the backpack helicopter is a possible substitute.

In the appendix of this paper is a historical section. Included are all backpack helicopters built. These helicopters failed because they could not meet one of the requirements above. If they were torque driven (this includes co-axial helicopters), they were difficult to fly, requiring the skills of a normal helicopter pilot. If they were tip driven, it was usually by jets or rockets and fuel consumption was in the order of one gallon per minute. This meant high operating costs. As mentioned earlier, my design avoids both of these problems.

Thus, a single bladed torqueless helicopter won't replace an automobile, but it should find successful military as well as civilian uses.



Performance (calculated)	
Top speed -	48 mph
Cruise speed -	38 mph
Maximum rate of climb -	420 ft/min
Minimum rate of descent (Power off) -	9.4 ft/sec
Fuel consumption at best endurance speed -	1.5 gal/hr
Dimensions	
Rotor radius -	12 ft
Empty weight -	75 lbs
Take-off weight -	270 lbs
Engine	
One McCulloch Racing Kart Engine (123 cc.) -	16 HP

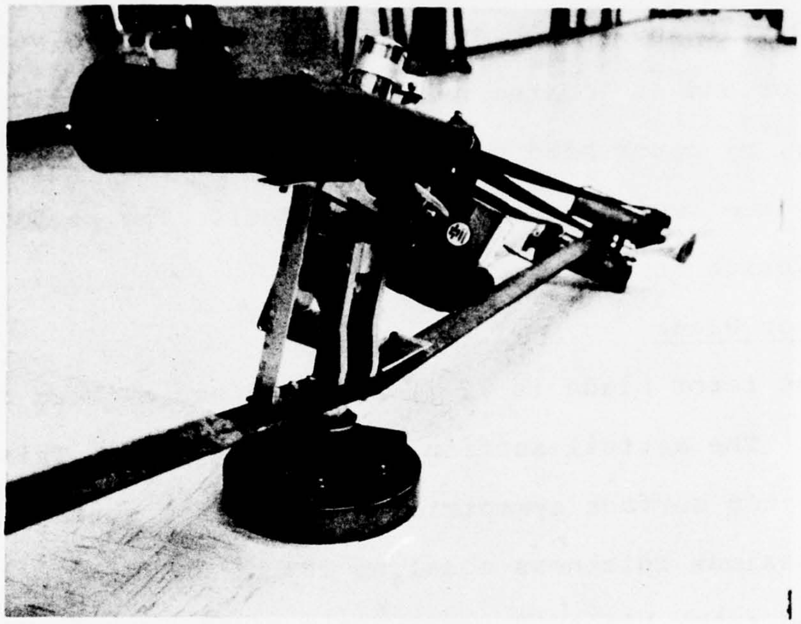


Photo 2 - Rotor mounted on rotor stand plate. In foreground is part of the rotor blade. Seen in the middle is the rotor head, engine, and tuned exhaust system. In the background is the timing belts, propeller mounts, and propellers.

General Description

My single bladed torqueless helicopter has several major components. A single rotor blade is counterbalanced by a spar supporting two counter rotating propellers. A reciprocating engine drives these propellers using a timing belt power transmission system. The engine revolves with the rotor and is located near the center of rotation. Finally, my rotor head provides automatic collective control. (see design section, rotor head). The performance of my design is listed on page 10.

The Rotor Blade

The rotor blade is 12 ft long and has a chord of 10 inches. The airfoil section is the NACA 0012. This section has the top surface symmetric to the bottom surface and it has a maximum thickness equal to 12% of chord.

The rotor blade is constructed of three materials: common aircraft streamline tubing, polyurethane foam and fiberglass cloth. The aircraft streamline tubing is 1 3/4 inches in equivalent diameter and is used as the leading edge of the rotor blade as well as the main load-carrying member. Polyurethane foam is glued to the streamline tubing to form the body of the rotor blade. The foam is formed by using a table saw. Repeated parallel cuts are made along the length of the foam; the depth of the cuts is adjusted to form the outline of the airfoil section. (Photo 3). The foam is sanded down to the proper airfoil

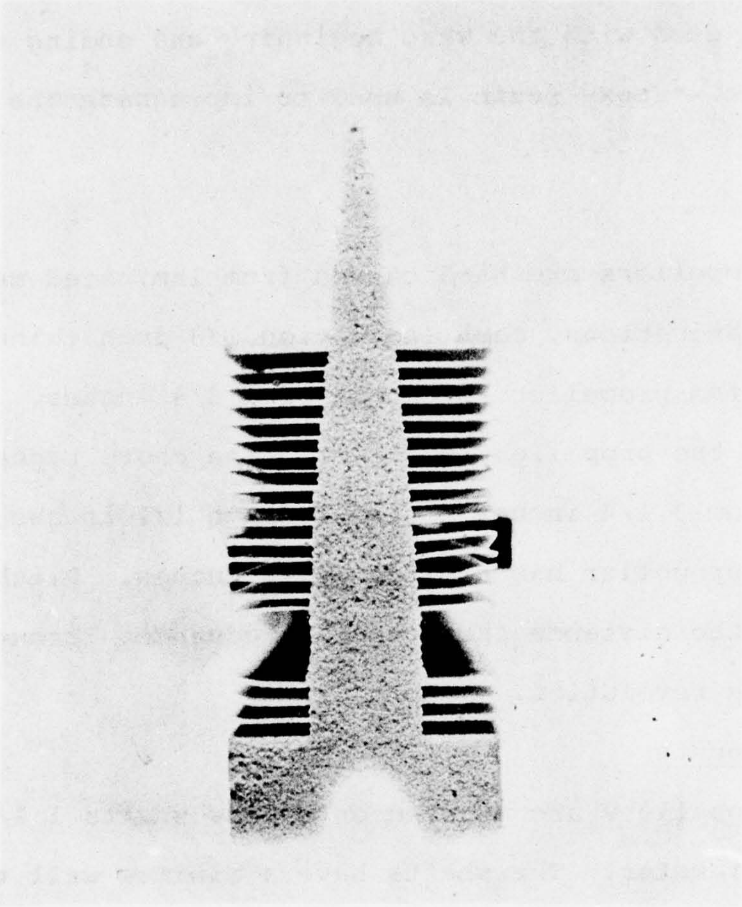


Photo 3 - Sample of foam after cuts have been made with table saw. The trailing edge has been sanded down.

section by using cuts as a guide. Fiberglass cloth covers the rotor blade. This gives support to the foam and provides the blade with a smooth, hard surface. Only one layer of cloth is used with the wrap beginning and ending at the leading edge. Epoxy resin is used to impregnate the cloth. (Photo 4).

Propellers

The propellers are hand carved from laminated maple. I used 14 laminations, each lamination 1/8 inch thick to give a maximum propeller thickness of 1 3/4 inches. The diameter of the propeller is 2 feet. The chord tapers linearly from 3 1/4 inches at the root to 1/2 inches at the tip. Each propeller has a pitch of 15 inches. Pitch is defined as the distance the propeller advances through the air for each revolution. (Photo 5).

Propeller Mounts

The propellers are mounted on hollow shafts 1 1/4 inches in diameter. The shafts have a minimum wall thickness of 1/8 inch. Constructed of steel,the shafts run in extra light series ball bearings (Type 3L07). These bearings are mounted 6 inches apart in a light-weight aluminum housing. The housing is attached to the spar through a short section of 2-inch square aluminum extrusion. (Photo 6).

Reciprocating Engine

A fan-cooled, single cylinder, two-stroke McCulloch

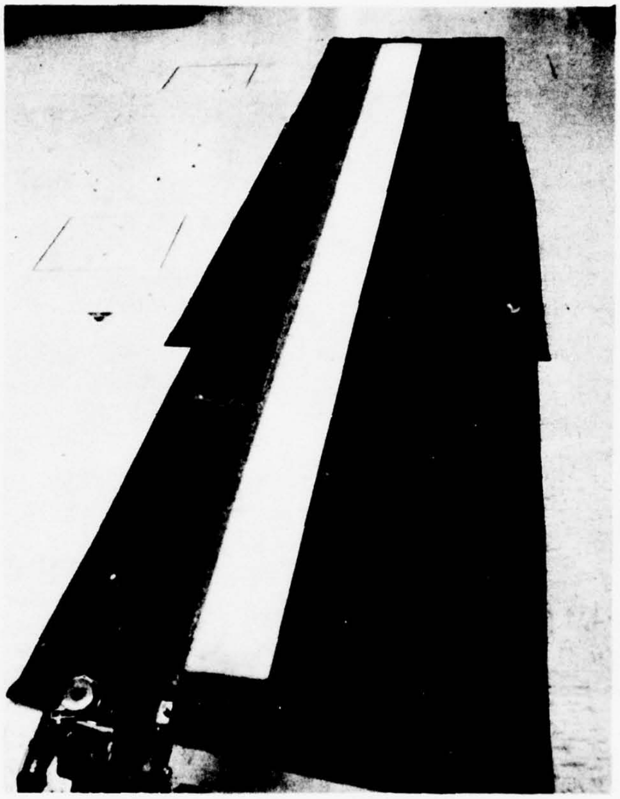


Photo 4 - Rotor Blade

Note streamline steel tubing leading edge, foam body.

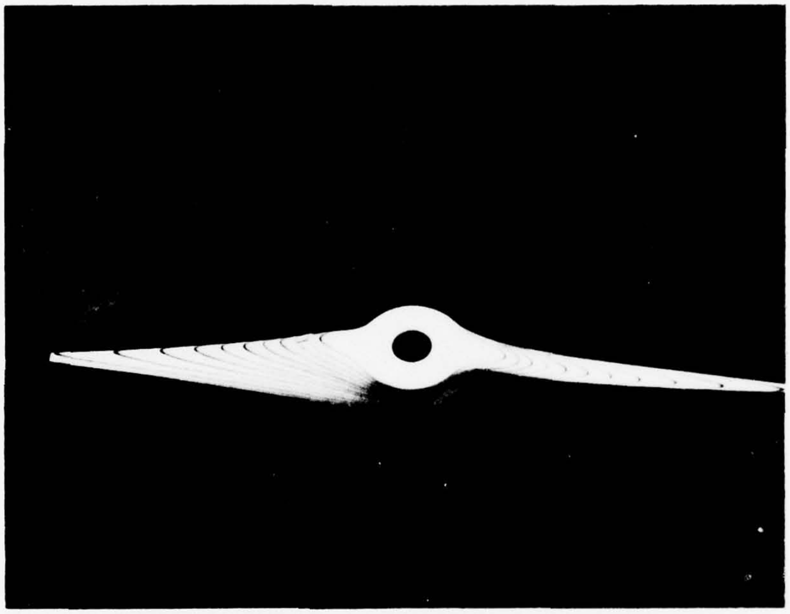


Photo 5 - Propeller
Note the Lamination Lines

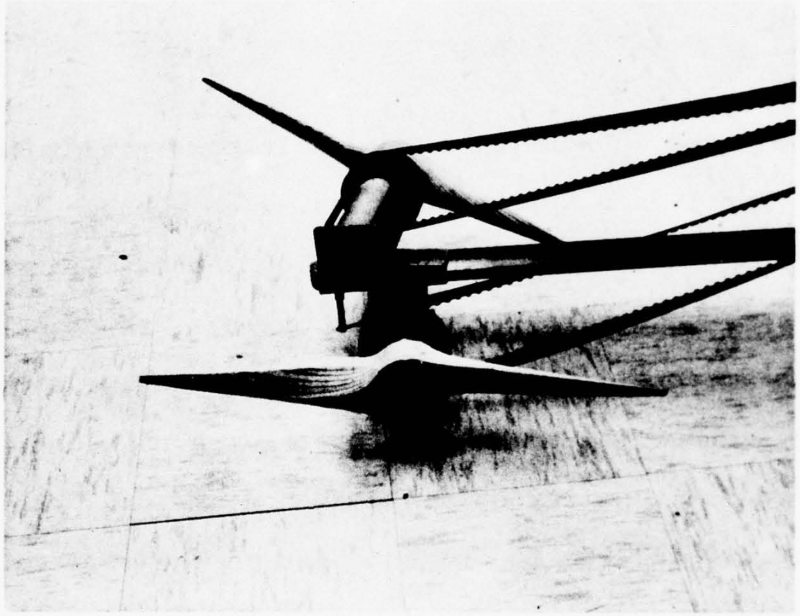


Photo 6 - Propeller
Mounts. Propeller in foreground is incomplete.

101B racing kart engine is used. This engine burns a mixture of gasoline and oil supplied from a small 8 Oz. fuel tank. A special Hartmen Enduro tuned exhaust provides 35% more power. The engine is attached to the rotor head by using an aluminum engine mount. It is mounted in such a way that the center of rotation of the rotor passes through the carburetor and the power take-off shaft is vertical. (Photo 7).

Power Transmission

I selected a Uniroyal timing belt power transmission system. Two 1-inch H-section belts, with a pitch length (the circumference of the belt) of 100 inches, transmit the power. Two power-grip timing belt pulleys are attached to engine power take-off shaft. These pulleys have a diameter of 3.183 inches; the propeller shafts each have one power-grip timing belt pulley of 4.456 inch diameter. The timing belts are twisted 90° in order to fit on the vertically mounted engine shaft and the horizontally mounted propeller shafts. (Photo 8).

Rotor Head

The rotor head has three major moving parts. The thrust bearing for the axis of rotation is provided by using the rotor head off of the prototype of the Kaman Lifesaver Ejection Seat. The other two moving parts are journal bearings for the feathering and flapping axis. These are just plain bearings (i.e., no balls or Needle bearings used). The

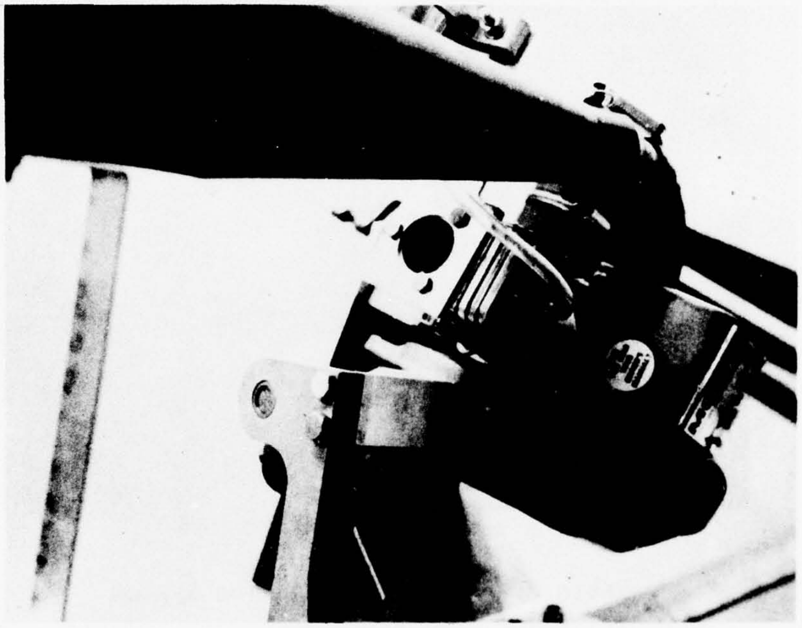


Photo 7 - Engine. Note carburetor location over the center of rotation. Engine shaft is vertical. Object across top of picture is tuned exhaust.

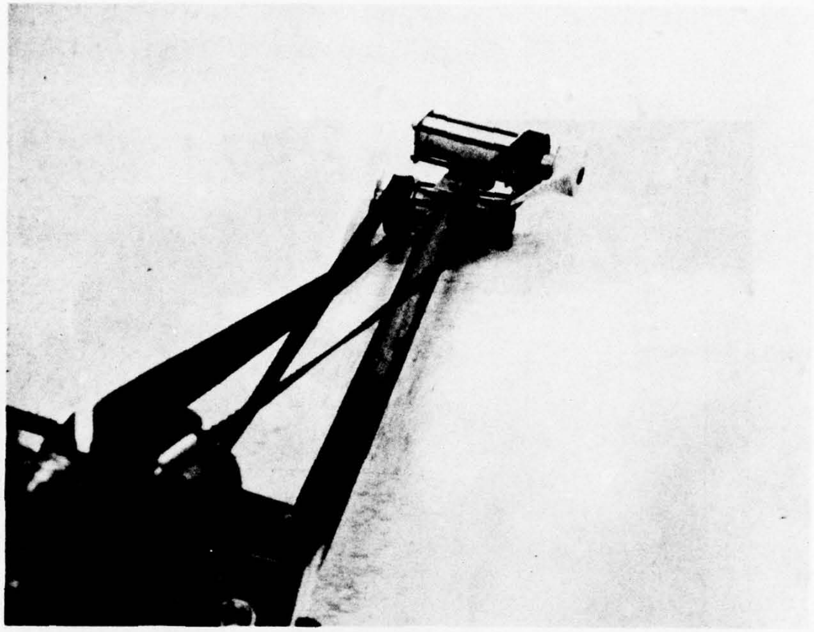


Photo 8 - Power Transmission System

Note 90° twist of belts. Belt on right side is twisted clockwise; belt on left side counter-clockwise rotor head is attached to the aircraft streamline tubing. This tubing is continuous and acts as both the leading edge of the rotor blade and the spar which supports the propellers. Continuity is provided by off-setting the spar to one side of the rotor spindle. (Photo 10)

Fuselage

(See design section)

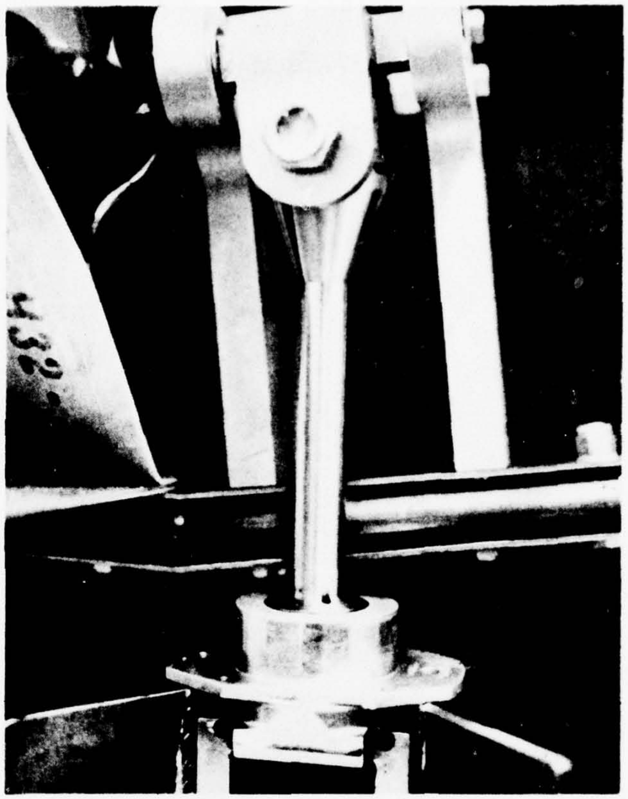


Photo 10 - Rotor Head

At the bottom of this picture is the thrust bearing for the axis of rotation. At the top are the bearings for the flapping and feathering axes. Note how spar passes to one side of the rotor spindle (center of the picture).

Design

This section of the paper describes the design problems encountered in my helicopter and their solutions.

Gross Weight

The first step in design is to estimate gross weight, that is the total weight the helicopter will have to lift. Research indicates that back pack helicopters without pilots have weighed between 40 lbs to 110 lbs. I weight 175 lbs. This means a total gross weight of 215 to 285 lbs is possible. Early in September I estimated 270 lbs as the gross weight of my aircraft. (See the appendix for the weight breakdown). This means my aircraft is capable of carrying 185% of its own weight. Most conventional helicopters are capable of carrying only 40% of their own weight.

Disc Loading

After estimating the gross weight of the aircraft, I was then able to estimate the disc loading. Disc loading is the ratio of the aircraft weight divided by the disc area of the rotor. This is analogous to the wing loading of an airplane. The disc loading of a helicopter is very important: it has a direct effect on performance and is interrelated with other design considerations. Since the gross weight was fixed, disc loading could be changed only by varying the rotor radius.

Of the many considerations favoring a low disc loading (i.e., a large rotor radius), the power required to hover is probably the most important. Power required is directly proportional to disc loading. The larger the rotor radius the smaller amount of power required to hover. Increased propeller efficiency is an additional benefit of a large rotor radius. The propeller efficiency increases as the propeller placement moves from the center of rotation. To keep the rotor balanced, the propeller must be placed further from the center of rotation as the rotor diameter is increased. Thus, propeller efficiency increases with increasing rotor radius. Both of these effects, decreased power required and increased propeller efficiency, allow a smaller engine to be used. This is important; small engines weigh little and burn small amounts of fuel. Finally, in the event of engine failure, the helicopter will descend in autorotation. The minimum vertical descent velocity and minimum landing speed are both directly proportional to the rotor radius. The larger the diameter, the slower the rate of descent, and the slower the landing speed. Since my legs will be acting as the landing gear, this is important.

The major disadvantage of a large diameter rotor may be its unwieldiness for ground landing. Thus, I may trip or fall easier. This can be disastrous. Finally, the weight of a large diameter rotor tends to counter the advantages of a small engine.

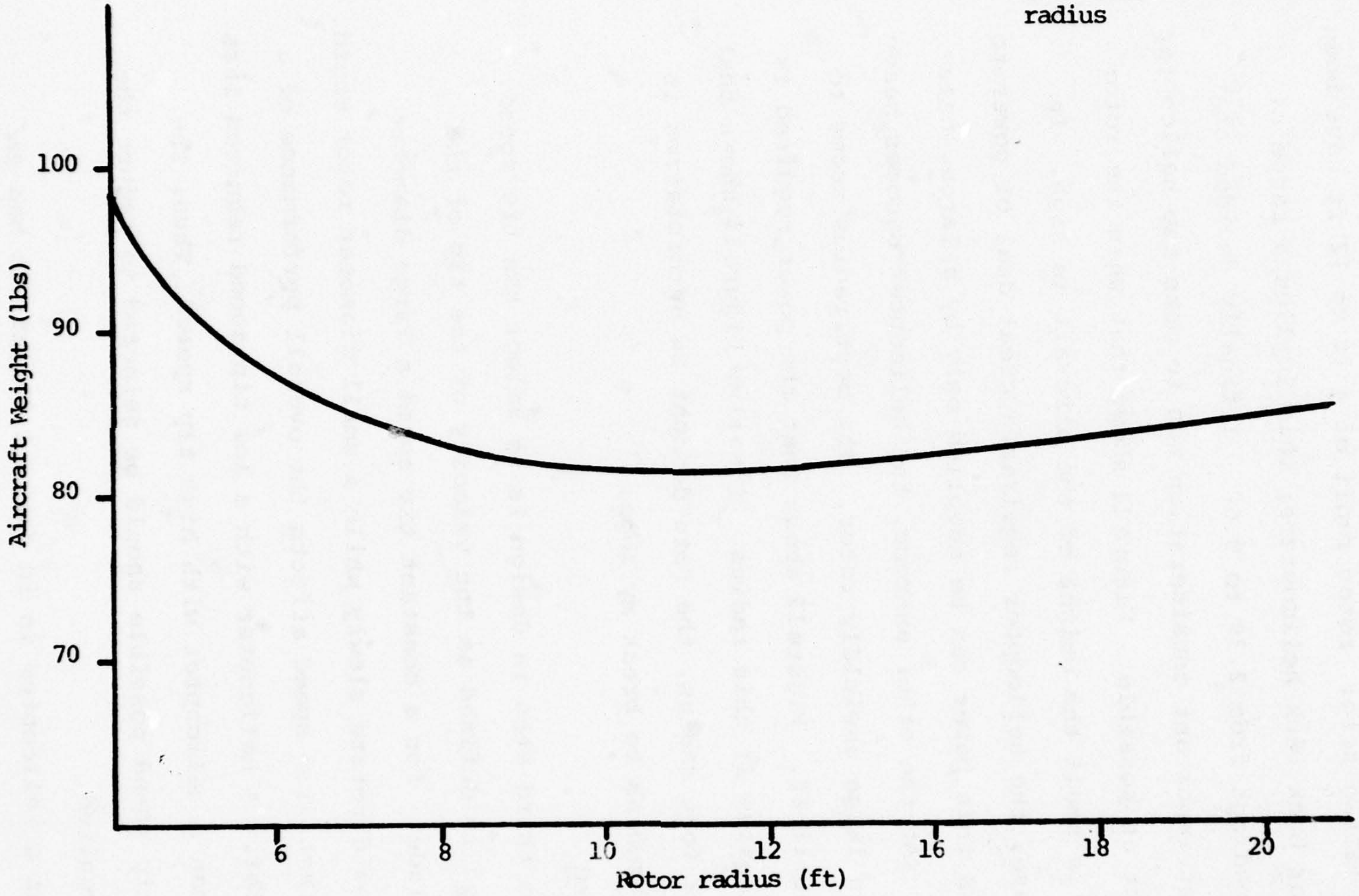
Since these factors are interrelated, it was very difficult to select the disc loading. Historical research was of little help: rotor radii of 6 ft to 12 ft have been used for back pack helicopters; this implies a range of disc loadings from 2.39 to 0.60. I finally decided that the most important consideration was to make the helicopter as light as possible. Figure 11 shows that when the rotor radius is small the weight of the aircraft is high. In this case, the helicopter requires a great deal of power to fly, and this power can be supplied only by a large, heavy engine. At the other extreme, the helicopter becomes heavy due to a large unwieldly rotor. The best radius seems to be about 12 ft. Figure 12 shows that the power required is not excessive at this radius. Finally, Figure 13 shows that for a 12 foot radius, the rate descent in autorotation is not so high as to break my legs.

Tip Speed

The third step in design is to select the tip speed. Tip speed is defined as the velocity of the tip of the rotor blade. For a constant tip speed a large diameter rotor would rotate slowly while a small diameter rotor would rotate fast. Tip speed affects the overall performance of a helicopter. A helicopter with a low tip speed requires less power than a helicopter with high tip speed. Thus, the lowest tip speed possible should be selected to reduce the power required.

When a helicopter is in forward flight, it has an

Fig. 11
Estimated Gross Weight as a function of rotor radius



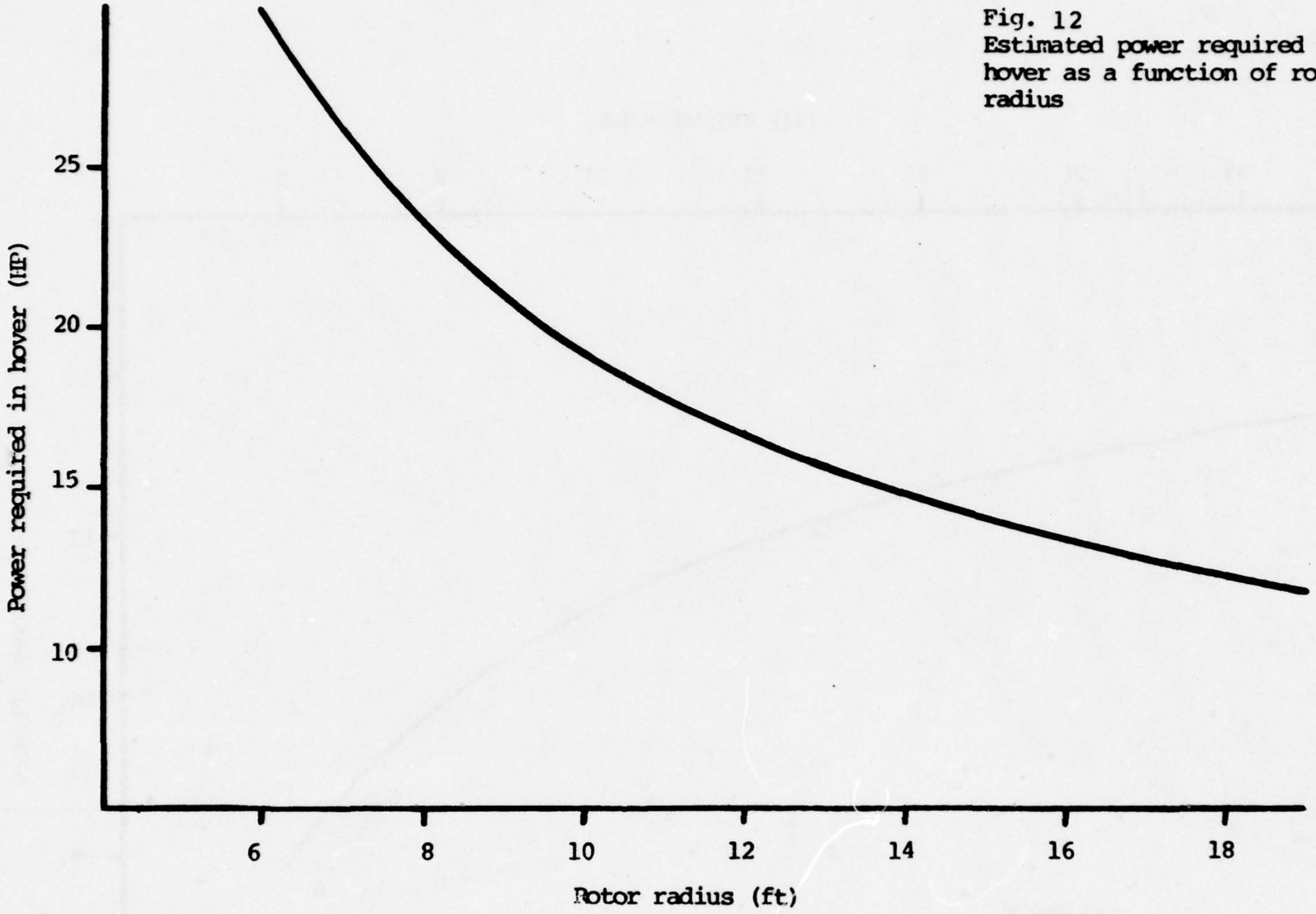


Fig. 12
Estimated power required in hover as a function of rotor radius

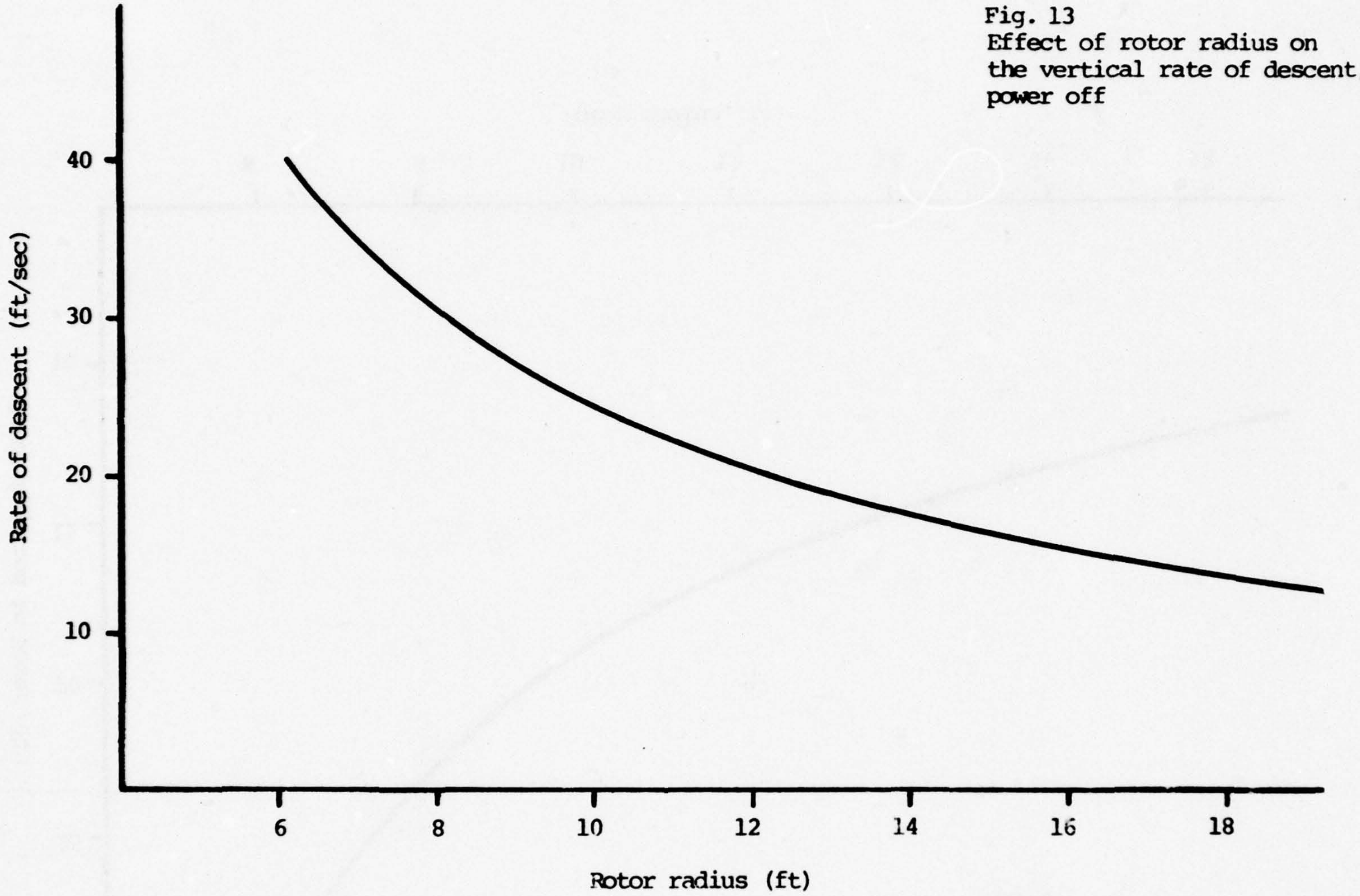


Fig. 13
Effect of rotor radius on the vertical rate of descent, power off

advancing blade and retreating blade. The velocity over these blades is different. (see Figure 14). Historically this difference in velocity has been used to select tip speed. A low tip speed is required to avoid compressibility drag rise on the advancing blade tip. Compressibility drag rise is a sudden increase in blade drag as the speed of sound is approached. At the other extreme, a high tip speed is required to delay retreating blade tip stall. This stall occurs only at high forward flight speeds when the difference between the blade rotation speed and the aircraft speed is small. These two effects, however, only become noticeable at aircraft speeds on the order of 200 mph. Research and performance calculations indicate speeds of only 50 mph are obtainable by back-pack helicopters. Thus, some other selection criteria must be used to determine blade tip speed.

The retreating blade experiences an additional effect. This is reversed flow near the root. When this reversal flow region covers 25% of the inner rotor radius, roughness in flight will be encountered. Setting reverse flow to 25%, in conjunction with the chosen value of 12 ft for the radius and the calculated top speed of 50 mph, is sufficient information to calculate tip speed. The calculated value is 300 ft/sec.

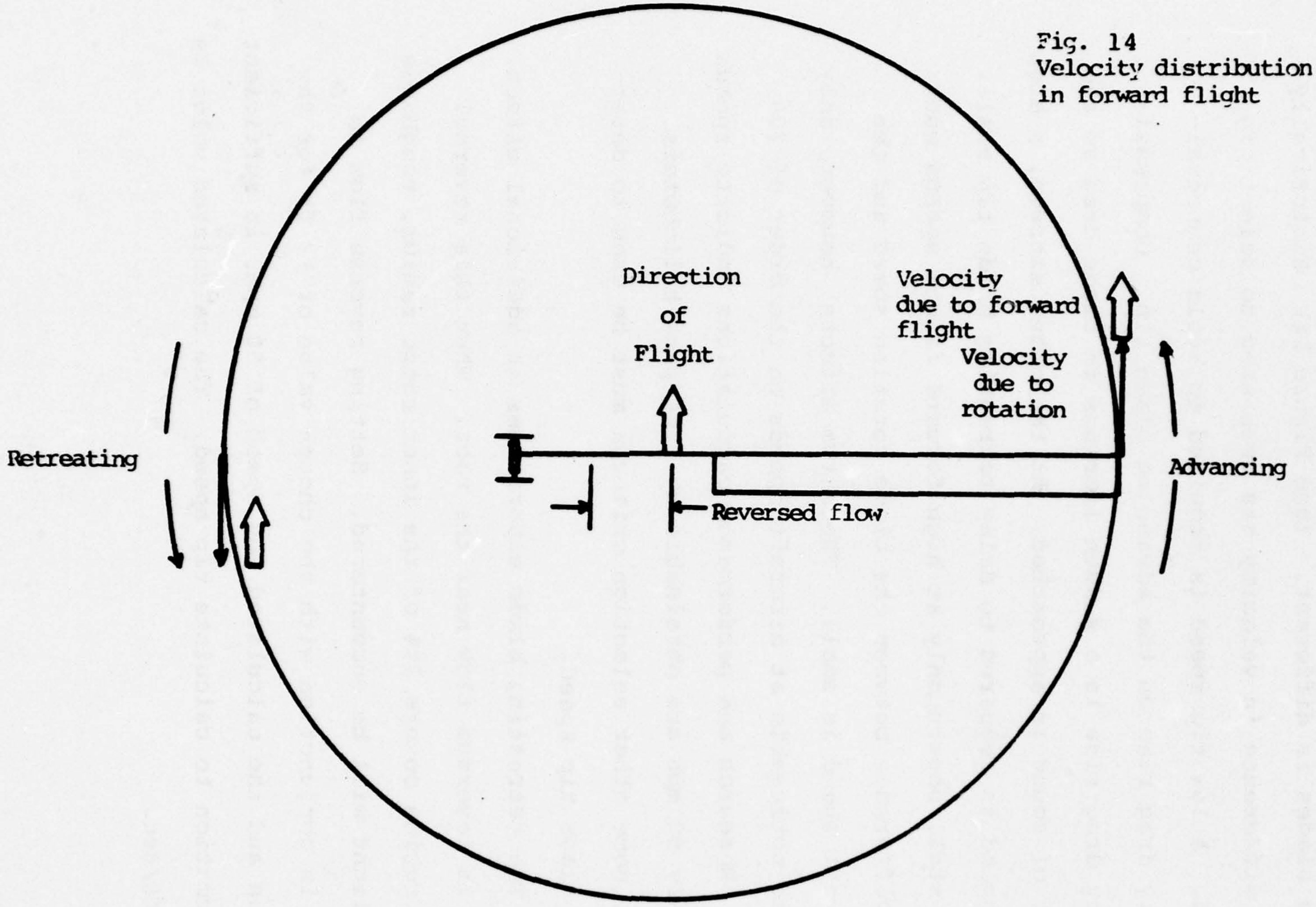


Fig. 14
Velocity distribution
in forward flight

Airfoil Selection

Airfoil selection was straightforward. I selected the NACA 0012 airfoil section. It is a symmetric section having a maximum thickness equal to 12% of chordwise (leading edge to trailing edge) length. Until just recently, the NACA 0012 or similar type airfoils have been used exclusively in helicopter rotor blades.

Efficiency

The final step before making routine calculations is to estimate efficiency. Efficiency is defined as the rotor power required divided by the engine power provided. Less than 100% efficiency results from propeller losses, hub rotational drag, and rotor tip losses. By calculating the theoretical power required by the Bensen B-4 and several Nagler and Rotz's helicopters, and comparing this to the actual power required, I was able to estimate efficiency. The lowest efficiency estimated was 54%. To allow for unexpected losses, I assumed the efficiency of my helicopter would be 50%.

Other Design Criteria

At this point all other aerodynamic calculations are routine. The selection of gross weight, disc loading, tip speed, airfoil section, and efficiency, have fixed all of the other design quantities. Briefly they are:

Chord - 10 in.

θ_{tip}-10.7° (the angle the blade tip makes with path of the blade tip)

Hover power required - 14 hp.

β-9.3° (coning angle, the angle the rotor blade makes with the plane of rotation. This is analogous to dihedral angle of wing. A rotor blade is held outward by centrifugal force and is deflected upward by blade lift).

Engine Selection

After aerodynamic considerations have been completed the engine may be chosen. There are several factors to consider when selecting an engine: fuel consumption, engine weight per horsepower, and total power available.

I chose a reciprocating engine over a jet or rocket engine because of its low fuel consumption. Jets and rockets become efficient only when they are moving through the air at high speeds, (in the order of 400 mph). This speed is not obtained by the helicopter propellers as they rotate about the rotor's center.

Figure 11, which is an adaptation of Figure 15, best shows the effects of engine weight per horsepower (k_e). It is simply the total engine weight divided by the maximum power available from the engine. For example, a 20 pound engine which produces 10 horsepower has a k_e of 2. A large k_e makes the helicopter too heavy for two reasons. First, the optimum rotor radius becomes larger as k_e increases: a large diameter rotor will be heavier than a small diameter rotor. Second, a large k_e means the engine itself will be

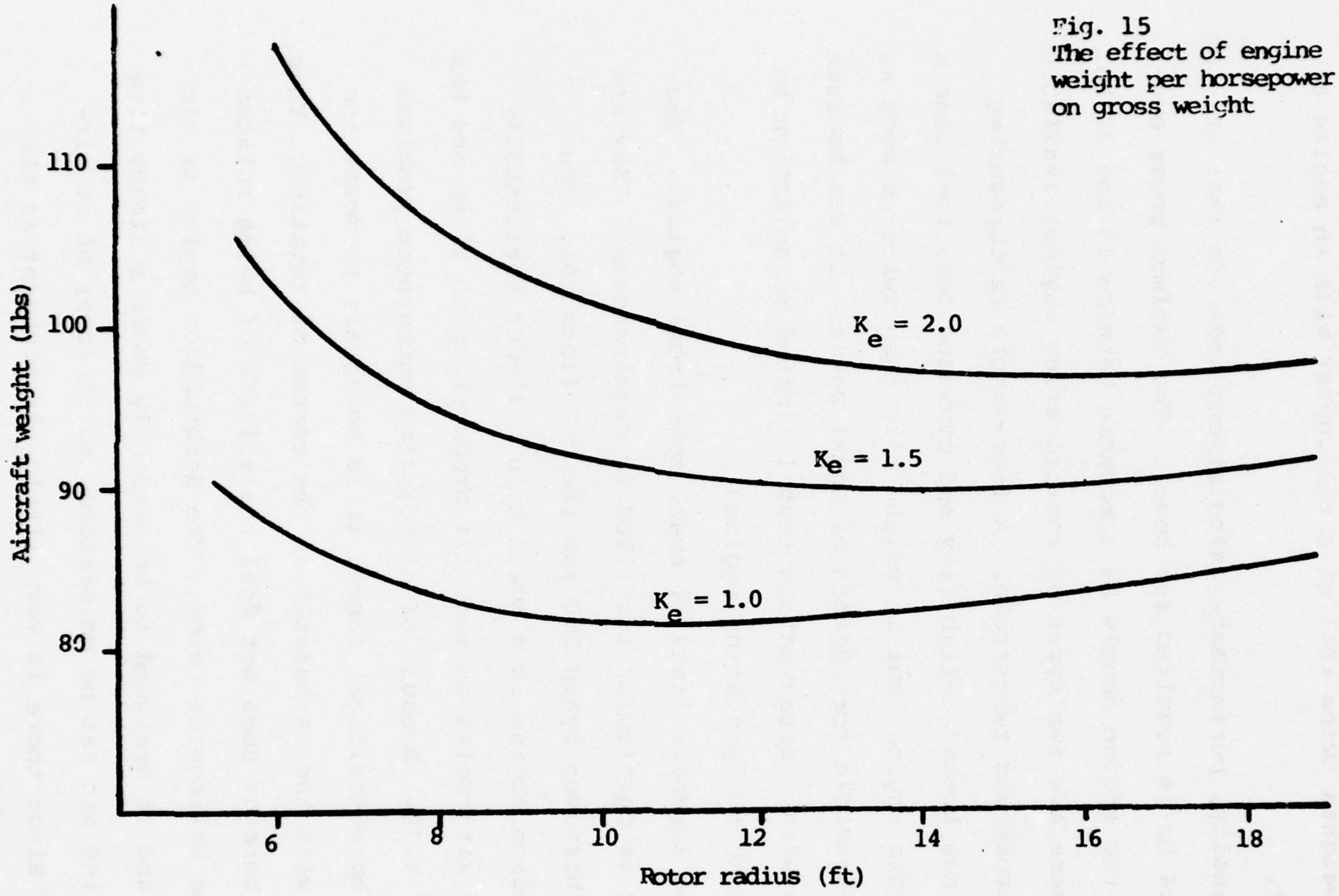


Fig. 15
The effect of engine weight per horsepower (K_e) on gross weight

heavier. A helicopter with a k_e of 2 will have an engine which weights twice that of a helicopter with an engine of k_e of 1.

Finally, performance calculations indicate that at least 14 hp is required for hover. The maximum power output of the engine should be somewhere between 14 and 20 hp.

There are two types of reciprocating engines available, four-stroke and two-stroke. A four-stroke reciprocating engine has better reliability and consumes less fuel than a two-stroke engine, but it weighs more than twice as much as as a two-stroke for engines of equal power. It was because of this weight disadvantage that I limited my selection to two-stroke reciprocating engines.

The appendix lists 31 small two-stroke engines. Two engines in particular fulfilled my requirements. They are the Herbrandson Dynad 280 and the McCulloch 101. The Herbrandson engine is a small twin cylinder horizontally opposed air-cooled engine. It produces up to 20 hp and has a k_e of 0.78. Because of anticipated carburetor problems caused by centrifugal force, it is necessary to mount the engine with the carburetor at the center of rotation. Thus, the carburetor does not feel the effects of being rotated with the helicopter rotor. The Herbrandson engine is air cooled and is designed to be used only where a steady flow of cooling air can be maintained, as in front of an airplane. Since there is very little air movement at the center of the rotor, the Herbrandson engine would tend to overheat. I selected the other engine, the McCulloch 101, a single cylinder, fan cooled engine. Since the McCulloch is fan cooled, it can be operated for long periods of time without fear of overheating. Normally it can provide only 13 hp and it has a k_e of 1.0. Thus, the McCulloch is underpowered. Fortunately, the power of any small two stroke engine can be increased by about 35% through the use of off-the-shelf exhaust tuning. Special fuels add 10% to the power. In all the power of the McCulloch can be boosted to over 18 hp.

Power Transmission

My design required a power transmission system. The engine is located at the center of rotation of the helicopter rotor so as to avoid carburetor problems. Two counterrotating propellers are located 4.1 feet away. A power transmission system must be used to transmit the power from the engine to the propellers.

There are several principle requirements for the power transmission system. First, it must provide for counterrotation of the propellers. In order to have their gyroscopic precession cancelled, one propeller must turn clockwise while the other propeller turns counter-clockwise. Further, the power transmission system must have a wide speed range, capable of accepting the McCulloch's output of 9500 rpm. Finally, it must be light in weight, simple, and available 'off-the shelf.'

Several power transmission systems were considered. This includes V-Belts, chain drives, stock gears with axle power transmission, flat belts, and timing belt drives. The requirement for a speed range up to 9500 rpm eliminated all the available systems but one. A timing belt power transmission system is the only system capable of operating at this speed. The closest competing system was V-Belts which are capable of accepting 5000 rpm.

Counter rotation of the propellers is provided by mounting the McCulloch engine with the power take-off shaft vertical. The two timing belts are each twisted 90° so that they can fit onto horizontally mounted propeller shafts. Counter-rotation is caused by twisting one belt 90° clockwise and the other 90° counter-clockwise.

I had difficulty in selecting the speed reduction of the power transmission system. Speed reduction is defined as the ratio of engine rpm to propeller rpm. The major consideration in chosing speed reduction is propeller efficiency. Propeller efficiency can be increased in two ways, by reducing propeller speed or by increasing the propeller placement distance (the distance between the propeller shafts and the rotor's center of rotation). These two methods conflict with each other. Reducing propeller speed calls for a large diameter pulley to be used at the propeller shaft. Large diameter pulleys weight more than small diameter pulleys. Increasing propeller placement distance requires the pulleys to be light in weight. The pulleys, in conjunction with the propellers, propeller shafts, bearings, and bearing holders balance the rotor blade. Thus, large diameter pulleys would mean a small propeller placement distance. The best compromise seems to be about 4.1 ft for the propeller placement distance and 1.3 for the speed reduction. This means the propeller efficiency is 59% and the propeller speed is 7300 rpm. Propeller efficiency needs to be higher and propeller speed should be lower. All other combinations, however, gave poorer results. The only other solutions were to increase the rotor blade weight or to decrease engine speed. Increased rotor blade weight would allow the propeller placement distance to be increased. The rotor blade balances the propeller, pulleys, etc., Since one of the major objectives is light gross weight, this is not a good solution. As for the other possibility, I had no control over engine design, therefore it was impossible to reduce engine speed. Using the specifications of 1.3 speed reduction and 4.1 ft propeller placement distance, I designed the timing drive power transmission using completely off the shelf components.

Propeller Design

The propellers were the most difficult parts to design. Propellers in helicopter rotors face several severe conditions not encountered in normal propeller operation. Also, there are several problems associated with counter-rotating propeller design.

The greatest problem is caused by gyroscopic precession. The propellers can be considered as gyroscopes. Since they are spinning about their own axis and are also rotating about the rotor's center they are subject to gyroscopic precession. This gyroscopic force acts at right angles to the direction of the rotation. If only a single propeller is used, an unbalanced moment is transmitted to the fuselage. Two propellers, one rotating counter to the other are required to cancel this gyroscopic precession.

These gyroscopic forces subject the propeller blades to an alternating bending stress. This means the propeller blades are being bent forward and then backward as they complete each revolution about the propeller axis. This type of stress is normally encountered in conventional aircraft propellers at magnitudes only one hundredth as great as found in my propeller. Since the material inboard must support the gyroscopic stresses caused by the material out toward the tip, the propeller blades are tapered from the root to the tip. This reduces the stress the inboard sections of the blade must support.

Counter rotation of propellers requires special consideration. It is customary to design each propeller as a single rotating propeller and then use them as a counter rotating propellers. This yields less than optimum results. Since each propeller is operating in the other's wake, allowances for the wake's effect on twist and chord distribution must be made. I was able to do this by using an advanced theory developed by Theodorsen (see NACA Report Number 924).

Forward flight causes a reduction in propeller efficiency. The propellers experience the same effects as do advancing and retreating rotor blades (see Figure 14). The airspeed of the propellers undergo a cyclic variation in airspeed: for an aircraft airspeed of 50 mph the propellers have an airspeed of 120 mph on the advancing side and an airspeed of 20 mph on the retreating side. For a fixed pitch propeller it is impossible to produce a design which will operate efficiently throughout this entire speed range. For a far more complicated constant-speed propeller, or one in which the blade angle may be varied, efficient operation is possible for speed ranges as great as 150 mph. This still limits aircraft speed to 75 mph. To keep my design simple, I used fixed pitch propellers. This means my aircraft top speed may be limited by propeller losses.

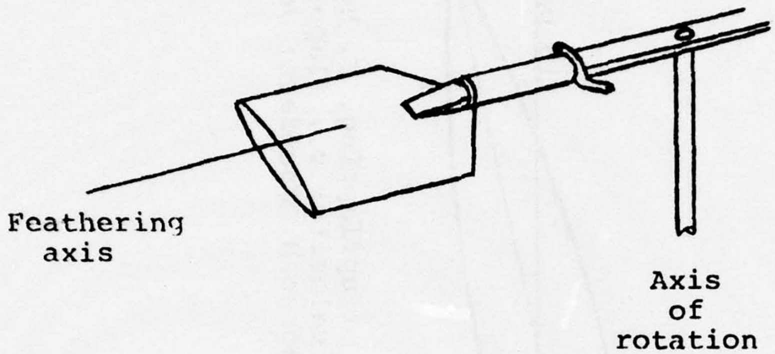
Rotor Head

The rotor head is probably the most complex part of the helicopter. It must provide for the rotation of the rotor, for blade flapping and for blade pitch changes. I experimented with three different types of rotor heads.

All helicopter rotor heads must provide for the rotation of the rotor. This means a shaft must be provided for the rotor blade to rotate around. Since my helicopter is torqueless, a simple thrust bearing may be used to mount the rotor shaft on. Torqueless means that no torque is transmitted to the helicopter's fuselage or body. This allows a simple fin instead of an anti-torque tail rotor to be used with the fuselage.

A helicopter rotor head must be able to accommodate for the dissymmetry of lift in forward flight. Figure 14 illustrates that the velocity over the rotor blades is different for the advancing and retreating side. For a fixed blade pitch, a large difference in lift between the advancing and retreating sides will exist because of this velocity differance. The solution is to somehow reduce the angle of attack on the advancing blade and increase it on the retreating blade, thus correcting for velocity asymmetry. There are two methods normally used to accomplish this. In what is know as a rigid rotor, the blade pitch is reduced on the advancing side and increased on the retreating side. (see Figure 16). The vast majority of conventional helicopters use what is known as flapping, however. In a flapping blade, the rotor is hinged so that it may flap up on the advancing side in response to the increased lift. (Figure 16 illustrates a simple type of flapping rotor, a teetering rotor). On the retreating side the blade flaps down in response to the decreased lift on that side. Figure 17 shows that for the advancing side, as a

Rigid Rotor



Teetering rotor

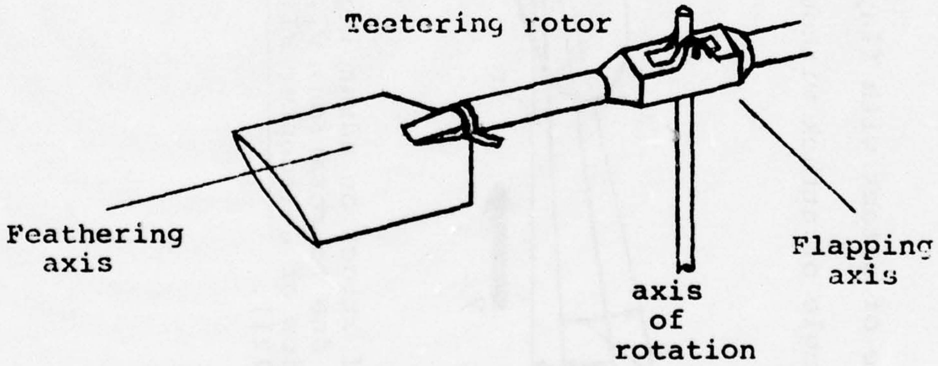


Figure 16

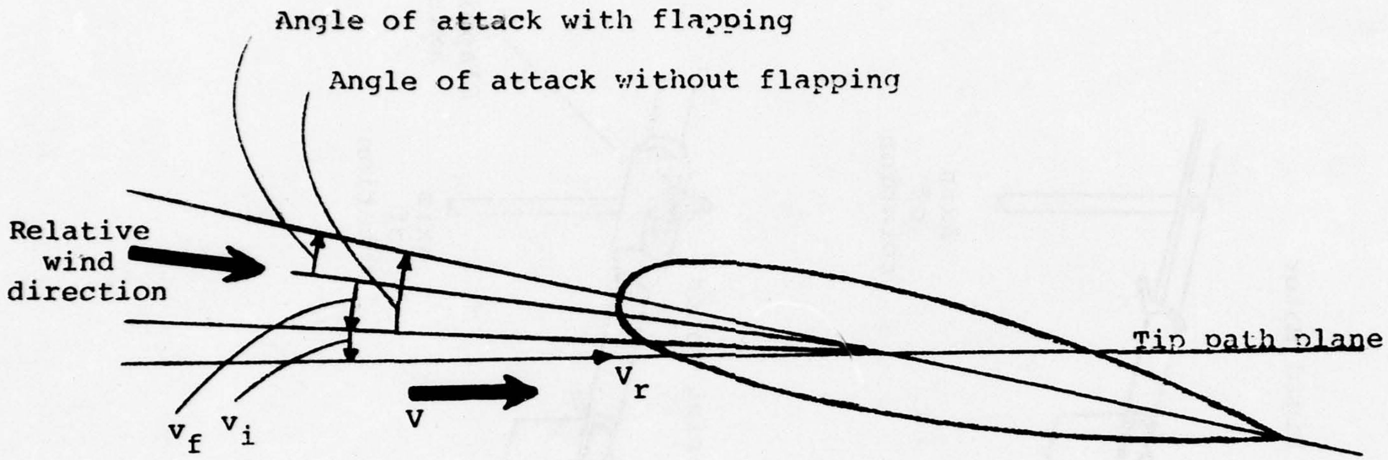


Figure 17
Decrease in angle of attack on advancing because of upflapping. V, helicopter forward speed; V_r, velocity due to rotation; v_i, induced velocity; v_f, flapping velocity. (Redrawn from Dynamics of Helicopter Flight by George H. Saunders; John Wiley & Sons Inc., New York; p. 121).

result of the additional upward flapping velocity the angle of attack is decreased. This decreases the lift generated on the advancing side. A similar increase in angle of attack on the retreating side is accomplished by allowing the blade to flap down. Thus, when compared to zero flapping, up flapping decreases lift and down flapping increases lift.

As an additional requirement, the rotor head must provide for a means of varying the rotor lift. Two methods may be used. The first involves holding the blade pitch fixed and varying the rotor speed. For this method there is approximately a 2% increase in thrust for each 1% increase in rotor rpm. The other method involves holding the rotor rpm constant and varying the blade pitch. This is known as blade pitch feathering. This method has the advantage of immediate response, there being no delay as the rotor accelerates or deccelerates to a new rotor speed. A combination of the above two method may be used, i.e. rotor speed and blade pitch may both be increased in order to increase blade lift. A helicopter is capable of a safe descent much like that of the seed of a maple tree. This power off descent is known as autorotation and can occur only if the rotor blade pitch is at the corect setting. Thus, regardless of which method is used, in the event of engine failure the blade pitch must be decreased to an autorotative setting of about 2° from the normal in flight setting of 8°

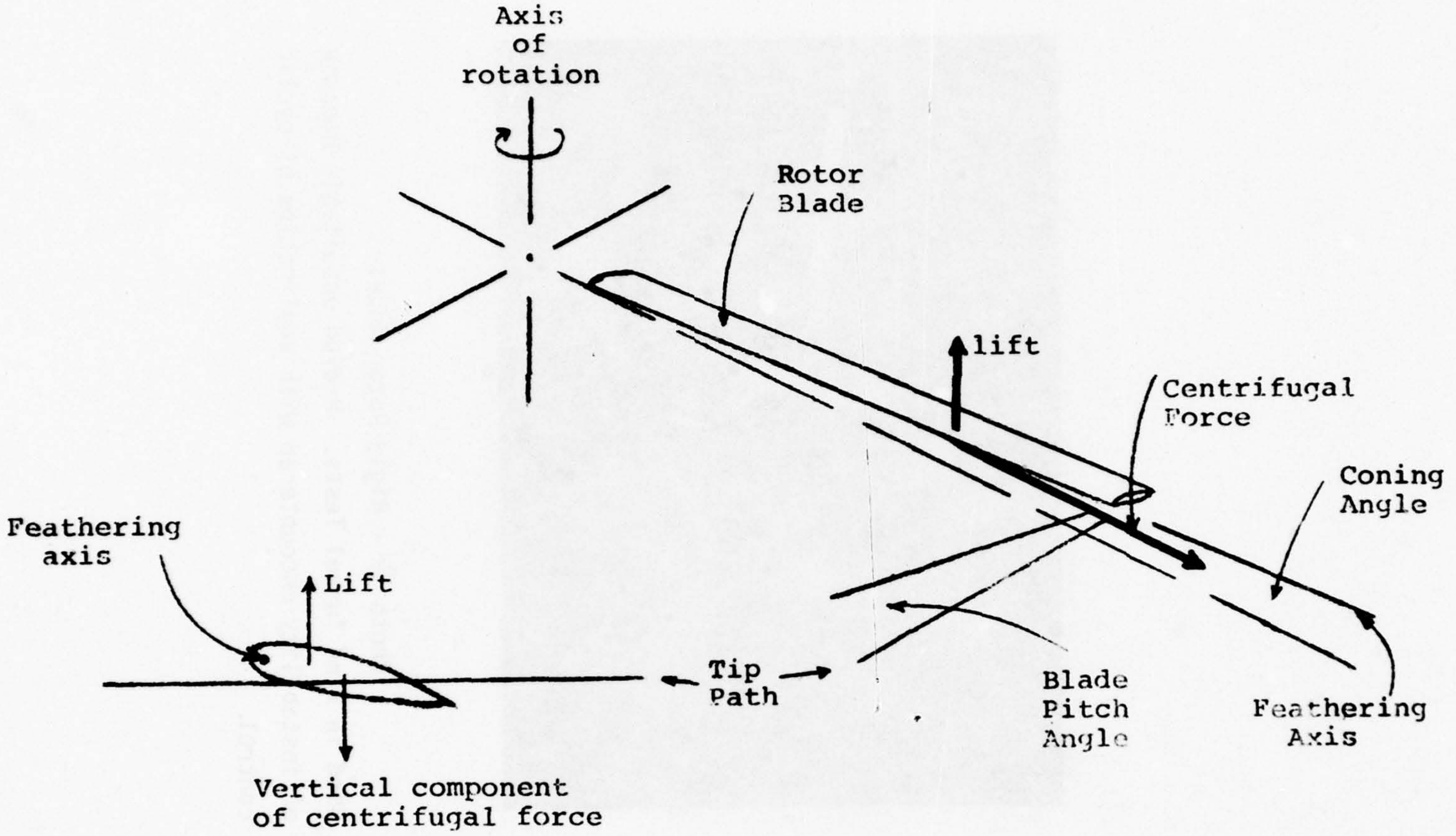
- 10°.

As a final requirement, cyclic control must be provided by the rotor head. The purpose of cyclic control is to tilt the axis of the rotor. This tilt of the rotor provides a horizontal component of lift. The magnitude and direction of this component controls the speed and direction the machine will move. On all back pack helicopters, this is done by center-of-gravity shifting. In other words, the pilot shifts his weight in relation to the rotor by means of an overhead control stick and this shift of center of gravity causes the rotor to tilt.

The first type of rotor head I experimented with was a rigid rotor. (see Figure 16). Unlike the conventional rotor head with three major moving parts, the rigid rotor offers the advantages of having only two moving parts, the shafts for the axis of rotation and the feathering axis. It has the disadvantage of requiring a thrust bearing for the feathering axis rather then a cheaper journal bearing. Figure 18 illustrates how a rigid rotor would work. The vertical component of centrifugal force balances the lift of the rotor blade. Blade pitch changes automatically in response to forward flight or in the event of engine failure. Preliminary wind tunnel tests were carried out using the model shown in Photo 19. In autorotation, satisfactory operation was obtained in steady flight. When cyclic control was applied, however, the rotor blades would become violently

Figure 19

Forces on a rigid rotor



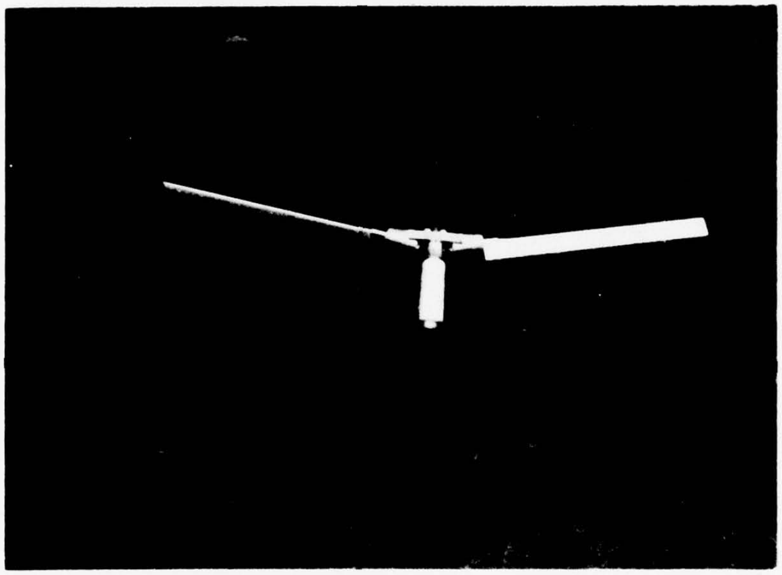


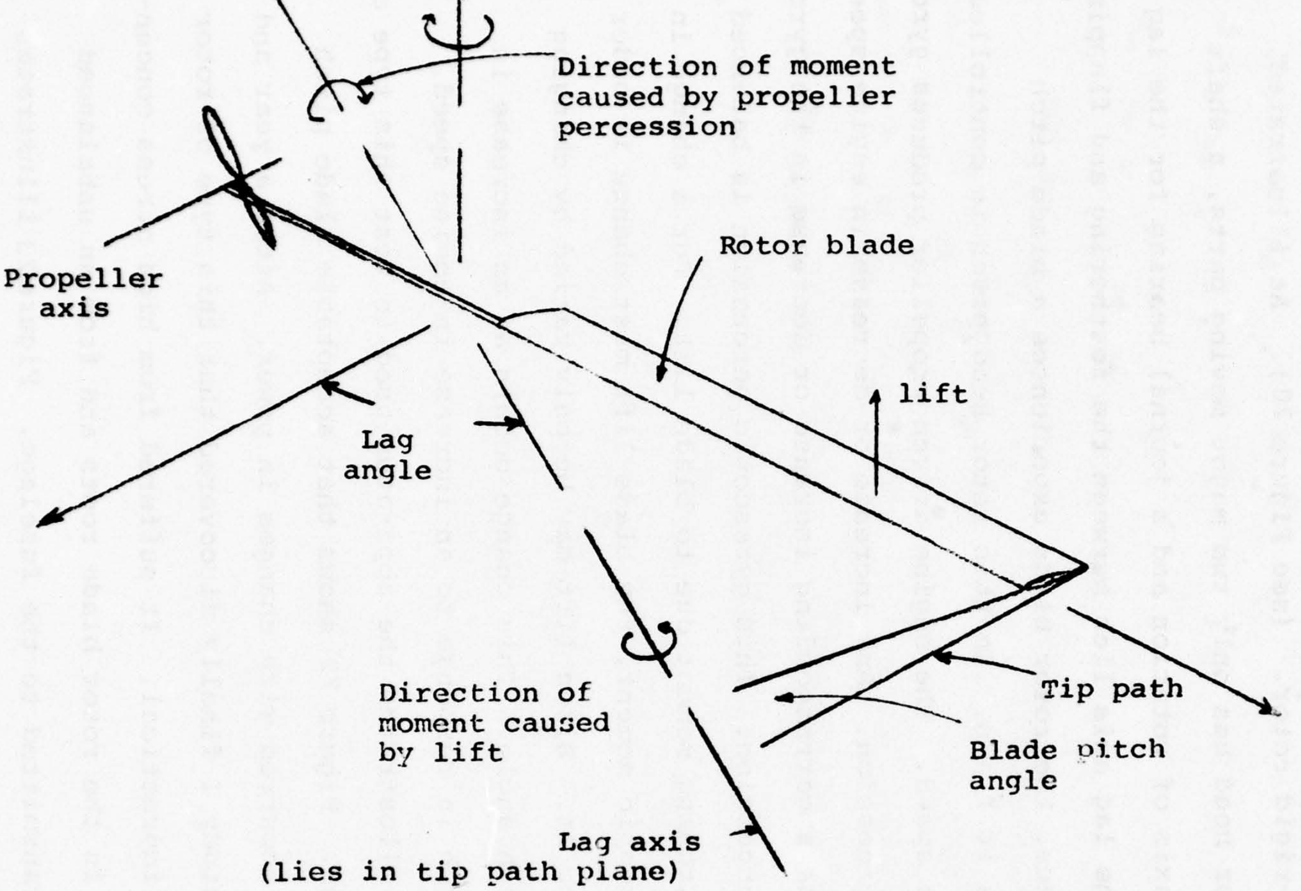
Photo 19 - Rigid Rotor Model

Used in Wind Tunnel Tests. Proved unsuitable because of instability encountered with application of cyclic control.

unstable. This characteristic eliminated the rigid rotor from consideration for my helicopter.

The second type of rotor head I experimented with was the semi-rigid rotor. (see Figure 20). As illustrated, this rotor head has only two major moving parts, a shaft for the axis of rotation and a journal bearing for the lag axis. The lag axis lies between the feathering and flapping axis. Thus, the rotor blade experiences a blade pitch change as it flaps. In this rotor head, pitch is controlled by engine speed. The engine driven propeller produces gyroscopic percession. Any increase or decrease in engine speed will cause a corresponding increase or decrease in the gyroscopic percession. This gyroscopic percession is balanced by the pitching moment due to blade lift. For a change in the gyroscopic moment, the blade lift must change in order to balance it. Blade lift may be only varied by changing blade pitch angle. This change occurs as an increase in blade pitch in response to an increase in engine speed. Photo 21 illustrates the apparatus used to test this type of rotor head. Figure 22 shows that acceptable blade pitch response occurred with changes in power. After a year and a half of study I finally discovered that this type of rotor head was impractical. It suffered from high stress concentrations in the rotor blade roots and from an unbalanced moment transmitted to the fuselage. Figure 23 illustrates the balance of moments in this type of rotor head and the

Figure 20
Semi-rigid rotor



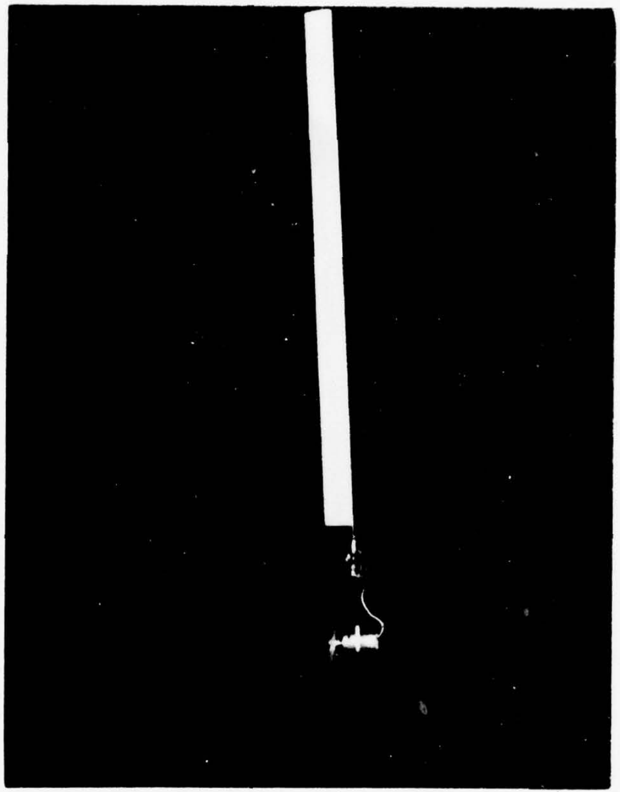


Photo 21 - Semi-Rigid Rotor Model

Blade radius 3 feet, chord 2 inches. Powered by a small D.C. electric motor.

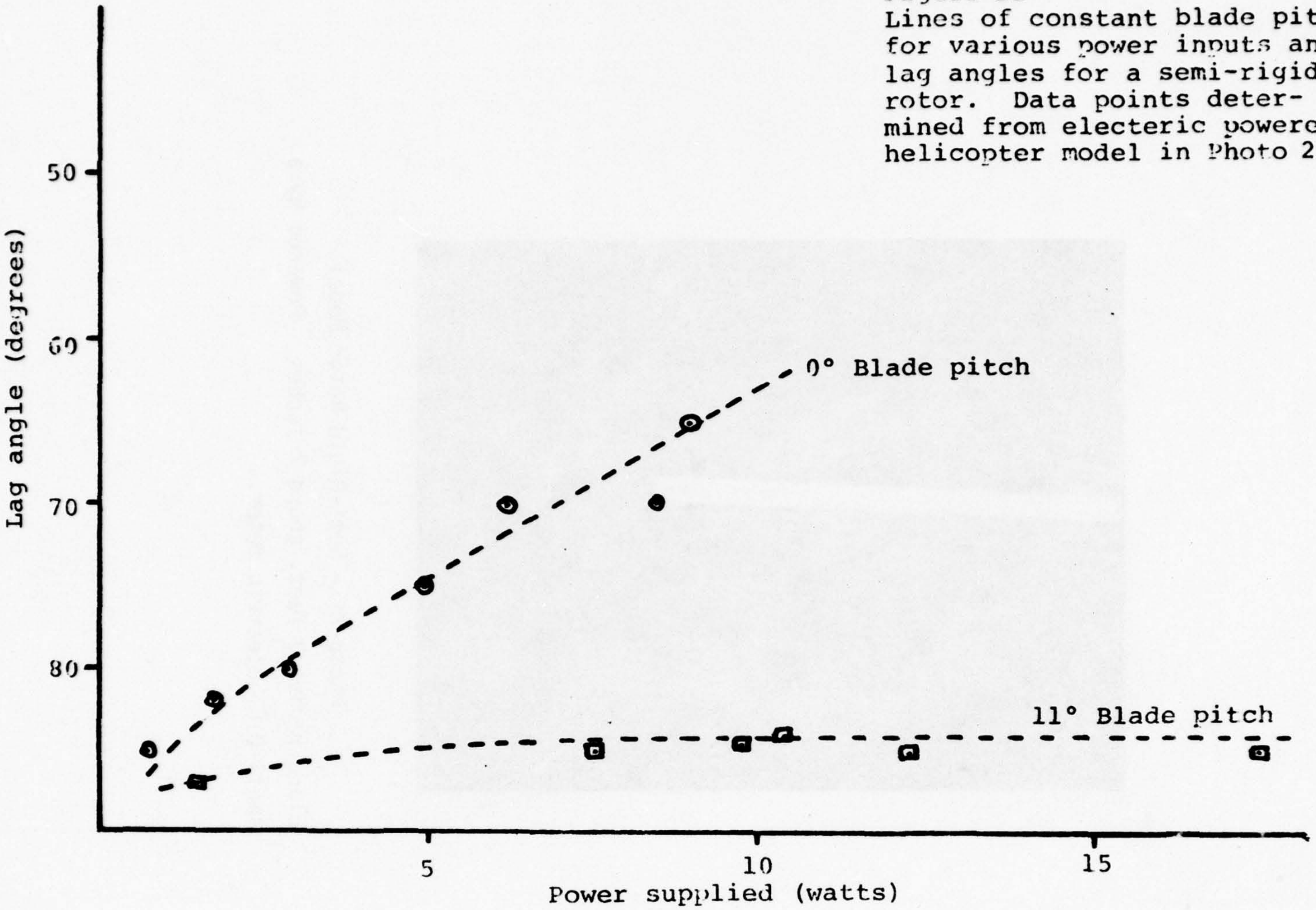


Figure 22
Lines of constant blade pitch for various power inputs and lag angles for a semi-rigid rotor. Data points determined from electeric powered helicopter model in Photo 21

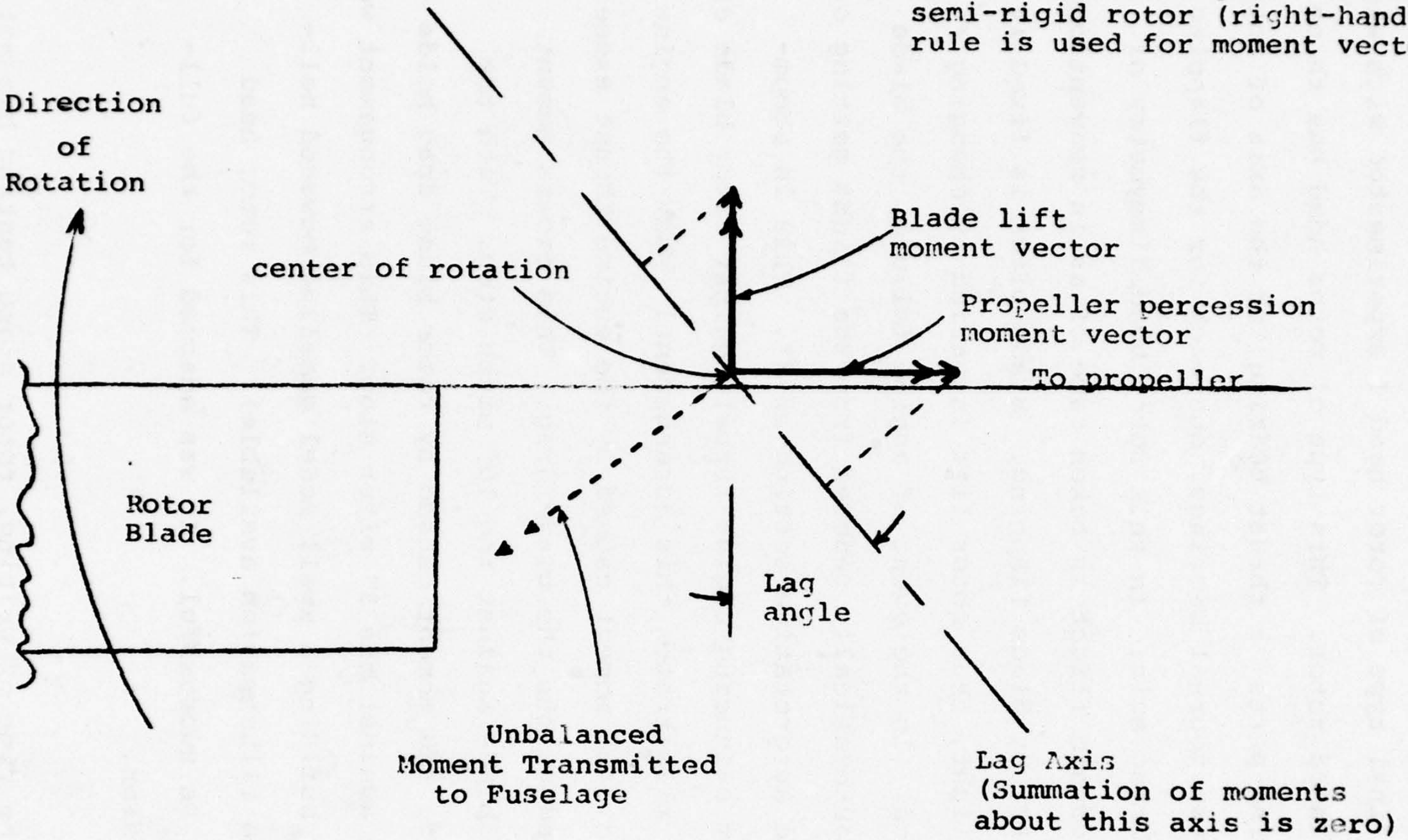


Figure 23
Moment vector diagram for a semi-rigid rotor (right-hand rule is used for moment vectors)

unbalanced moment transmitted to the fuselage.

The final type of rotor head I experimented with was an articulated rotor. This type of rotor head has three major moving parts, a thrust bearing for the axis of rotation and two journal bearings, one each for the flapping and feathering axis. In this rotor head, dissymetry of lift in forward flight is taken care of as in conventional helicopters, by blade flapping. Blade pitch is fixed in powered flight, thus rotor lift is varied by changing rotor speed. In the event of engine failure, the blade pitch is automatically reduced from the flight setting of 10° to the autorotative setting of 2°. This is accomplished by balancing engine thrust against rotor blade drag. Figure 24 illustrates this arrangement. When the engine is running, the moment caused by the engine thrust exceeds that caused by the the blade drag. This excess moment holds the blade against the 10° pitch stop. With the engine off, the moment caused by rotor blade drag holds the blade against the 2° pitch stop. This arrangement was tested by building a small model gasoline powered helicopter (no illustration available). This rotor head proved to be successful. It was adapted for the full-scale version.

Fuselage

At the time of writing, rotor stand testing has not been started, so the fuselage has not been built. The

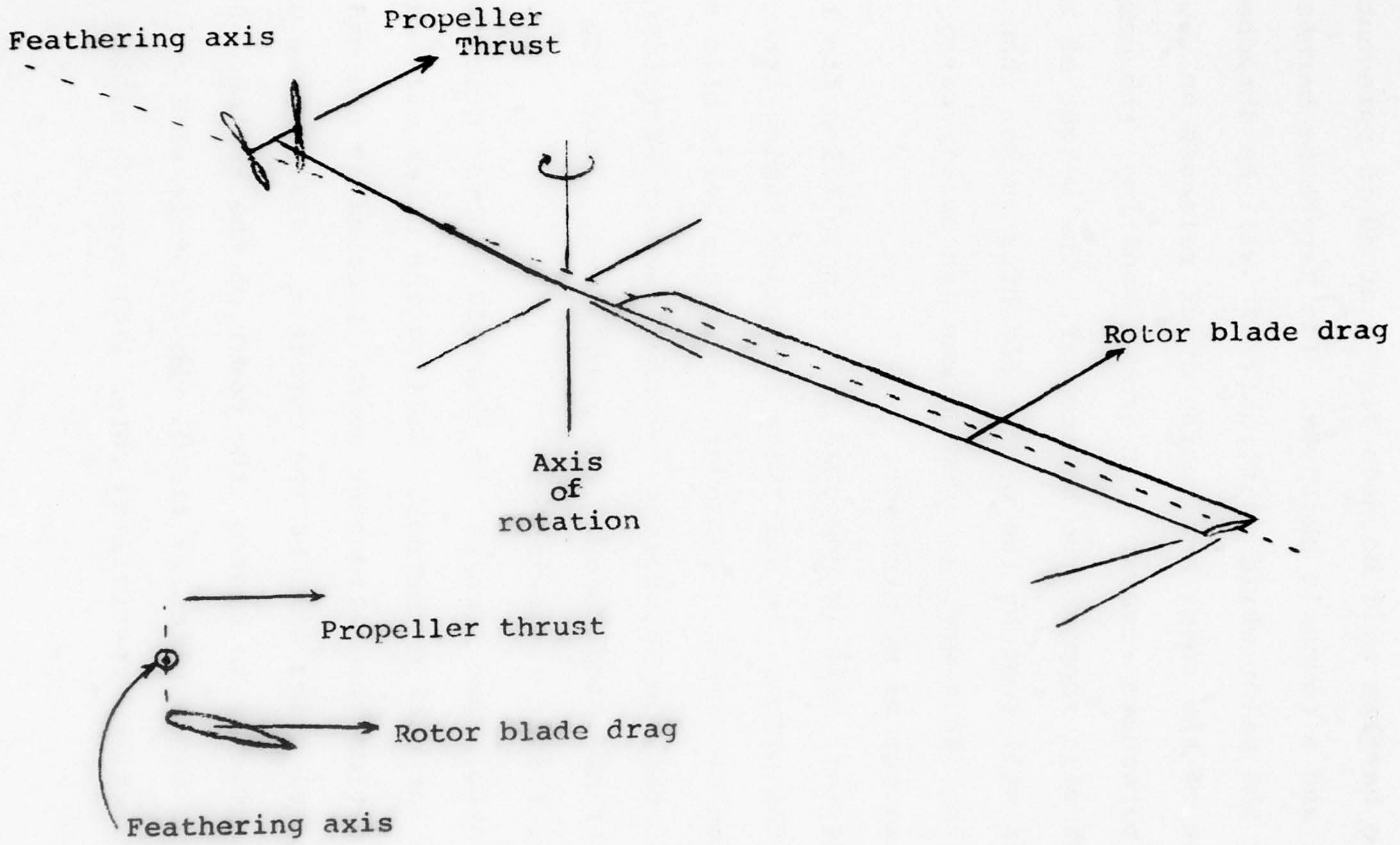


Figure 24
Balance of forces about
Feathering axis for an
articulated rotor

fuselage will be composed of three major components: harness, tail unit and controls.

The harness will be made from a standard parachute harness and a camper's backpack. The parachute harness will support the pilot while in flight. It will be attached to the base of the rotor head using quick releases on the end of the parachute risers. For ground handling, the camper's backpack will support the helicopter. The weight of the aircraft will rest on the operator's hips rather than his shoulders. This way, an average man can easily carry the 75 lb. weight of my aircraft.

The tail unit is composed of a single fixed fin located behind the pilot. It will keep the pilot facing into the direction of flight. In hover, the propeller's slip stream will hit the fin countering the small amount of frictional torque transmitted through the rotor head. Thus, the hovering flight is possible.

Controls are simple. An overhead control stick will be used for cyclic control. Tilting the stick will control the direction the helicopter goes. Located at the end of the control stick will be the throttle. The purpose of the throttle is to control the power of the engine. Since the rotor blade pitch is fixed, the throttle will act as the collective, controlling rotor lift through engine power.

Recommendations

The helicopter described in this paper is not a device that fullfills the requirements for success listed in the utility section. The helicopter I built is simply a working prototype, the first step up from model testing. It is too complicated, heavy, and bulky.

The first objective of any future design is to reduce complexity. This can be best accomplished by using either a fuel injected reciprocating engine or a turboprop engine instead of the conventional reciprocating engine I used. Since these types of engines are not affected by centrifugal force they can be placed out with the propellers. Thus, there is no need for a power transmission system. A further reduction in complexity can be had by chosing a turboprop engine over the fuel-injected reciprocating engine. Only a single propeller is needed with the turboprop engine instead of the two needed for the reciprocating engine. In a turboprop engine, the gyroscopic precession of the propeller would be balanced by the smaller, faster turning turbine.

The weight of the helicopter will be reduced by the selection of a fuel injected reciprocating engine or a turboprop engine. The weight of my power transmission system accounted for 23 lbs of the total 75 lb weight. By selecting the turboprop engine, a further weight reduction can be made. A turboprop has a weight to power ratio of about 0.4, compared to about 1.0 for a reciprocating engine. Thus, with a turboprop engine, a aircraft weight of 40-45 lbs is possible

Finally, the rotor radius can be reduced by using a turboprop engine. A small weight to power ratio reduces the optimum rotor radius needed for the least gross weight. (sec Figure 15).

In summary, by selecting a fuel injected reciprocating engine, the complexity and weight of the aircraft can be reduced. By selecting a turboprop engine, the helicopter will be simpler, lighter and less bulky.

Appendix

The appendix is divided into two major sections, the historical section and the design calculations. The historical section contains information on all single bladed helicopters, backpack helicopters, and propeller-in-the rotor helicopters that have been constructed. This information was used to prevent making the same mistakes of the past. This information was obtained at the Hubschrauber Museum in Bückeburg, Germany. Special thanks goes to Mr. Werner Noltemeyer, the curator of the museum, who was kind enough to open the museum archives and provided me with housing for my five-day stay in Germany.

The design calculations section of the appendix includes all important calculations I made in designing my aircraft.

Purpose: To estimate the design gross weight of the helicopter

Method: Use historical research data and design estimates to estimate the gross weight of the aircraft

Solution: The design gross weight is estimated at 270 lbs.

The breakdown is as follows:

Pilot	175 LBS
Rotor head	12 LBS
Engine (Mc 101)	15 LBS
Propellers	4 LBS
Propeller mounts	22 LBS
Rotor blade	15 LBS
Fuel & tank (8 oz. of fuel)	5 LBS
Pack and stand	10 LBS
	258 LBS
+ Safety Factor	12.9 LBS
	270.9 LBS

Purpose: To determine quantitatively disc loading (i.e., rotor radius)

Method: Fix disc loading so as to minimize aircraft weight

Solution:

Aircraft weight is given by

$$W = W_f + W_v$$

Substituting k_b and k_e for W_v

$$W = W_f + k_b R + K_e\, P \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where

$$P = \frac{C_p\, \rho A V_T^{3}}{\eta}$$

Using simple momentum theory it can be shown that

$$C_p = \frac{C_T^{3/2}}{\sqrt{2}} + \frac{\sigma\, \bar{C}d}{8}$$

Substituting

$$P = \frac{\rho A V_T^{3}}{\eta} \left[\frac{C_T^{3/2}}{\sqrt{2}} + \frac{\sigma\, \bar{C}d}{8} \right]$$

where

$\sigma = \frac{BC}{\pi R}$ for a blade of uniform chord and

$$C_T = \frac{T}{\rho \pi R^2 (\Omega R)^2}$$

Therefore

$$P = \frac{\rho \pi R^2 (\Omega R)^3}{n} \frac{1}{\sqrt{2}} \left[\frac{T}{\rho \pi R^2 (\Omega R)^2} \right]^{3/2} + \frac{\rho \pi R (\Omega R)^3}{n} \; \frac{BC}{\pi R} \; \frac{\bar{C}d}{8} \ldots (2)$$

It can be shown that

$$C_T = \frac{C_L \sigma}{6} = \frac{C_L\, BC}{6 \pi R}$$

and

$$V_T = \Omega R = \sqrt{\frac{T}{\rho\pi R^2 \; C_T}} = \sqrt{\frac{6T\pi R}{\rho\pi R^2 C_L BC}} = \sqrt{\frac{6T}{\rho RC_L \; BC}}$$

Substituting into (2)

$$P = \frac{\rho\pi R^2 (\Omega R)^3}{n\sqrt{2}} \left[\frac{T}{\rho\pi R^2 (\Omega R)^3}\right] \sqrt{\frac{T}{\rho\pi R^2}} + \frac{\rho\pi R^2}{n} \left[\frac{6T}{\rho RC_L \; BC}\right]^{3/2} \frac{BC}{\pi R} \; \frac{\bar{C}d}{8}$$

$$P = \frac{T}{nR} \sqrt{\frac{T}{2\rho\pi}} + \frac{\rho\pi R^2}{n} \left[\frac{6T}{\rho RC_L BC}\right] \sqrt{\frac{6T}{\rho RC_L BC}} \; \frac{BC}{\pi R} \; \frac{\bar{C}d}{8}$$

$$P = \frac{T}{nR} \sqrt{\frac{T}{2\rho\pi}} + \frac{6T}{8n} \; \frac{\bar{C}d}{C_L} \; V_T$$

20% excess power is normal for a helicopter in hover. Divide by 550 to convert into horsepower.

$$P = \frac{1.2}{550} \left[\frac{T}{nR} \sqrt{\frac{T}{2\rho\pi}} + \frac{.75 \; T \; V_T}{n} \; \frac{\bar{C}d}{C_L}\right]$$

The two following values were assumed or calculated.

$T = 270$ lb.

$n = 50\%$

$\rho = .002378$ slugs/ft^3

$C_L = .75$

$\bar{C}_D = .01$

Thus

$$P = \frac{158.4}{R} + .01178 \; V_T \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Substituting back into Eq. (1)

$$W = W_f + K_b R + K_e \left[\frac{158.4}{R} + .01178 \; V_T\right] \ldots\ldots\ldots\ldots\ldots (4)$$

The following values were used to plot Figure 11

$W_f = 50$ lbs

$K_b = 1.25$ lbs/ft

k_e = 1.00 lbs/hp

V_T = 300 ft/sec

Thus

$$W = 50 + 1.25\,R + 1.0\left[\frac{158.4}{R} + 3.53\right]$$

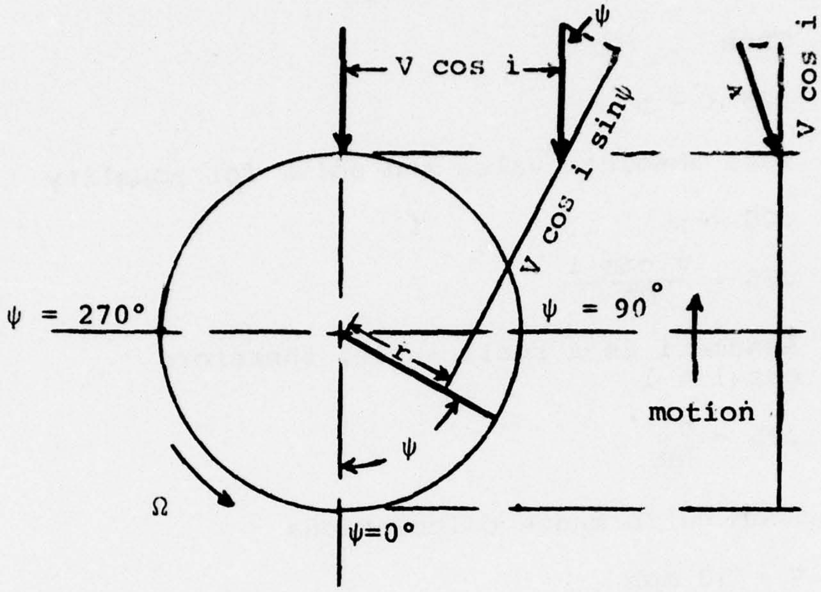
Nomenclature

A	Disc area of rotor: Equal to πR^2 (ft^2)
B	Number of rotor blades
C	Chord of rotor blade (ft)
$\bar{C}d$	Average drag coefficient of the rotor blade
C_L	Average coefficient of lift of rotor blade
C_p	Coefficient of power: Equal to $\frac{P}{\rho A V_T^3}$
C_T	Coefficient of thrust: Equal to $\frac{T}{\rho A V_T^2}$
k_b	Weight of the rotor blade per foot (lb/ft)
k_e	Weight of the engine per horsepower (lb/hp)
P	Power required to hover
R	Rotor radius (ft)
T	Rotor thrust (lb)
V_T	Velocity of rotor tip (ft/sec)
W	Total gross weight of aircraft (lb)
W_f	Fixed weight of aircraft: fuselage, useful load (lb)
W_v	Variable weight of aircraft: rotor blade, engine (lb)
n:	Efficiency: equal to $\frac{\text{Hover Power required}}{\text{Engine shaft power req.}}$
σ	Solidity: equal to $\frac{BC}{\pi R}$

ρ	Air density: at sea level equal to .002378 slugs/ ft^3
Ω	Rotor rotational speed (rad/sec)
π	3.14159

Purpose: To determine minimum tip speed

Method: Limit region of reverse flow to 25% of retreating blade



Solution:

Reversed flow occurs when

V cosi sinψ >Ωr

This can be rewritten as

μR sinψ>r

where

$\mu = \frac{V \cos i}{\Omega R}$

Substituting $x = \frac{r}{R}$ gives

x = μ sini.................................(1)

From the above illustration maximum reversal occurs at

ψ = - 3/2π

Substituting into (1) gives

$x = -\mu$

Since $x < 25\%$ (from above)

Then

$.25 < -\mu$

Take absolute value and solve for equality

$.25 = \mu$

$$.25 = \frac{V \cos i}{\Omega R}$$

Assume i is a small angle, therefore
$\cos i = 1$

$$.25 = \frac{V}{\Omega R}$$

From performance calculations

$V = 50$ mph

$R = 12$ ft.

Thus

$\Omega = 24.44$ rad/sec $= 25$ rad/sec

Since

$V_T = \Omega R$

$V_T = 300$ ft/sec

Nomeclature

V	Aircraft flight velocity
i	Rotor disk incidence to forward flight path
ψ	Rotor blade azimuth position
Ω	Rotor rotational speed (rad/sec)
r	Elemental rotor radius (ft)
R	Rotor radius (ft)

x	Equal to r/R
μ	Advanced ratio
V_T	Tip speed (ft/sec)

Purpose: To determine the efficiency of a helicopter with propellers in the rotor

Method: Use data on Nagler and Rotz's NR. 54 V2, NR.55 and Bensen's B-4 Sky-Scooter.

Source: B.1.O.S overall report No. 8, Rotating Wing Activities in Germany during the period 1939-1945 by Captain R. N. Liptrot, C-B-E, B.A. and preliminary specifications to Bensen's B-4 Sky Scooter

Nagler and Rolz
Model NR. 54 V2 (Refer to Figure 25)

Given:		
	Rotor radius (R)	13.1 ft.
	Gross weight (W)	315 lb
	Design forward speed	50 mph
	Rate of climb (R/C)	8 ft/sec
	Vertical rate of descent (R/D)	16 ft/sec
	(R/D) one engine out vertical	4 ft/sec
	Rotor Chord	1 ft
	Number of blades	2
	Number of engines	2
	Max. engine power	8 hp
Calculated:	Rotor rotational speed	117 rpm
Assumed:	Equivalent flat plate area (Sp)	4 and 6 ft^2

Calculations

$$(R/C)_{max} = \frac{\Delta P}{W}$$

$$\Delta P = (R/C)_{max} W = (8 \text{ ft/sec})(315 \text{ lb})\left(\frac{1 \text{ hp}}{550 \frac{\text{ft-lb}}{\text{sec}}}\right)$$

$$\Delta P = 4.58 \text{ hp.} = P_{available} - P_{required\ min.}$$

$$@ \quad Sp = 4 \text{ ft}^2 \qquad P_{req\ min} = 3.72 \text{ hp.}$$

$$\therefore P_{aval} = 8.3 \text{ hp}$$

$$@ \quad P_{ava} = 8.3 \text{ hp}$$

(check)
Forward speed = 55 mph

$$\text{Eff.} = \frac{8.3}{16} \times 100\% = 51.8\%$$

$@\ Sp = 6\ ft^2 \qquad P_{req_{min}} = 3.94\ hp$

$\therefore\ P_{ava} = 8.52\ hp$

$@\ P_{ava} = 8.52\ hp$ (check) Forward speed = 48 mph

$$Eff. = \frac{8.52\ hp}{16\ hp} = 100\% = 53.25\%$$

Bensen's B-4 Sky Scooter (refer to Figure 26)

Given:	Rotor radius	14.5 ft
	Gross weight	740 lbs
	Design forward speed	60 mph
	R/C	750 ft/min
	R/D min	880 ft/min
	Number of blades	2
	Max engine power	40 hp
	Rotor speed	190 rpm
Calculated:	Rotor Chord	0.75 ft
Assumed:	Equivalent flat plate area	8 ft^2

Calculations:

$$(R/C)_{max} = \frac{\Delta P}{W}$$

$$\Delta P = (R/C)_{max}W = (750\ ft/min)\left(\frac{1\ min}{60\ sec}\right)(740\ lbs)\left(\frac{1\ hp}{550\ \frac{ft\text{-}lb}{sec}}\right)$$

$$\Delta P = 16.72\ hp = P_{ava} - P_{req\ min}$$

$$P_{req\ min} = 13.45\ hp$$

$$\therefore\ P_{ava} = 30.26\ hp$$

$@\ P_{ava} = 30.26\ hp$ Forward speed = 68 mph

$$Eff. = \frac{30.26}{40} \times 100\% = \underline{\underline{75.7\%}}$$

Hover power = 24.7 hp

$$EFF: = \frac{24.7}{40} \times 100\% = \underline{\underline{61.8\%}}$$

Nagler and Rotz
Model NR 55

Given:	Rotor radius	17.5 ft.
	Gross weight	770 lb
	Design forward speed	60 mph
	Rotor chord	19.5 in
	Rotor rotational speed	135 rpm
	Number of blades	1
	Number of engines	1
	Max. engine power	40 hp
Assumed:	Equivalent flat plate area	12 ft^2

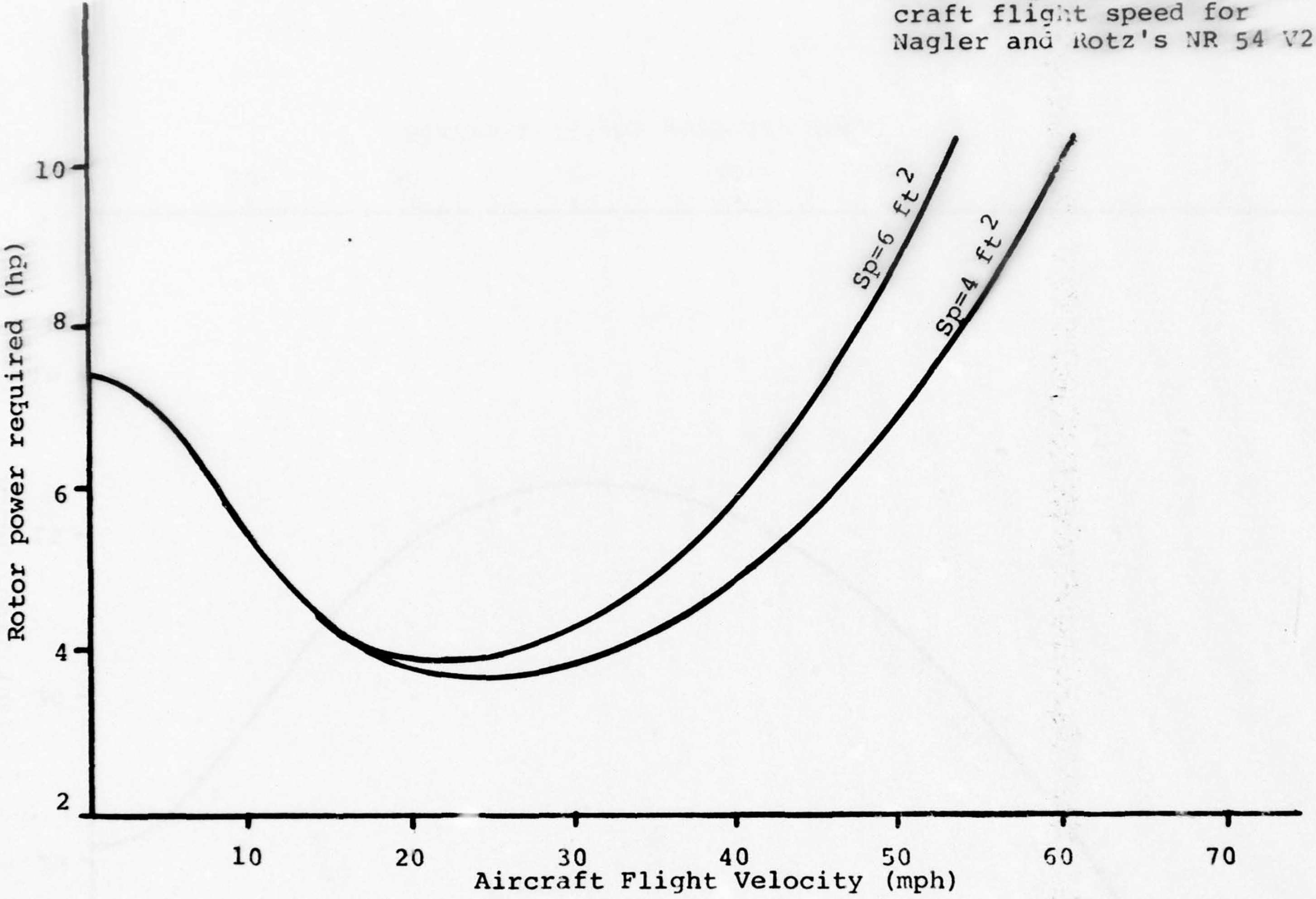
Calculations

$$P_{\text{required}_{\text{hover}}} = 21.93$$

$$\text{EFF.} = \frac{21.93}{40.1} \times 100\% = 54.83\%$$

This assumes no excess power is available at hover.

Figure 25
Power required versus aircraft flight speed for Nagler and Rotz's NR 54 V2



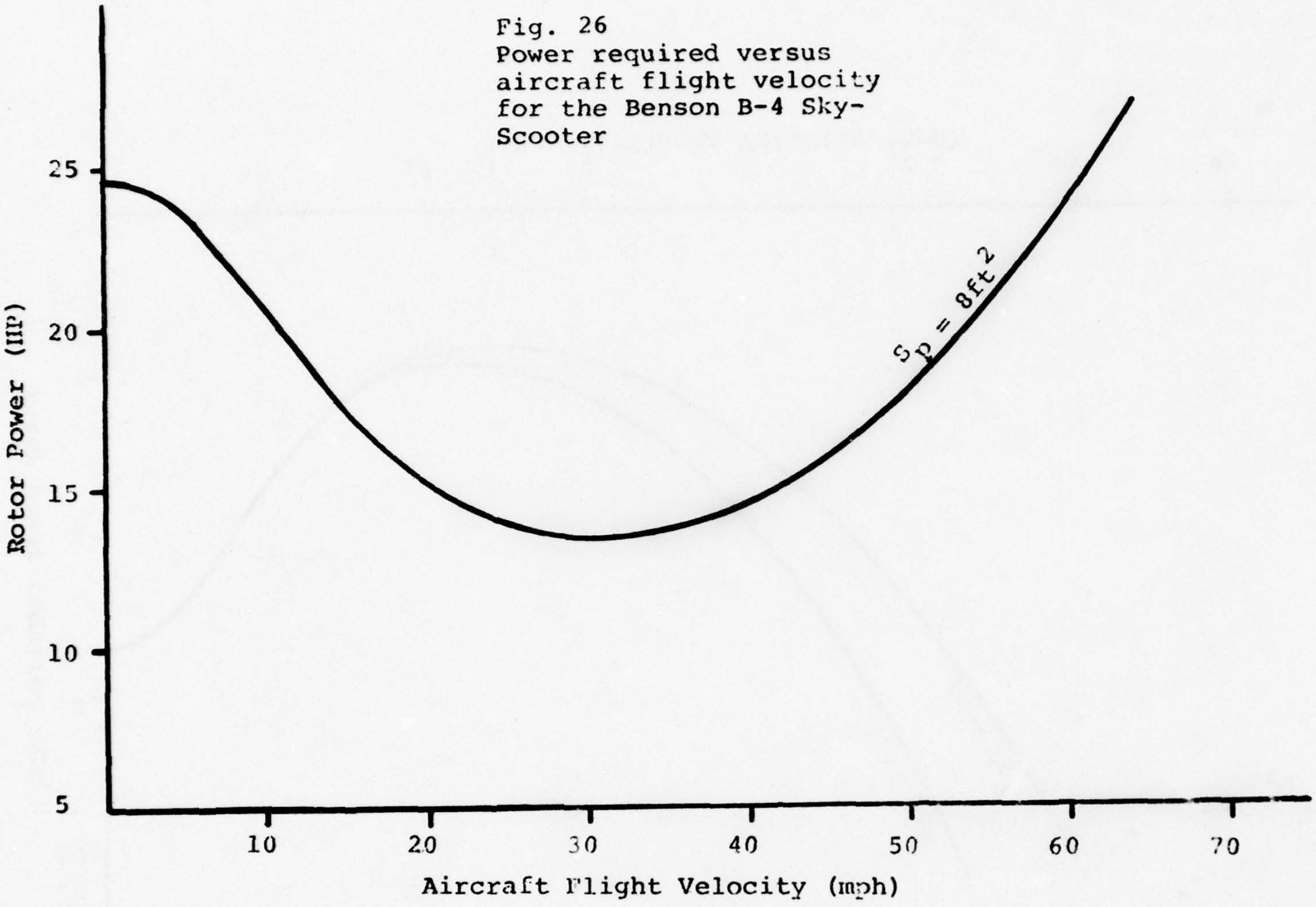


Fig. 26
Power required versus aircraft flight velocity for the Benson B-4 Sky-Scooter

Purpose: To determine chord

Method: Determine minimum chord possible by using limits set by reversed flow considerations.

Solution:

$$\mu_{stall} = 1 - \sqrt{\frac{6\ C_T}{\sigma\ C_{L_{max}}}\ \frac{k}{3}}$$

Rearranging terms give

$$\sigma = \frac{6C_T}{C_{L_{max}}\ (1-\mu_{stall})^2}\ \frac{k}{3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

By defination

$\sigma = \frac{BC}{\pi R}$ for a blade of uniform chord

or

$$C = \frac{\pi R}{B}$$

Substitution into (1)

$$C = \frac{6\ \pi\ R\ C_T}{C_{L_{max}}\ \ B(1-\mu_{stall})^2}\ \frac{k}{3}$$

From McCormick's "Aerodynamics of V/STOL Flight"

$k = 3.17 - 2.7\ \Delta\theta$

and for an untwisted blade

$\Delta\theta = 0$

Therefore

$$C = \frac{6.34\ \pi\ R\ C_T}{C_{L_{max}}\ \ B\ (1-\mu_{stall})^2}$$

The following values are calculated in other sections:

$R = 12$ ft

$C_T = 2.789\text{x}10^{-3}$

$C_{L_{max}} = 1.4$

$B = 1$ blade

$\mu_{stall} = .25$

Substituting these values give

$C = 10.16$ in

<u>Nomeclature</u>

B	Number of rotor blades
C	Chord of rotor blade (in)
k	Constant of proportionality
R	Rotor radius (ft)
C_T	coefficient of thrust, equal to $\frac{T}{\rho A V_T^2}$
$C_{L_{max}}$	Maximum coefficient of lift for the the blade airfoil section
σ	Solidity
μ_{stall}	Advance ratio
$\Delta\theta$	Total twist, in radians

Purpose: To determine the amount of undersling required

Method: Assume the C. G. of the rotor lies on the teetering (or flapping) hinge axis

Solution:

$$\Sigma M_z = 0$$

$$\Sigma M_z = M_{RB} + M_{CW} + M_E$$

$$M_{RB} = (15\ \text{lps})(-\ z + (6.21)(\frac{12\ \text{in.}}{\text{ft}})\sin 9.34°)$$

$$= -15z + 181.4$$

$$M_{CW} = (22.5\ \text{lb})(-z) = -\ 22.5z$$

$$M_E = (12.5\ \text{lbs})(0) = 0$$

$$\Sigma M_z = 0 = -15z + 181.4 - 22.5z$$

$$z = 4.84\ \text{in}$$

Assume undersling of 5 in

Nomenclature

ΣM_z	Sum of moments about the teetering hinge axis
M_{RB}	Rotor blade moment about the teetering hinge axis
M_{CW}	Propeller counter weight moment about the teetering hinge axis
M_E	Engine moment about the teetering hinge axis
z	Undersling (in)

Purpose: To calculate the weight of a proposed rotor blade and the location of its center of gravity

Method: 4130 streamline tubing will be used for the main spar. Plastic foam filler and polypropylene-epoxy laminate skin will be used for the blade. The tubing size needed is 1 3/4". The rotor has a radius of 12 ft with 1 1/2 ft of cutout and a chord of 10 in. The airfoil section is NACA 0012.

Solution: A steel 4130 tube has a density of $\delta_s = .893$ lbs/ft

$$W_s = (.893 \text{ lbs/ft})(12 \text{ ft})$$

$$W_s = 10.72 \text{ lbs}$$

The cross-section area of a symmetric airfoil can be show to equal

$$A_n = 1.368\, nc^2$$

Assume that the foam's density is $\delta_f = 2\#/\text{ft}^3$

$$W_f = (R - R_{\text{cut-out}})\, A_n \delta_f$$

$$W_f = (12 \text{ ft} - 1.5\text{ft}) 1.368 (.06) (\tfrac{10}{12}\text{ft})^2 2 \text{ lbs/ft}^3$$

$$W_f = 1.20 \text{ lbs}$$

Assume the skin is 2.05c in perimeter and is .015" thick. The density of the laminate is $\delta_e = .0680\ \#/\text{in}^3$

$$W_e = (2.05)(.015)\, c\, \delta_e R$$

$$W_e = (2.05)(.015)(10)(.0680\#/\text{in}^3)(12 \text{ ft} \times 12 \text{ in/ft})$$

$$W_e = 3.01 \text{ lbs}$$

$$W_b = W_e + W_s + W_f = 3.01 + 1.20 + 10.72$$

$$W_b = 14.93 \cong 15 \text{ lbs.}$$

C.G. Location Calculation

$$X = \frac{W_s X_s + W_f X_f + W_e X_e}{W_s + W_f + W_e}$$

$$X = \frac{(10.72)(6) + 1.20\left(\frac{12+1.5}{2} + 1.5\right) + 3.01\left(\frac{12+1.5}{2} + 1.5\right)}{10.72 + 1.20 + 3.01}$$

$$X = 6.21 \text{ ft}$$

Nomenclature

A_n	Cross-sectional area
C	Chord
n	Equal to 1/2 the percent thickness of the airfoil
R	Radius
W	Weight (lbs)
δ	Density (lbs/ft length or lbs/ft^3)
X	C.G. location from center of rotation

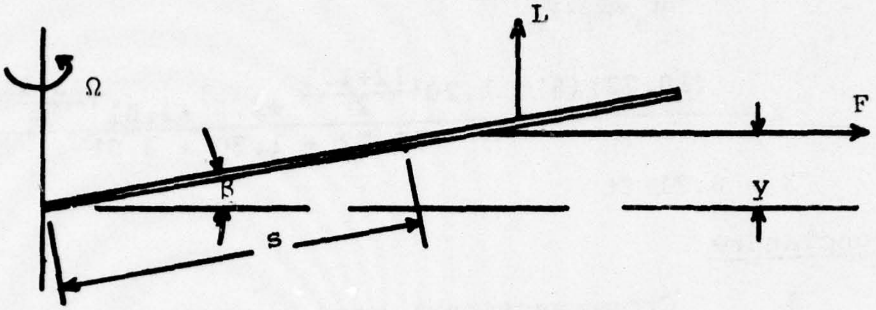
Subscripts

b	Blade
f	Foam
e	laminate
s	spar

Purpose: To determine coning angle

Method: Assume the summation of the moments about the blade root is zero

Solution:



Inertia force is given by

$F = \Omega^2 s \cos \beta \, w/g$

The moment arm is

$y = \frac{4}{3} s \sin \beta$

(Inertia force has a trianqular distribution, the centroid of a triangle is 2/3 times the base. s is equal to about 1/2 the rotor radius)

The moment is

$M = 4/3 \, \Omega^2 s^2 \sin \beta \cos \beta \frac{w}{g}$

Lift is simply equal to L

The moment arm is .75R.

The moment is $M = (.75R)(L)$

Equating the two moments give

$\frac{4}{2} \Omega^2 s^2 \sin \beta \cos \beta \frac{w}{9} = (.75 R)(L)$

Assume $\cos \beta = 1$

$\frac{4}{3} \Omega^2 s^2 \sin \beta \frac{w}{9} = (.75R)(L)$

$\beta = \sin^{-1}\left(\frac{.75 R L}{\frac{4}{3} \Omega^2 s^2 \boxed{\frac{w}{9}}}\right)$

The following values are used

$w = 15$ lbs

$s = 6.21$ ft.

$L = 270$ lbs

$R = 12$ ft.

$\Omega = 25$ rad/sec

Therefore

$\beta = 9.34^\circ$

Nomenclature

W	Blade weight
L	Rotor Thrust
s	C.G. location of rotor blades
R	rotor radius
Ω	Rotor Rotational speed
β	Coning angle
g	Gravitational constant

CURRENTLY AVAILABLE SMALL TWO-STROKE ENGINES

MFC. & MODEL		HP	RATED RPM	WT LB	DISP	NO CYL	METHODS OF STARTING	SPEC FUEL CONS	LBS/HP	PRICE $
McCulloch	101A	13*	9500	13	123cc	1	Pull	1.0	1.00	150
"	199cc	15	6000		199cc	1	Elect			
"	399cc	30	6000		399cc	2	Elect			
"	92cc			12	99cc	1	Pull			
"	49e			12	88cc	1	Pull			
"	4318e	72	4100	77	1640cc	4			1.07	495
"	4318G	90	4500	77		4			.78	1195
Curtiss Wright	225	12.5	5500	35.5	225cc	1	Pull (cr)		2.34	120-
" "	312	19.5	5500	46.5	312cc	1	Pull (cr)		2.38	165-
" "	375	23.5	5000	56.7	372cc	1	Pull (cr)		2.41	180-
" "	400	30	5700	60.0	397cc	2	Pull/elect	.88	2.00	275-
Chrysler	820	8	7000	13.5	134.5cc	1	Pull		1.69	130-
Rockwell JLO	LR440	35	6250	62	428cc	2	Pull/elect	.75	1.77	285-
" "	LR760	45	5000	97	744cc	2	Pull/elect	.82	2.16	262-
" "	L-230	14	6000	29.1	223	1	Pull	.82	2.08	159-
" "	L-295	21.5	6000	48.5	292	1	Pull/elect	.74	2.26	105-
" "	L-340	23.5	6000	49.7	336	1	Pull/elect	.82	2.11	
" "	L-395	24.5	5000	59.5	396	1	Pull/elect	.835	2.43	150-
" "	LR340	26	6000	62	339cc	2	Pull/elect	.70	2.38	230-
" "	LR399	30	6500	62	398	2	Pull/elect	.72	2.07	275
(Twin carb.)	1B600	38	5500	55	594cc	2	Pull/elect	.836	1.45	235
(Single carb.)	LB600	45	5500	55	594cc	2	Pull/elect	.836	1.22	258-
Teledyne/Hirth	230R	80	6500	105	793	3	Elect	1.1	1.31	1041-
" "	171R	36	5500	77		2	Pull/elect		2.14	
" "	280R	55	6750	82.5	650cc	2	Pull/elect		1.50	
Rowena	6507J	13	6400		137cc		Pull (cr)			
Davanelli	B29	20	6000		293cc	1				
"	B34	25	5800		366cc	1				
"	B65	42	5500		645cc	2				
Sachs-Wankel	KM24	23	6000	46	294cc		Pull		2.00	562-
Herbrandson DYAD	280	20	6500	13	274cc	2			.65	1000-

Purpose: Completion of helicopter preliminary design

Method: Utilize standard helicopter design procedures and equations to complete preliminary design

Solution:

1) The airfoil section used is the NACA 0012. It has the following characteristics.

$C_{L_{max}} = 1.4$

$a = 5.73$ per rad

$C_d = 0.008-0.00579\ C_L + 0.01179 C_L^2$

$\alpha_{stall} = 14°$

2) Compute coefficient of thrust for the helicopter

$$C_T = \frac{T}{\rho A V_T^2} = \frac{270}{(0.002378)\ \pi (12)^2 (300)^2}$$

$C_T = 2.789 \times 10^{-3}$

3) Compute solidity

$$\sigma = \frac{BC}{\pi R}$$

$$\sigma = \frac{1\ (10.16)(1/12)}{\pi (12)}$$

$\sigma = 0.02246$

4) Compute average lift coefficient of the rotor blade

$$\bar{C}_L = \frac{6C_T}{\sigma}$$

$$\bar{C}_L = \frac{(2.789\times 10^{-3})(6)}{0.02246}$$

$\bar{C}_L = 0.745$

5) Compute average drag coefficient

$\bar{C}_d = 0.008 - 0.00579\ \bar{C}_L + 0.01179\ \bar{C}_L^2$

$$\bar{C}_d = 0.008 - 0.00579\ (0.745) + 0.01179\ (0.745)^2$$

$$\bar{C}_d = 0.0102$$

6) Compute blade pitch angle

$$C_T = \frac{\sigma a}{2}\left[\frac{\theta}{3} - \frac{1}{2}\sqrt{\frac{C_T}{2}}\right]$$

$$\theta = \frac{6}{\sigma}\frac{C_T}{a} + \frac{3}{2}\sqrt{\frac{C_T}{2}}$$

$$\theta = \frac{6(2.789\text{x}10^{-3})}{(0.02246)(5.73)} + \frac{3}{2}\sqrt{\frac{2.789\text{x}10^{-3}}{2}}$$

θ = 0.1860 rad or 10.66°

7) Compute angle of attack at rotor tip

$$\theta = \alpha_{TIP} + \sqrt{\frac{C_T}{2}}$$

$$\alpha_{TIP} = \theta - \sqrt{\frac{C_T}{2}}$$

$$\alpha_{TIP} = 0.1860 - \sqrt{\frac{2.789\text{x}10^{-3}}{2}}$$

α_{TIP} = 0.1487 rad. or 8.52°

8) Compute hover coefficient of torque (or Power)

$$C_Q = \frac{\sigma\ \bar{C}d}{8} + \frac{C_T^{\ 3/2}}{\sqrt{2}}$$

$$C_Q = \frac{(0.02246)(0.0102)}{8} + \frac{(2.789\text{x}10^{-3})^{3/2}}{\sqrt{2}}$$

$$C_Q = 1.3279\ \text{x}10^{-4}$$

9) Compute hover power required

$$P = C_Q \rho \pi R^2 (\Omega R)^3$$

$$P = (1.3279\text{x}10^{-4})(0.002378)(\pi)(12)^2(300)^3$$

P = 3857 ft-lbs/sec

P = 7.013 HP

10) Efficiency is estimated at 50%

11) Engine power required is 14.03 HP

Nomenclature

A	Disc area of rotor
a	Slope of the lift curve
α_{stall}	Angle of attack for stall
α_{tip}	Angle of attack for the rotor tip
B	Number of rotor blades
C	Chord of the rotor blade
$\bar{C}_d$	Average drag coefficient of the rotor blade
$C_{L_{max}}$	Maximum lift coefficient of the blade section
$\bar{C}_L$	Average lift coefficient of the blade section
C_Q	Coefficient of Torque
C_T	Coefficient of thrust
P	Power
ρ	Air density (.002378 slugs/ft^2)
R	Rotor radius
T	Rotor thrust
V_T	Tip speed of the rotor blade
σ	Solidity
θ	Blade pitch angle
Ω	Rotor rotation speed

Purpose: To estimate helicopter performance

Method: Use computor output of aircraft power required versus aircraft flight speed. (See Figure 27)

Solution:
1) Top speed - 48 mph
2) Maximum rate of climb

$$R/C = \frac{\Delta P}{W}$$

$$= \frac{(8 \text{ h.p.} - 4.6 \text{ h.p})(550)}{270 \text{ lbs}} (60)$$

$$= 416 \text{ ft/min}$$

3) Velocity of maximum rate of climb - 24 mph

4) Angle of climb at best rate of climb

$$\text{Tan } \gamma = \frac{416 \text{ ft/min}}{24 \text{ mph}(\frac{5280}{60})}$$

$$= 11.1°$$

5) Minimum rate of descent, power off

$$R/D = \frac{P}{W}$$

$$= \frac{(4.6 \text{ hp})(550)}{270 \text{ lbs}}$$

$$= 9.4 \text{ ft/sec}$$

6) Aircraft flight velocity for maximum range - 38 mph

7) Aircraft flight velocity for maximum endurance - 24 mph

8) $(L/D)_{max}$, equivalent

$$(L/D)_{max} = (W/D)_{max}$$

$$P = VD$$

$$D = \frac{VD}{V} = \frac{P}{V}$$

Minimum drag occurs at aircraft flight velocity for maximum range.

$$D = \frac{(5.8\ \text{hp})(550)}{(38\ \text{mph})(\frac{5280}{3600})}$$

$$D = 57.24\ \text{lbs}$$

$$L/D = W/D = \frac{220}{57.24} = 4.72$$

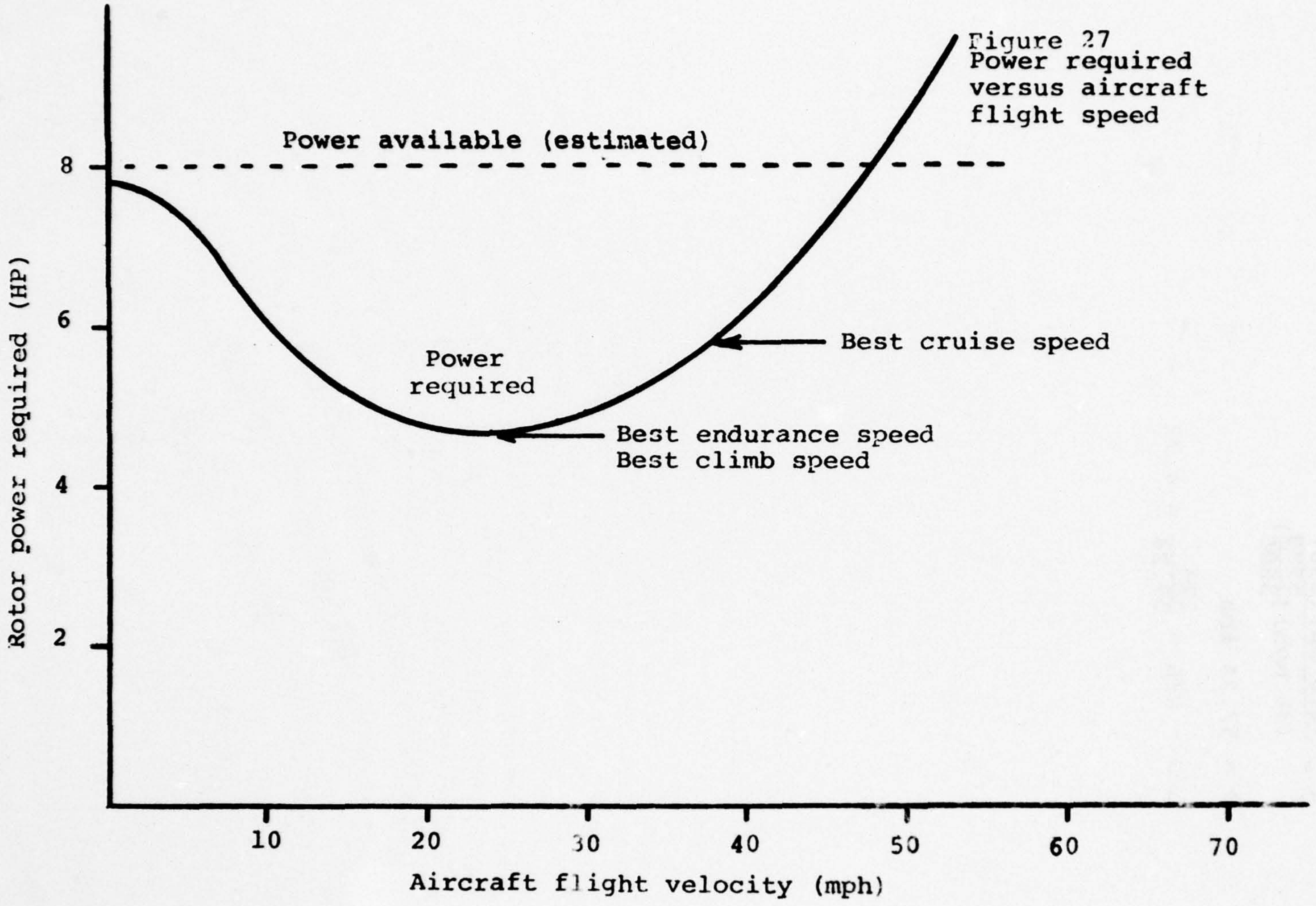


Figure 27
Power required versus aircraft flight speed

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LIST

EAVIII    16 MAY 77  11:48

100 ' THIS PROGRAM OUPUTS THE POWER REQUIRED (HP) TO FLY FOR A
110 'HELICOPTER VERUS AIRCRAFT FLIGHT VELOCITY (MPH). INPUTS
120 'NEEDED ARE THE ROTOR RADUIS(FT.),ROTOR SPEED(RPM),
130 'THRUST(LBS.),AIRCRAFT ALTITUTE(FT.),BLADE CHORD(FT.),
140 'NUMBER OF BLADES,AND EQUILVALENT FLAT PLATE AREA(FT^2).
150 READ R,W,T,H,C,B
160 READ F
170 LET A=3.1416*R*R
180 LET S=B*C/(3.1416*R)
190 LET W2=W*R*0.1047
200 LET RO=0.002378*(1-(0.689E-5)*H)^4.256
210 LET T4=T/(RO*A*W2*W2)
220 LET L4=6*T4/S
230 LET D4=0.008-0.0057*L4+0.0117*L4*L4
240 FOR V=0 TO 150 STEP 2.9333333
250 LET C1=3.438*RO/T
260 LET C2=S*D4/(4*T4*W2)
270 LET I=C1*V*V+C2*V
280 LET X=C1*V*V-TAN(I)+C2*V*COS(I)
290 LET Y=1/(COS(I))^2+C2*V*SIN(I)
300 IF ABS(X/Y)<0.0000001 THEN 330
310 LET I=I+X/Y
320 GOTO 280
330 LET U=V*COS(I)/W2
340 LET L=SQR(T4/2)
350 LET X=U*TAN(I)-L+T4/(2*(L*L+U*U)^0.5)
360 LET Y=1+T4*L/(2*(L*L+U*U)^1.5)
370 IF ABS(X/Y)<0.0000001 THEN 400
380 LET L=L+X/Y
390 GOTO 350
400 LET P1=T4*T4/(2*(L*L+U*U)^0.5)
410 LET P2=S*D4/8*(1+4.6*U*U)
420 LET P3=0.6*F/A*(V/W2)^3
430 LET P0=P1+P2+P3
440 LET P=P0*RO*A*W2^3
450 LET V=V*0.6818
460 LET P=P/550
470 PRINT V,P
480 LET V=V/0.6818
490 NEXT V
500 DATA 12,300,270,0,.83,1
510 DATA 5
520 END
READY
```

Nomenclature used in computer program

A - Disc area (ft^2)

B - Number of blades

C - Chord (ft)

C1, C_2 - Constants used in program

D4 - Coefficient of drag

F - Equivalent flat plate area (ft^2)

H - Altitude (ft)

I - Rotor incidence

L - Inflow ratio

L4 - Coefficient of lift

P - Power

PO - coefficient of power

P1 - Induced power coefficient

P2 - Profile power coefficient

P3 - Parasite power coefficient

R - Rotor radius (ft)

R0 - Mass air density

S - Solidity

T - Rotor thrust

T4 - Coefficient of thrust

U - Advanced ratio

V - Aircraft flight velocity

W - Rotor speed

W2 - Tip Speed

X,Y - Variables used in computer search

Purpose: To design two counter rotating propellers

Assume: Only a 1.30 speed-down ratio is possible, since engine rpm is 9,500 rpm, the propeller rpm is 7,300 rpm. The power per propeller 7.5 hp. The propeller is located 4.10 ft from the center of rotation and the rotor rotational speed is 25 rad/sec.

Solution: Calculate speed-power coefficient

$$C_s = \frac{0.638 \times TAS \times (\rho/\rho_0)^{1/5}}{(b.hp)^{1/5} \times (rpm)^{2/5}}$$

$$C_s = \frac{0.638 \times (25\frac{rad}{sec} \times 4.1\ ft \times \frac{3600}{5280}) \times (1)^{1/5}}{(7.5)^{1/5} \times (7300)^{2/5}}$$

$$C_s = 0.8489$$

Using Fig. 12 (design chart for propeller 5649 Clark Y section, 2 blades) from report No. 623, NACA.

$\frac{V}{nD} = .40$ @ $C_s = .8489$ at line of max efficiency for C_s

Calculate Diameter:

$$D = \frac{TAS \times 88}{rpm \times \frac{V}{nD}}$$

$$D = \frac{(25 \times 4.1 \times \frac{3600}{5280}) \times 88}{7300 \times .40}$$

$$D = 2.10\ ft.$$

Calculate Tip Speed

$$V_T = rpm \times \frac{2\pi}{60} \times \frac{D}{2}$$

$$V_T = (7300) \times \frac{2\pi}{60} \times \frac{2.10}{2}$$

$$V_T = 805\ ft/sec$$

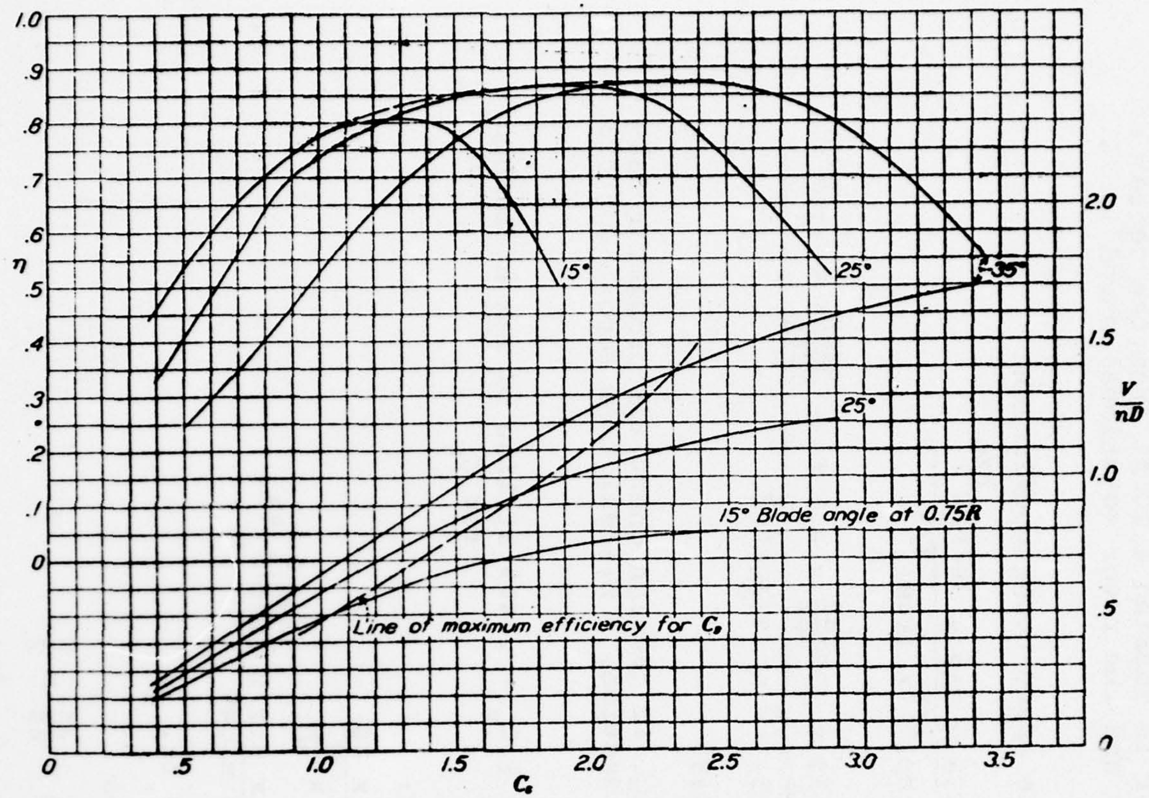


FIGURE 12.—Design chart for propeller 5049.

Reprinted from NACA Report 623,
"The Aerodynamic characteristics
of four full-scale propellers
having different plan forms."

At sea level on a standard day

$$M = \frac{V_T}{c} = \frac{805 \text{ ft/sec}}{1116 \text{ ft/sec}} = 0.721$$

Calculate thrust

Propulsion efficiency is given by

$$\eta = \frac{.85}{1 + \frac{T}{qD^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\text{Where } q = 25.5 \left(\frac{V}{100}\right)^2 = 25.5\left(\frac{25\text{x}4.1 \text{ x } \frac{3600}{5280}}{100}\right)^2 = 12.45$$

Power required is given by $\text{bHp} = .00267 \frac{T\ v}{\eta}$

Solving for η: $\eta = .00267 \frac{TV}{\text{bHp}}$

Setting equal to the Equation (1)

$$\frac{.85}{1 + \frac{T}{qD^2}} = .00267 \frac{TV}{\text{bHp}}$$

Solving for T and substituting in the calculated values for HP, D, V, and q

$$.00267 \frac{(T)(v)}{\text{bHp}} + .00267 \frac{T^2 v}{\text{bHp } q\ D^2} - .85 = 0$$

$$T^2(4.532 \text{ x } 10^{-4}) + T(0.02488) - .85 = 0$$

$$T = \frac{-0.02488 \pm \sqrt{(0.02488)^2 - 4(4.532\text{x}10^{-4})(-.85)}}{2(4.532 \text{ x } 10^{-4})}$$

T = 23.82 lbs

Propulsion efficiency is

$$\eta = \frac{.85}{1 + \frac{T}{qD^2}}$$

$\eta = .593 = 59.3\%$

As a check

$$\text{bHp} = .00267\ \frac{T\ v}{\eta}$$

$$= \frac{.00267\ (23.82)(25\text{x}4.1\text{x}\frac{3600}{5280})}{.593}$$

$$= 7.495\ \text{Hp}$$

Calculate Propeller Blade area

$$A_b = 2{,}000{,}000\ \frac{T}{(D)^2(\text{rpm})^2}$$

$$A_b = 2{,}000{,}000\ \frac{23.82}{(2.10)^2(7300)^2}$$

$$A_b = 0.2027\ \text{sq. ft.}$$

The average blade width (Chord)

$$b = \frac{A_b}{D} = \frac{.2027\ \text{ft}^2}{2.10\ \text{ft}} = .0965\ \text{ft} = 1.158\ \text{in.}$$

This may be increased up to 50% or 1.74 in.

Calculate induced velocity and total velocity

$$V_i = \frac{T}{2.94(\rho)(A_\rho)(\text{ TAS})}$$

$$V_i = \frac{23.82}{2.94\ (.002378)(\pi)(\frac{2.10}{2})^2(69.89)}$$

$$V_i = 14.07\ \text{ft/sec}$$

Total Velocity

$$V = 1.47\ \text{x}\ (\text{TAS}) + V_i$$

$$V = 1.47\ \text{x}\ (69.89) + 14.07$$

$$V = 116.8\ \text{ft/sec}$$

Calculate Efffective Pitch

$$\text{E.P.} = 720\ \frac{V_p}{\text{rpm}}$$

$$\text{E.P.} = 720\ \frac{116.8}{7300}$$

E.P. = 11.52 inches

Effective Pitch Angle

$$E.P.A. = \text{Tan}^{-1} \frac{E.P.}{2\pi \quad R_{.75}}$$

$$E.P.A = \text{Tan}^{-1} \frac{11.52}{2\pi(9.45)} = 10.98°$$

Chord Line Pitch Angle (β)

β = E.P.A. + 3° ← angle for best L/D for Clark Y

$\beta = 10.98° + 3° = 14.0°$

Rated Pitch

$$RP = 2\pi \quad R_{.75} \quad (\text{Tan } \beta_{.75})$$

$$RP = 2\pi(9.45)(\text{Tan } 14°)$$

RP = 14.80 inches

Pitch Angles

$$\beta = \text{Tan}^{-1} \frac{RP}{2\pi(x)(R)}$$

Twist Schedule

x (%)	β (degrees)
0	90°
25	36.79°
40	25.05°
50	20.50°
60	17.31°
70	14.95°
80	13.15°
90	11.73°
100	10.59°

Chord Distribution

The following work refers to NACA Report 924 - Application of Theodorsen's Theory to Propeller Design. The purpose is to calculate the chord distribution for counter rotating propellers.

The following data is used:

Power, Horsepower	15 hp
Density, slugs per cubic foot	.002378

Velocity, miles per hour	69.89 mph
Rotational Speed, rps	121.7
Propeller diameter, ft.	2.10
Number of blades	4
V/nD	.40
C_L	.8

The total P_{CT}

$$P_{CT} = \frac{P}{\frac{1}{2}\rho V^3 \pi R^2}$$

$$= \frac{(15)\ (550)}{\frac{1}{2}(0.002378)(102.5)^3 \pi (1.05)^2}$$

$$= 1.8603$$

$$P_C = 2k\bar{w}\ (1 + \bar{w})\ (1 + \frac{\varepsilon}{k}\bar{w})$$

where $P_c = P_{CT}$

Figure 11a, Report 924, NACA was used to obtain the following table

$\bar{w}$	$\frac{v+\bar{w}}{n+D}$	k	ε/k	P_c
0	.40	.89	.94	0
.1	.44	.87	.93	0.209
.2	.48	.86	.93	0.490
.3	.52	.85	.92	0.846
.4	.56	.84	.91	1.283
.5	.60	.83	.90	1.805
.6	.64	.82	.89	2.415

From the table when $P_C = 1.8603$

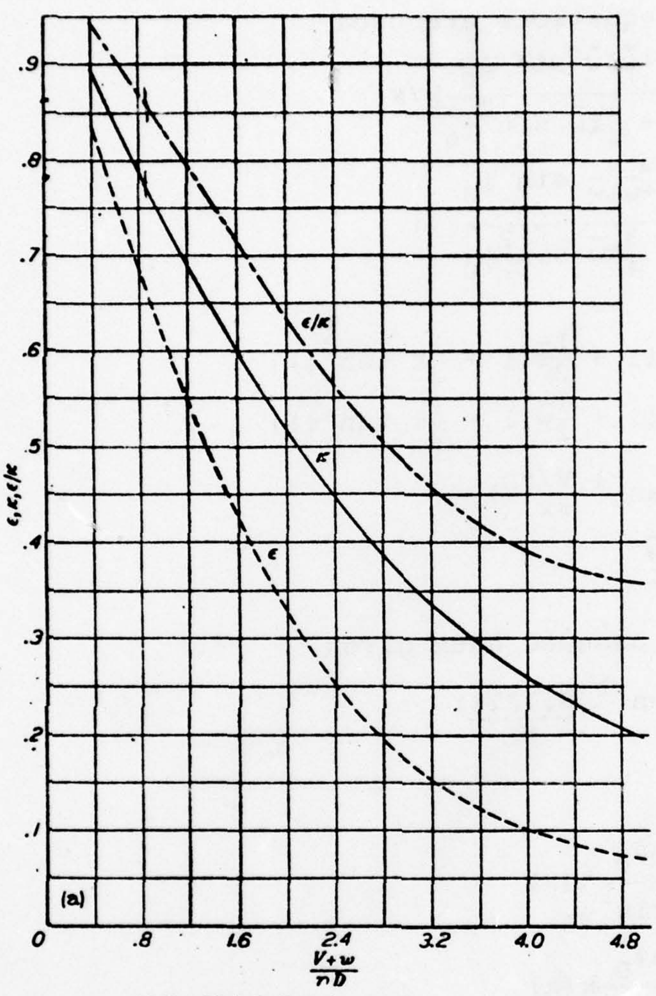
Then $\bar{w} = .505$

Therefore

$$\frac{V}{nD}(1 + \bar{w}) = 0.602$$

$$k = 0.825$$

$$\frac{P_C}{k} = 2.255$$



(a) Four-blade dual-rotating propeller.

FIGURE 11.—Values of ϵ and κ for dual-rotating propellers.

Reprinted from NACA Report 924
"Application of Theodorsen's
Theory to Propeller Design."

and

$$\eta_i = 0.67 = 67\%$$

The following equations are used

$$b_F = \frac{V}{nD}\,\frac{R}{C_L}\,\frac{(1+\bar{w})\bar{w}\ \sin\phi_0}{1 + \frac{1}{4}k\bar{w}\ \sin^2\phi_0}k(x)$$

$$b_R = \frac{V}{nD}\,\frac{R}{C_L}\,\frac{(1+\bar{w})\bar{w}\ \sin\phi_0}{1 + \frac{3}{4}k\bar{w}\ \sin^2\phi_0}k(x)$$

$$\mathrm{Tan}\phi_F = \frac{V}{nD}\,\frac{1}{\pi x}\ [1 + \frac{1}{2}\bar{w}(1 + \frac{1}{2}k\ \tan^2\phi)]$$

$$\mathrm{Tan}\phi_R = \frac{V}{nD}\,\frac{1}{\pi x}\ [1 + \frac{1}{2}\bar{w}(1 - \frac{1}{2}k\ \tan^2\phi)]$$

where

$$\sin\phi_0 = \sin\ (\tan^{-1}\ \frac{V/nD}{\pi x})$$

and $\mathrm{Tan}\phi = \frac{1}{\pi}\,\frac{V}{nD}\,\frac{1+\frac{1}{2}\bar{w}}{x}$

Substituting in the assumed data gives

$$\sin\phi_0 = \sin\ (\mathrm{Tan}^{-1}\ \frac{0.1278}{x})$$

$$\mathrm{Tan}\phi_0 = \frac{.1585}{x}$$

$$b_F = \frac{4.7881\ \sin\phi_0}{1+0.1042\ \sin^2\phi_0}k(x)$$

$$b_R = \frac{4.7881\ \sin\phi_0}{1+0.3125\ \sin\phi_0}k(x)$$

$$\mathrm{Tan}_{\phi F} = \frac{0.1595}{x} + \frac{.0003374}{x^3}$$

$$\mathrm{Tan}\phi_R = \frac{0.1595}{x} - \frac{.00033374}{x^3}$$

Fig. 4 is used to supply the values of k(x). The equations were put on the computer and solved.

AD-A045 375 NAVAL ACADEMY ANNAPOLIS MD F/G 1/3
SINGLE BLADED TORQUELESS HELICOPTER DESIGN.(U)
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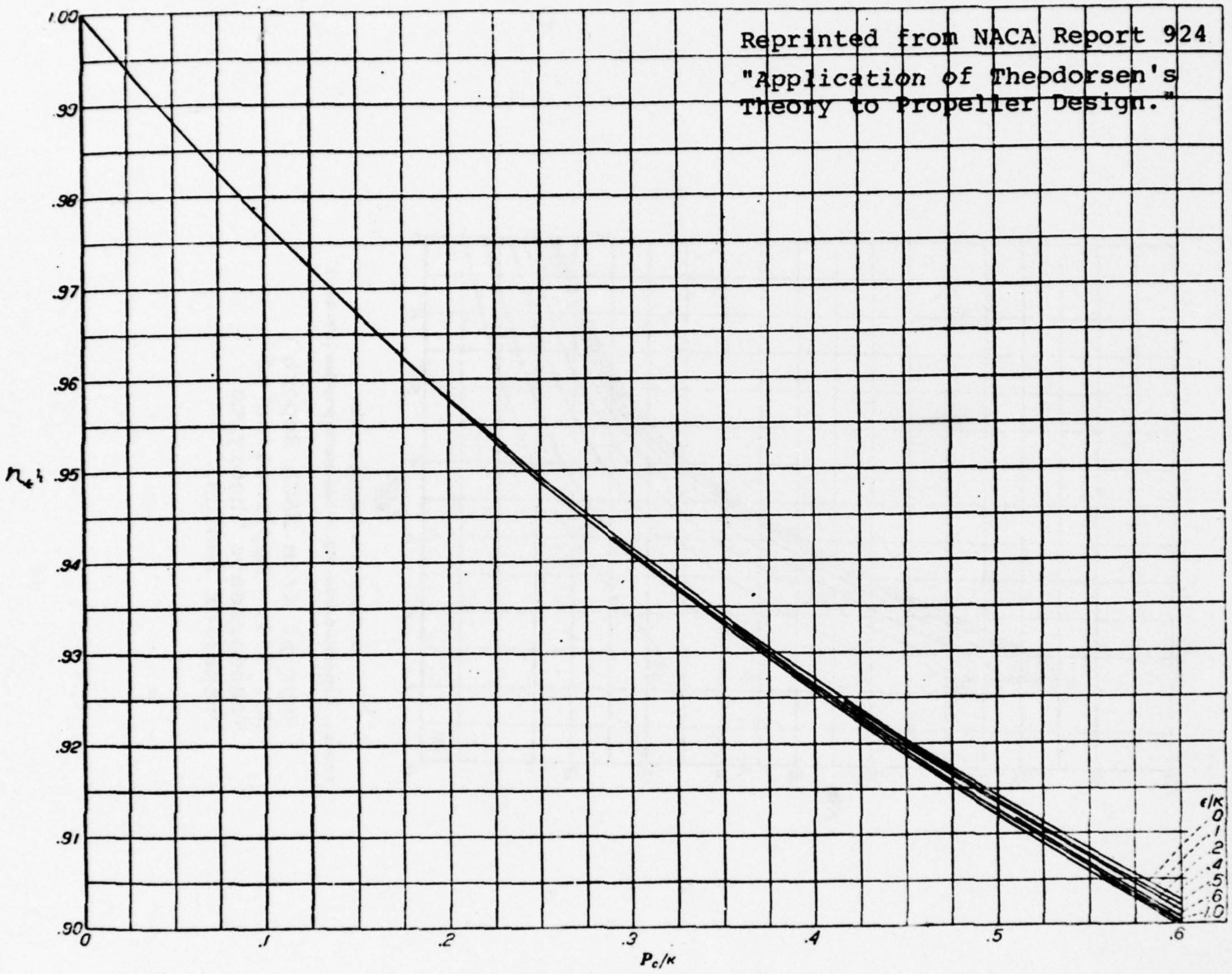
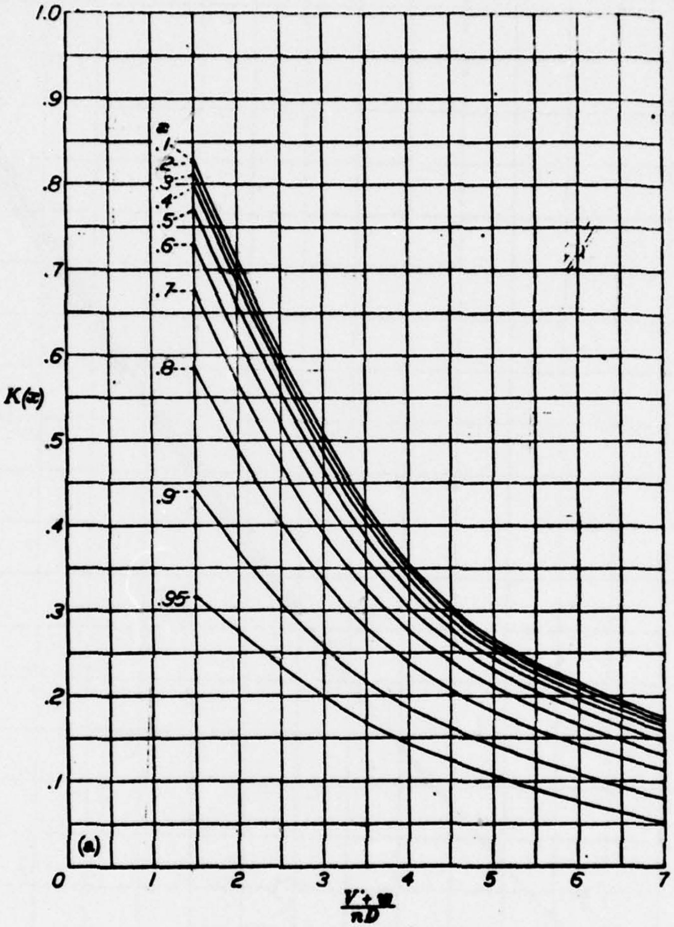


Reprinted from NACA Report 924
"Application of Theodorsen's Theory to Propeller Design."

FIGURE 9.—Propeller efficiency against P_c/κ.



(a) Four-blade dual-rotating propeller.

FIGURE 4.—Circulation function $K(x)$ for dual-rotating propellers (reference 1).

Reprint from NACA Report No. 924, "Application of Theodorsen's Theory to Propeller Design."

Nomenclature

A_b	Total area of all blades (ft^2)
bhp	Brake horsepower
b_f	Chord of front propeller-blade element (in)
b_R	Chord of rear propeller-blade element (in)
β	Blade angle (degrees)
c	Speed of sound (1116 ft/sec)
C_s	Speed-power coefficient
D	Diameter (ft)
EP	Effective pitch
EPA	Effective pitch angle
ε	Axial energy loss factor
k	mass coefficient ($2 \int_0^1 k(x)\ x\ dx$)
k(x)	Circulation function
M	Mach number
n	Propeller Rotational s[illegible] (rps)
η	Propeller efficiency
η_i	Propeller efficiency, ideal
ϕ_F	Angle of resultant velocity at the plane of rotation for the front blade
ϕ_R	Angle of resultant velocity at the plane of rotation for the rear blade
ϕ_o	$= \text{TAN}^{-1} \frac{v/nD}{\pi x}$
ϕ	Angle of the resultant velocity
P_c	Ideal power coefficient
P_{CT}	Total power coefficient

ρ	Mass density of air
ρ_0	Mass density of air at sea level
q	Dynamic pressure
rpm	Propeller rotational speed in rpm
$R_{.75}$	.75 of the propeller radius
RP	rated pitch
T	Propeller thrust (lbs)
TAS	True air speed (mph) of propeller's forward motion
$\bar{w}$	Ratio of displacement velocity to forward velocity
V	Total velocity (ft/sec)
V_i	Induced velocity (ft/sec)
V_T	Tip speed (ft/sec)
x	Radial location of blade element (r/R)

Designer: Baumgartl, Paul

Country: Austria

Date: 1939-1945

Aircraft names: Heliofly I -III

General type:

Rotor radius: - - -

Engine: - - -

Empty wt; Gross wt:

Remarks: The Heliofly I was a small strap-on autogyro. It was built as a sporting glider which could be used to glide down hills in a matter similar to present day hang gliders. Empty weight was 38 lbs.

The Heliofly II was a back-pack helicopter. It consisted of two coaxial single-blade rotors. Balancing each rotor blade was a small 8 HP engine. The engine, an Argus AS.8, could no longer be obtained so the project was abandoned. Blade radius was 7.8 ft and empty weight was expected to be 42 lbs.

The Heliofly III was similar to the Heliofly II. It consisted of two coaxial single blade rotors. The lower carried a 16 HP engine as a counter weight. The upper rotor had a streamlined counter weight. The rotor radius was 10 ft, empty weight 77 lbs and gross weight 265 lbs. Blade collision was prevented as in the Heliofly II by incorporating different coning angles in the upper and lower rotors. The separation was further increased by using a periodic differential blade pitch variation. The Heliofly III achieved hovering flight stablized by ropes. The aircraft illustrated is the Heliofly I.

"Rotating Wing Activities in Germany during
the period 1939-1945." Captain R. N. Liptrot

Baumgartl's Heliofly I

Designer: Bensen, Igor

Country: U.S.A.

Date: 1955

Aircraft name: B-4 Skyscooter

General type: Prop-in-rotor; Two bladed single seater

Rotor radius: 14.5 ft

Engine: Nelsen H-59; 40 HP

Empty wt; Gross wt: 370 lb; 720 lb

Remarks:

Performance

Max- speed	60 MPH
Range	118 miles
Endurance	2 hours
Ceiling	11,500 ft

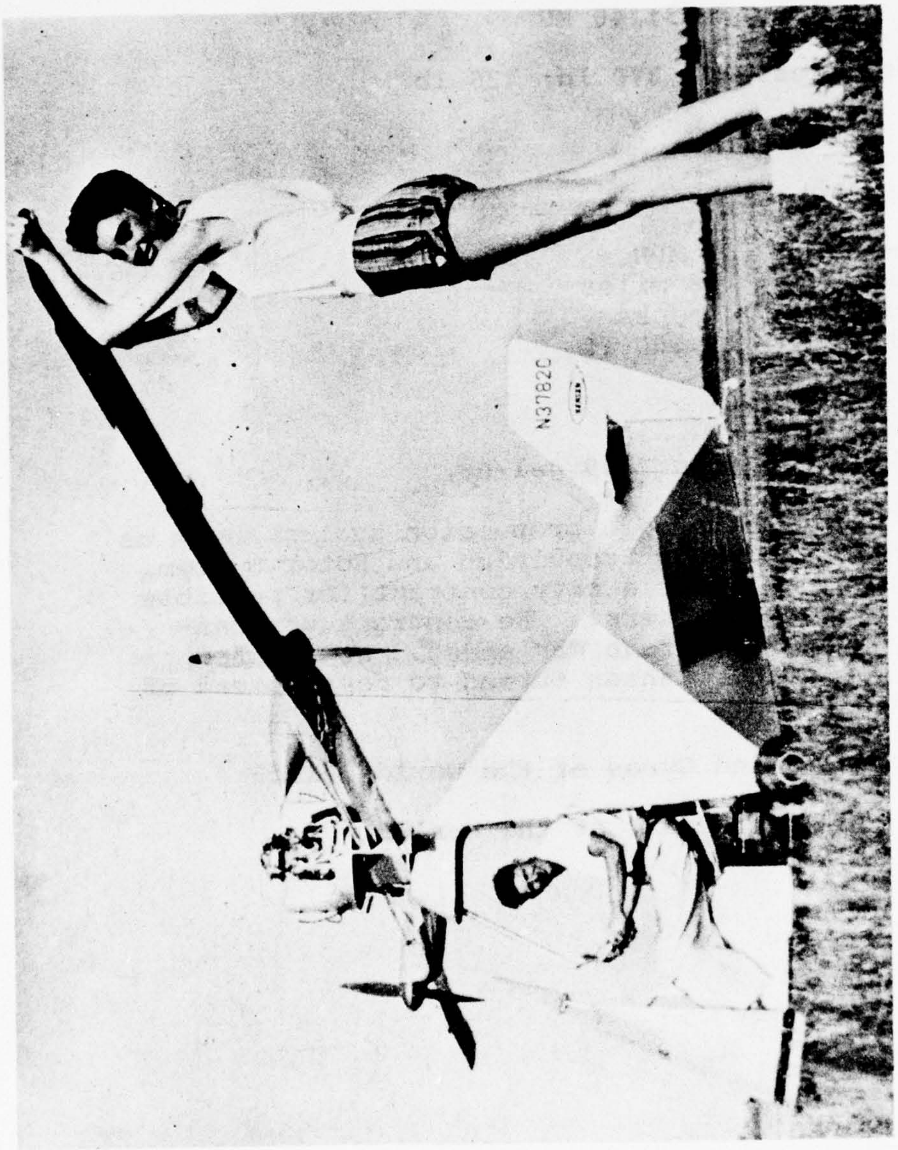
Other:

Fuel consumption 3.9 gal/hr

This aircraft demonstrated a propulsion system known as "HEPARS", High Efficiency Propulsion and Rotor System, which was developed under a navy contract for possible use in sky crane helicopters. The contract was cancelled early when the Korean War ended. No further development was done. Bensen turned to development of simpler gyro-gliders.

"Helicopters and Gyros of the World," 1959

"The Aircraft of the World"



Bensen's B-4 Skyscooter

Designer: Bleeker, Maitland B.

Country: U.S.A., Long Island

Date: 1929

Aircraft name: Curtiss-Bleeker Helicopter

General type: Prop-in-Rotor

Rotor radius; 23.5 ft., 4 blades

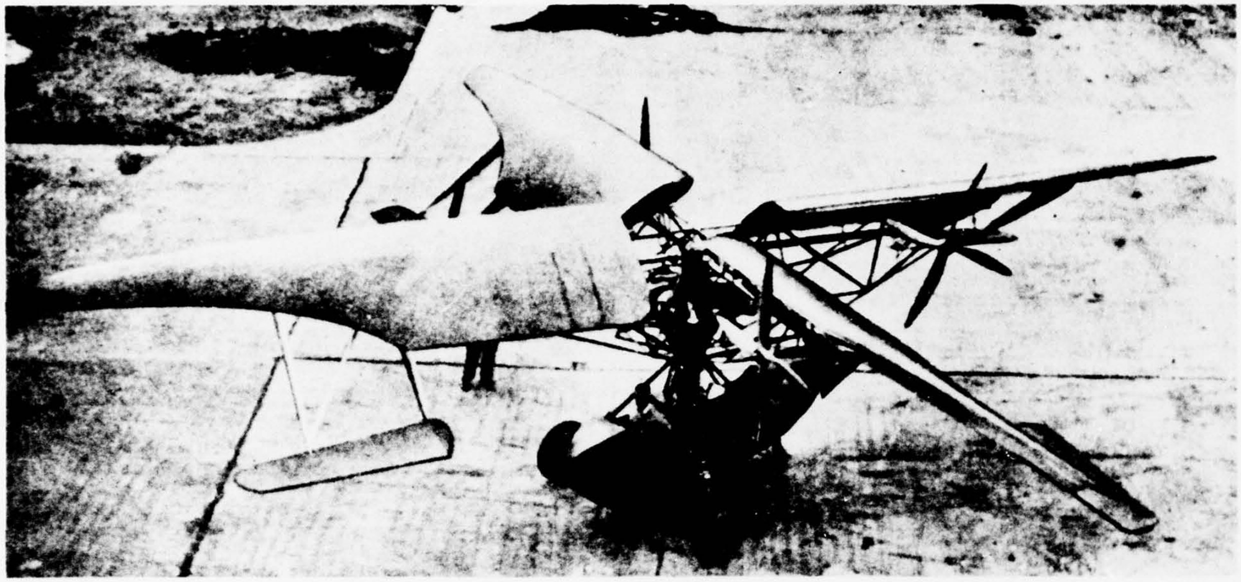
Engine: Pratt and Whitney Wasp: 425 HP

Empty wt; Gross wt: 2700 lbs, 3400 lbs

Remarks: The engine powered 4 seven foot diameter propellers through a complicated mechanical system of gears and shafts extending from the engine. With this method of drive it was not possible to use the hinged blade system. The Curtiss-Bleeker was an early attempt to build a rigid rotor helicopter. Cyclic and collective control was achieved by changing the incidence of the auxilary surface attached aft of each rotor blade. These were known as "stabovators." Yaw control was achieved with the rudder which operated in the downwash of the rotor. Horizontal flight was obtained by tilting the complete rotor unit forward. Work was discontinued after four years of effort due to the machine's poor lifting qualities, tremendous vibration, and poor control.

"Flying Windmills" by Frank Ross, Jr., 1956

"Modern Developments in the Helicopter" R. N. Liptrot.



Curtiss - Bleeker's Helicopter

Designer: Brennan

Country: England

Date: 1924

Aircraft name: - - -

General type: Prop-in-rotor

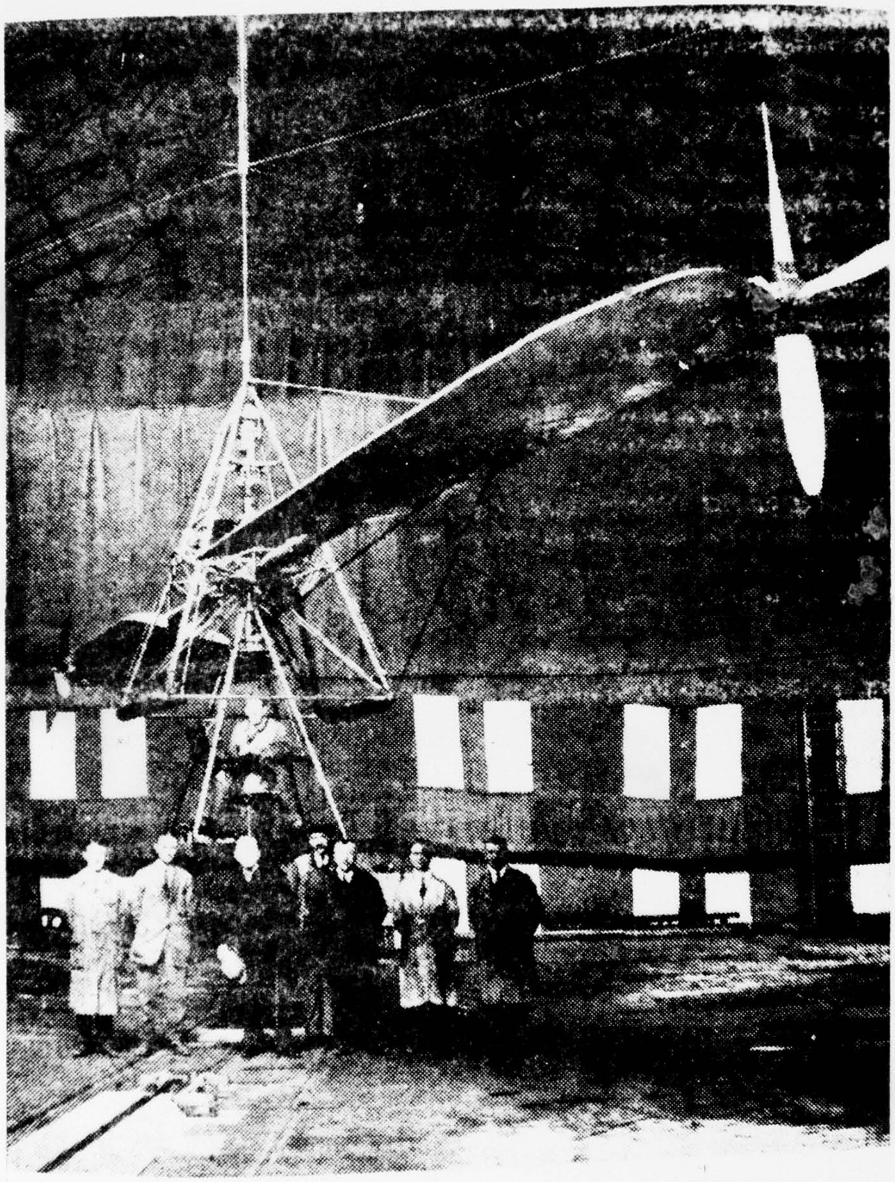
Rotor radius: 30 ft

Engine: Bentley B.R.2 230 HP

Empty wt; Gross wt: - - -; 3300 lb

Remarks: This aircraft was built at Farnborough on the recommendation of Winston Churchill. It made over 200 flights of an average of three minutes in duration and it showed itself capable of lifting five men. This aircraft flew in free flight in 1925. A crash stopped experiments for good in 1926.

"The Aero Plane" - July 8, 1955
"Helicopter and Autogyros of the world"- 1959



Brennan's Helicopter

Designer: Claesson, Ing. Sven

Country: Sweden

Date: 1944

Aircraft Names - - -

General type; Back-Pack Autogyro

Rotor radius: - - -

Engine: none

Empty wt: Gross wt: - - -

Remarks: No further information available

Claesson's Autogyro

Designer: Georges, Gerard

Country: Germany

Date: 1974

Aircraft name:- - -

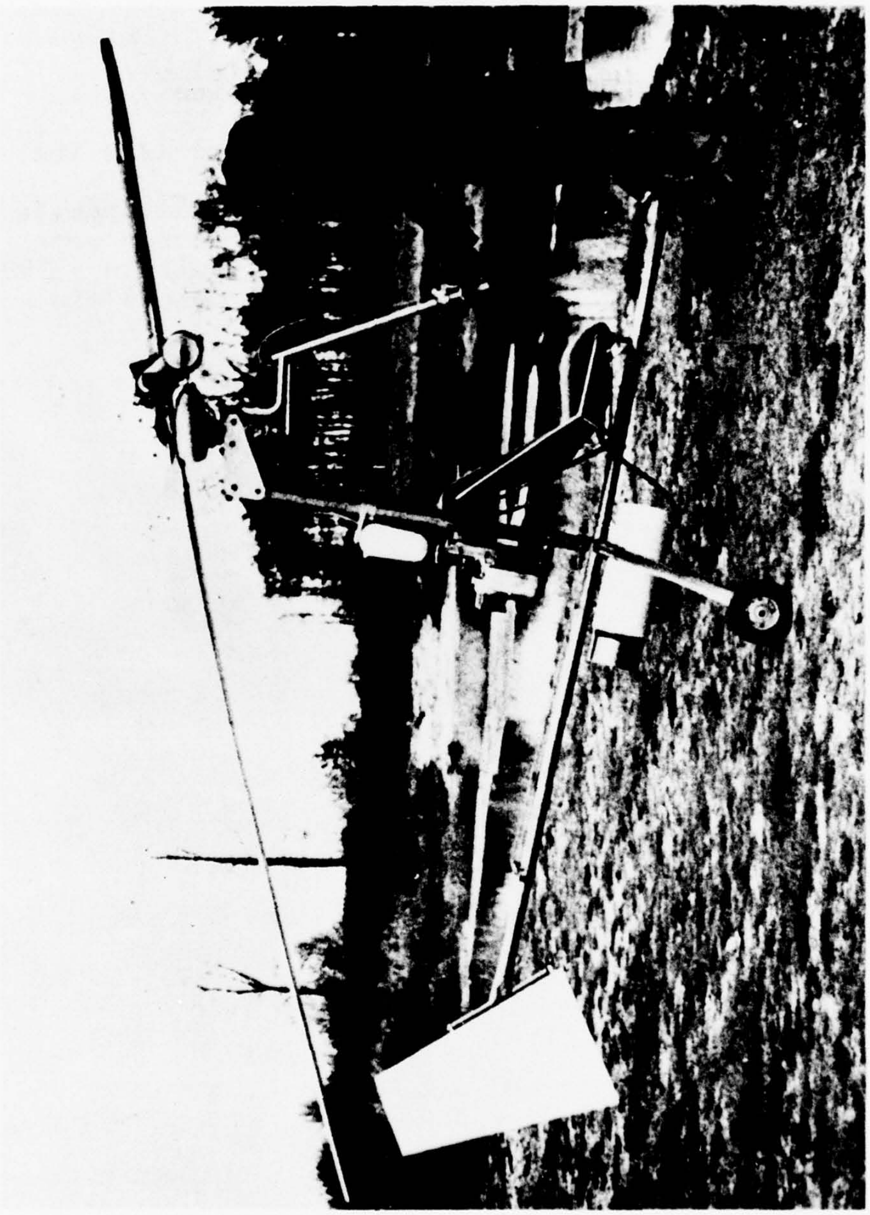
General type: Single bladed helicopter jet driven

Rotor radius: 3 meters (9.9 feet)

Engine: One 30 kg (67 lbs) thrust turbine

Empty wt; Gross wt: 60 kg(137 lbs) 170 kg (380 lbs)

Remarks: The turbine was constructed from a automobile turbo charger. The following performance figures were available: Top speed - 110 km/h (69 mph), ceiling - 3500 meters (11500 ft), and rate of climb - 150 meters/min (490 ft/min).



Georges' Single Bladed Helicopter

Designer: Gluhareff, Eugene M.

Country: U.S.A.

Date: 1960

Aircraft names: MEG-2X and MEG-1X

General type: Single and two bladed back-pack helicopter

Rotor radius: 10 ft

Engine: One or two G8-2-15 Tip-Jets, max thrust 18 lbs, propane fueled

Empty wt; Gross wt: 68 lb; 270 lb

Remarks: Performance (estimated)

Max forward speed - 47.5 knots

Hovering ceiling - 4,500 feet

Service ceiling - 17,000 feet

Fuel consumption is 14 gallons of propane an hour. The three gallon tank used gives 18 minutes of flight. Calculated range is 25 miles. The MEG-2X is illustrated.

"The Aeroplane", Oct 18, 1957

Gluhareff's MEG-2X

Designer: Flettner, Auton

Country: Germany

Date: 1927

Aircraft Name:

General type: Prop-in-rotor

Rotor radius: 49ft

Engine: Two Auzani 30 HP engines

Empty wt; Gross weight: - - -; 880 lbs

Remarks: The helicopter had an engine at the tip of each of its two blades which drove propellers. Using ropes to stabilize the aircraft, flights of 20 feet were achieved. Cyclic pitch was ineffective due to the twisting of the rotor blades. The aircraft wrecked itself in a high wind when it overturned. No pictures are available.

B.L.O.S Overall Report No. 8 by Liptrot, 1948

Designer: Junker, Arnold

Country: Canada, Quebec

Date: - - -

Aircraft Names: - - -

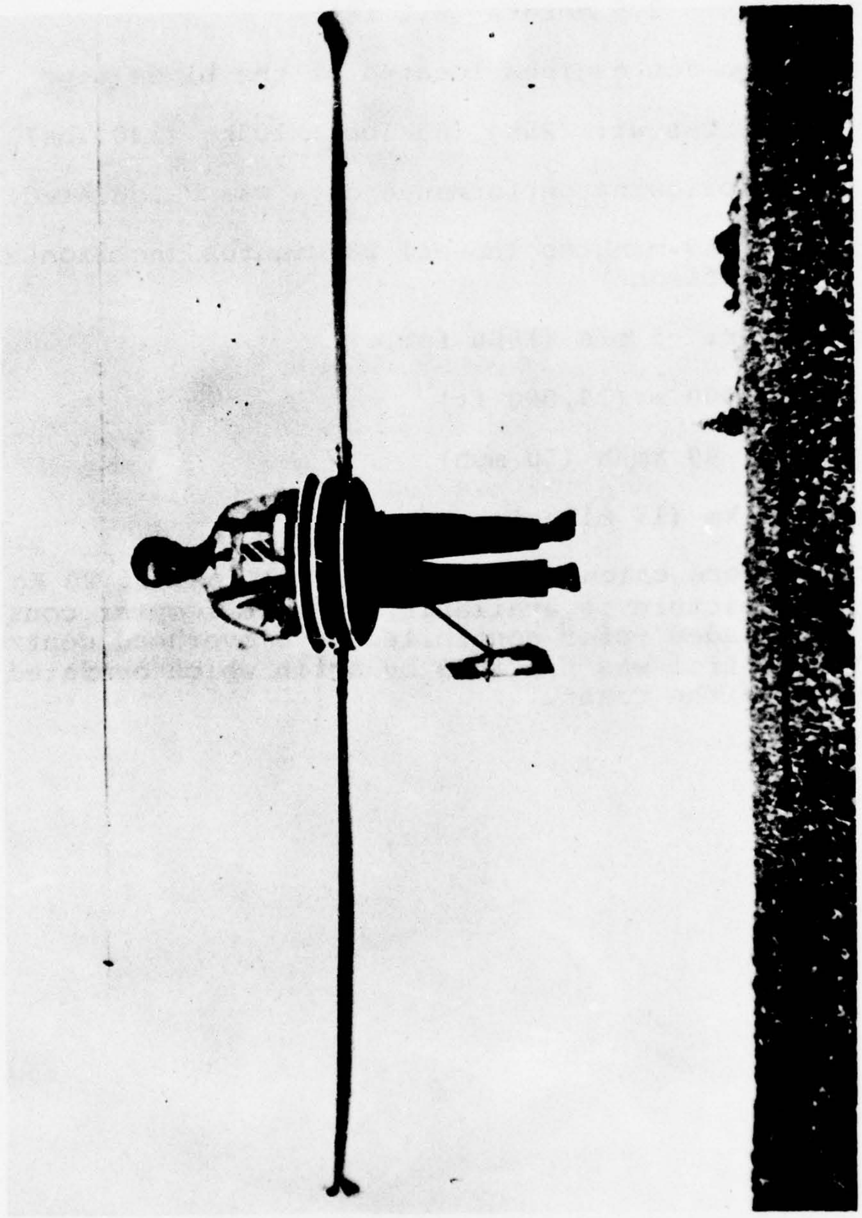
General type: Swiss flying belt design, revived in Canada

Rotor radius: 8 ft

Engine: Two pulse jet engines

Empty wt: Gross wt: 105 lbs; 375 lbs

Remarks: Original pulse jet tip units were Japanese. First model was destroyed in a crash, pilot was not seriously hurt.



Junker's Flying Belt

Designer: Just, Dr. W.

Country: Germany

Date: 1960

Aircraft name: JS-71

General type: Back-Pack Helicopter

Rotor radius: 2.5 meters (8.2 ft)

Engine: Two Jet engines located at the blade tips

Empty wt; Gross wt: 25kg (55 lbs); 105kg (230 lbs)

Remarks: The following performance data was calculated:

Endurance: 19 minutes (hover) 23 minutes (horizontal flight)

R/C in hover: 5 m/s (1000 fpm)

Ceiling: 3000 m (10,000 ft)

Top speed: 80 km/h (50 mph)

Range: 27 km (17 miles)

These figures were calculated using a fuel load of 20 Kg (44 lbs). No picture is available. The helicopter consisted of a two bladed rotor controlled by a overhead control stick. Yaw control was provided by a fin which operated in the downwash of the rotor.

Designer: Haustetter

Country: France

Date: 1950

Aircraft name: - - -

General type: Back-Pack Helicopter; torque driven

Rotor radius: - - -

Engine: 45 cc. two-stoke

Empty wt; Gross wt: 40 lbs; - - -

Remarks: No further information available. This machine probably doesn't fly.

Haustetter's Helicopter

Designer: Isacco, Vittorio

Country: England

Date: 1928-34

Aircraft Name: Helicogyro

General Type: Prop-in-Rotor

Rotor radius: 23.5 ft

Engine: Four Bristol Cherub; 32 HP each

Empty wt; Gross wt: - - -; 2,400 lbs

Remarks: The helicogyro illustrated is the second of three machines built by Mr. Isacco. The first machine was a single seater with a 41 ft diameter two bladed rotor with a Cherub engine at each tip. Total weight was 1,235 lbs.

The third machine had four De Havilland 120 HP engines mounted on the tips of a four bladed 90 ft diameter rotor. The engine in the nose was a 300 HP Wright. Total weight was 7000 lbs.

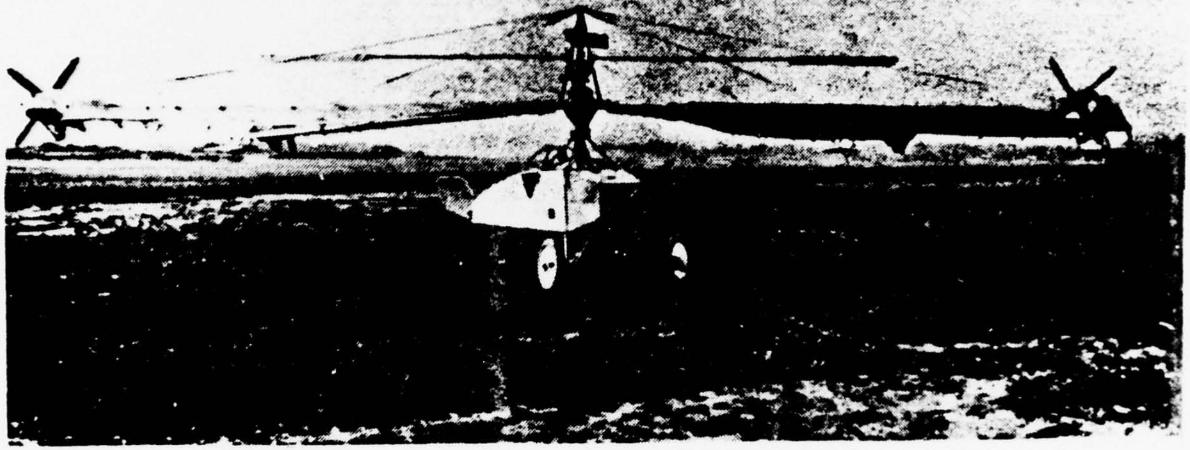
The first two machines were built for the British air ministry. They both achieved flight. The first required the engines to develop a total of 60 HP for a rotor RPM of 55. The second required 120 HP and a rotor RPM of 45. The third machine was built for the Civil Aviation Institute in Moscow. Before trials were carried out, Isacco left Russia.

"Helicopters and Auto Gyros of the World" 1959

"Development of Helicopter" by Roy Blay

"Modern Developments in the Helicopter", Liptrot

The Royal Aeronautical Society



HELICOPTER WITH TWO ROTOR-TIP POWERPLANTS—1927 (LEFT).

Isacco's Helicogyro

Designer: Kahnt, Hellesen

Country: France

Date: 1925

Aircraft name: - - -

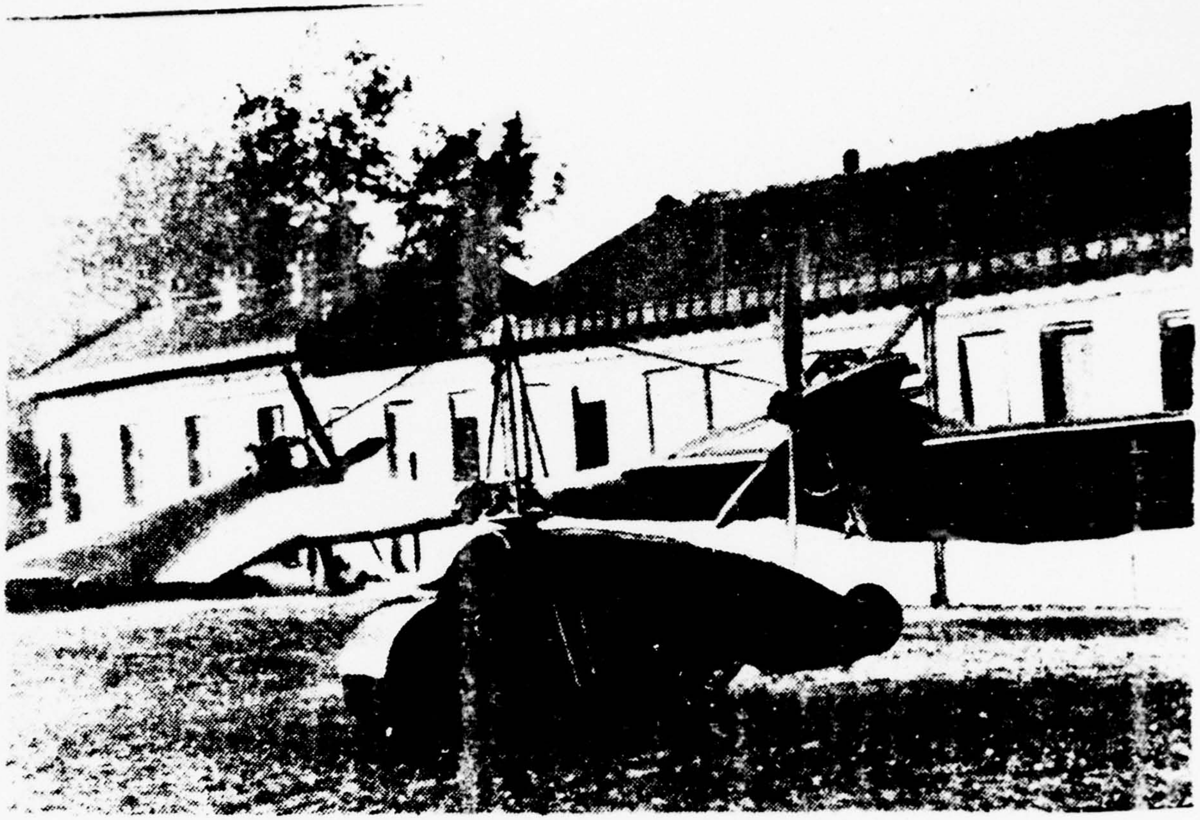
General type: Propeller in rotor

Rotor radius: 21 ft

Engine: Two Auzani 70-80 HP

Empty wt; Gross wt: - - -; 1760 lbs

Remarks: No further information is available.



Kahnt's Helicopter

Designer: Lemmerzahl

Country: Germany

Date: 1955

Aircraft Name: HL1

General type: Prop- rotor, single bladed helicopter

Rotor radius: 12 meters (39 feet)

Engine: One 30 HP Volkswagen engine

Empty wt; Gross wt:530 lbs (est); 400 Kg (880 lbs)

Remarks: The inventor claims the following performance figures:

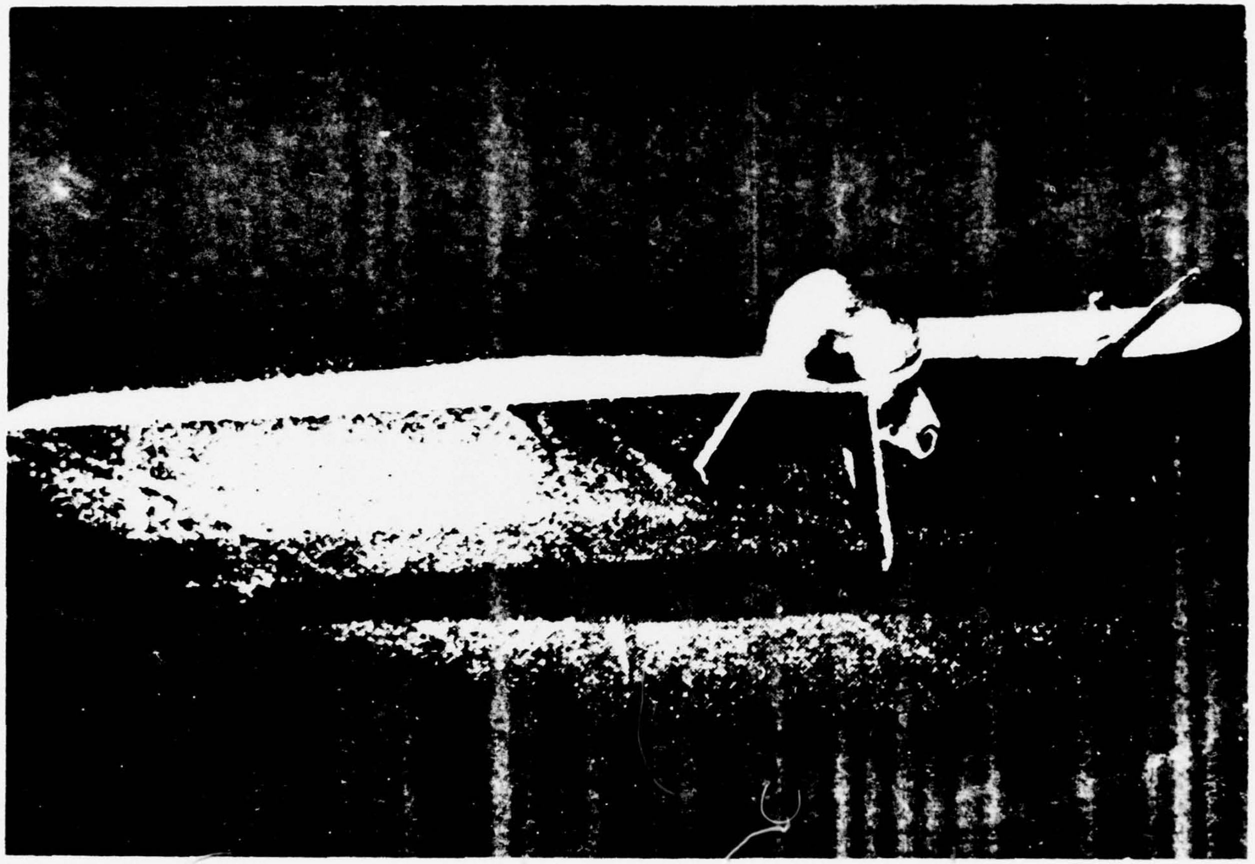
Cruise speed = 180 km/h (112 mph)

Action radius = 560 km (312 miles)

Fuel consumption - 6 liters/100 km (41 mpg)

This helicopter carried two people inside an enclosed sphere. The rotor spun around this sphere. Fins were provided on the landing gear for yaw control. The upper half of the sphere was made of plexiglas.

"Mechanikus" 1955



Model of Lemmenzahl's Helicopter

Designer: Magill, Gilbert W.

Country: U.S.A., Glendale, CA (1954), Odessa, TX (1975)

Date: 1954 - 1975

Aircraft names: Rotor-craft RH-1 Pinwheel (1954)
Aerospace General Mini-Copter (1975)

General type: Back-Pack Helicopter

Rotor radius: 8.5 ft

Engine: Two hydrogen-Peroxide rockets located at the blade tips. 20 lbs static thrust each

Empty wt; Gross wt: 165 lb; 400 lb

Remarks: The Rotor-Craft Pinwheel was developed for the U. S. Navy under a 1950 contract from the Office of Naval Research. The craft first flew in 1954. The craft was later reintroduced by Aerospace General as the Mini-copter. In 1975 the Navy purchased three of these aircraft for possible use as pilot rescue. The helicopter can fold into a compact package and may be dropped by parachute to downed pilots. Top speed is about 70 mph and it is capable of climbing vertically at 2000 fpm. Fuel capacity is 10 gallons and this gives the machine a flight endurance of 10 minutes.

"Jane's All the World's Aircraft" 1959

"The Aeroplane " May 10,1957

"Aviation Week " April 22, 1957

"Army " August 1973

The Pinwheel in Flight

Designer: Nagler

Country: U. S. A.

Date: 1952

Aircraft Name: XNH 1 Heliglider

General type: Two-Bladed Back-Pack helicopter

Rotor radius: - - -

Engine: Six 20 lb rockets

Empty wt; Gross wt: 65 lbs; 240 lbs

Remarks: "The XNH 1 intended use was to cross rivers or other obstacles. The required height was to be reached by power from six solid-propellent rockets, fired in pairs and providing a 20 lb thrust for about twenty seconds. Slow descent was ensured by the auto-rotation of the rotor. The six rockets could be replaced for later use."

"Helicopters and Autogyros of the World"- 1959

Nagler's Heliglider

Designer: Nagler and Rolz

Country: Germany

Date: 1939-1945

Aircraft Name: NR-54V1 and V2 and NR-55

General Type: Prop-in-rotor

Rotor radius: - - -

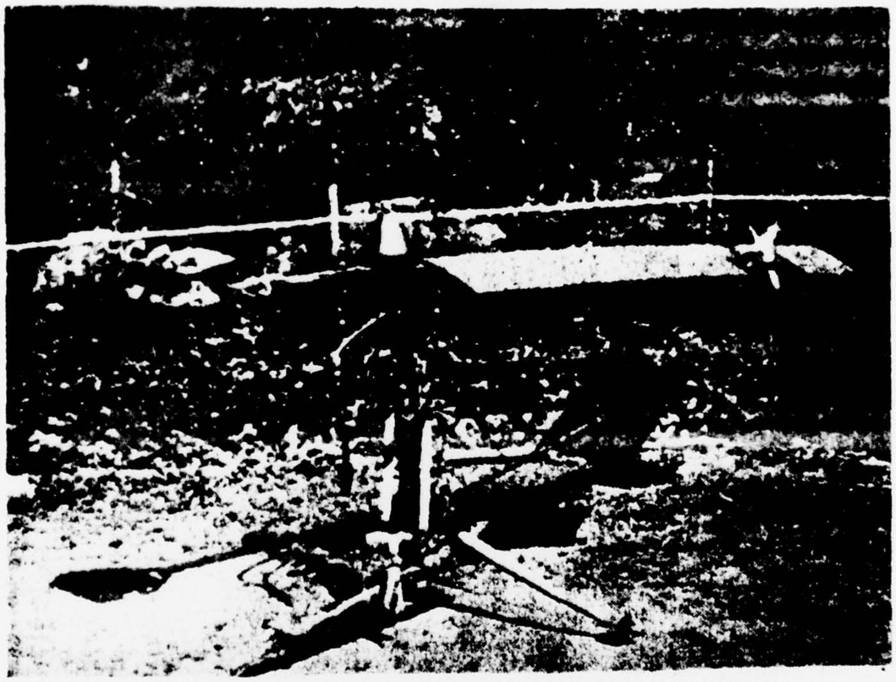
Engine: - - -

Empty wt; Gross wt: - - -

Remarks: "Bruno Nagler and Franz Rolz's first machine was the NR.55. The NR.55 has a single-bladed rotor, possessing a radius of approximately 17.5 feet and a blade chord of 1 ft. 7 1/2 in. A 40 hp engine was mounted as a counter poise to the blade, and twin contra-rotating airscrews, each having a diameter of about 1 ft. 10 1/2 in., were mounted on the blade 9 ft. 9 in. from the centre of rotation, and were driven at engine speed by shafting. To avoid carburation difficulties, the fuel tank and carburetters were mounted above the centre of rotation. The rotor turned at 135 rpm and was equipped with an automatic pitch-changing device to reduce the pitch from the flight setting (12° when hovering) to 4° for autorotation in the event of a power failure. The designed maximum speed was 60 mph, the NR.55 had a loaded weight of 770 pounds, and hovering tests were carried out inside a building, but no horizontal flight trials were completed.

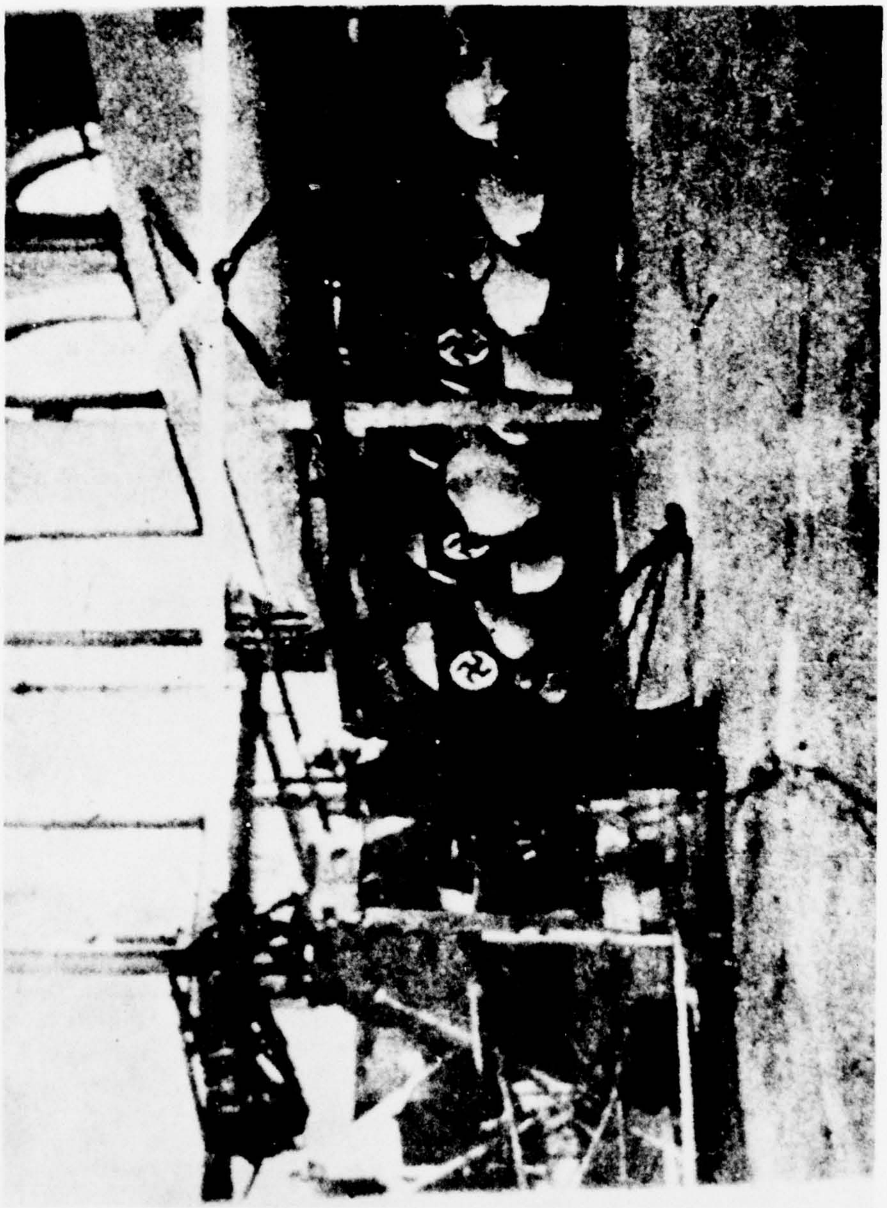
The NR. 54V1 was generally similar to the NR.55, but could be folded for transportation. Weighing 176 lb. empty and 396 lb. loaded, the NR.54V1 has a 24 hp engine and its single-bladed rotor had a radius of 13 ft. The designed maximum speed was 55-60 mph, but owing to unsatisfactory carburation, no flight tests were undertaken. The NR.54V2 differed from its predecessors in being a twin-engined machine with a two-blade rotor. An Argus short-stroke engine, developing 8 hp at 6,000 rpm was mounted on each of the two blades and, weighing 315 lb. loaded, the Nr.54V2 was designed for a maximum forward speed of 50 mph and a vertical climb rate of 480 ft./min. Vertical descent without power was estimated at 960 ft/min and, with one engine operating, 240 ft./min. The engines were located about one-third of the rotor radius from axis of rotation, and the blades were provided with flapping hinges but no drag hinges. The framework could be folded for transportation and could be easily carried by a man." All three machines are illustrated.

"Royal Air Force Review", September 1957



Nagler and Rotz's NR. 54 V1

Nagler and Rotz's NR.54V2



Nagler and Rotz's NR.55

Designer: Papin and Rouilly

Country: France

Date: 1915

Aircraft Name: Gyropter

General type: single - bladed helicopter

Rotor Radius: - - -

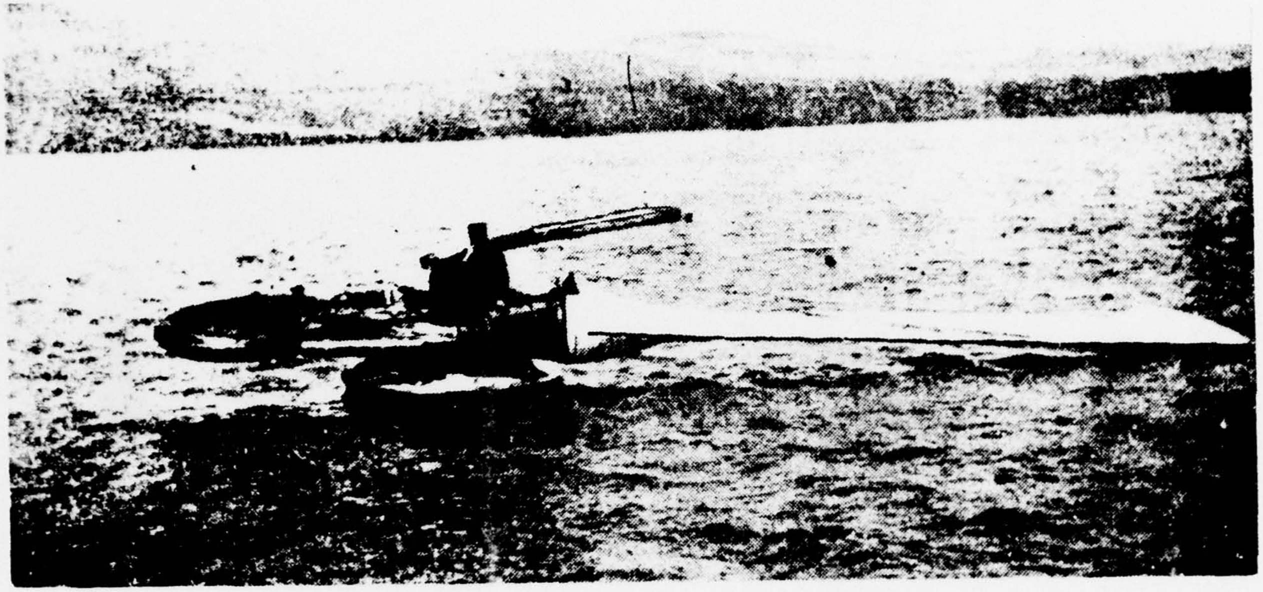
Engine: LE Rhone, 80 HP, Rotary Engine

Empty wt; Gross wt: - - -; 1,102 lbs

Remarks: Tests were carried out on 31 March 1915 on Lake Cercey on the Cote d'OR, and a rotor speed of 47 rpm was reached. Unfortunately the aircraft became unstable and the pilot had to abandon it, after which it sank.

"Helicopters and Auto Gyros of the World" 1959"

"Popular Science" 1922



Papin and Rouilly's Single Bladed Helicopter

Designer: Pentecost, Horace T.

Country: U.S.A.

Date: 1945

Aircraft name: Hoppi-Copter 1

General type: Back-Pack helicopter; coaxial

Rotor Radius: - - -

Engine: Two-stoke horizontally opposed engine, 20 HP

Empty wt; Gross wt: 110 lbs; 200 lbs

Remarks: Some twenty hops were made with the use of safety cables attached to the pilot. This strap-on helicopter can now be found in the Smithsonian Institution in Washington, D. C. A cruise speed of 50 mph was calculated for this machine.

"Helicopters and Auto Gyros of the World"

Pentecost's Hoppi-copter

Designer: Seremet, Wladislaw Vincent

Country: Denmark, Copenhagen

Date: 1965

Aircraft Name: - - -

General Type: Back-Pack Helicopter, torque driven with a conventional anti torque rotor.

Rotor radius: 4.9 ft

Engine: 15 Hp Two-Stroke

Empty wt; Gross wt: 81 lbs; 300 lbs

Remarks: A very successful helicopter. Simply a conventional torque driven helicopter scaled down.

Seremet's Miniature Helicopter

Designer: Weihrauch, Willi

Country: Germany

Date: 1952

Aircraft name: - - -

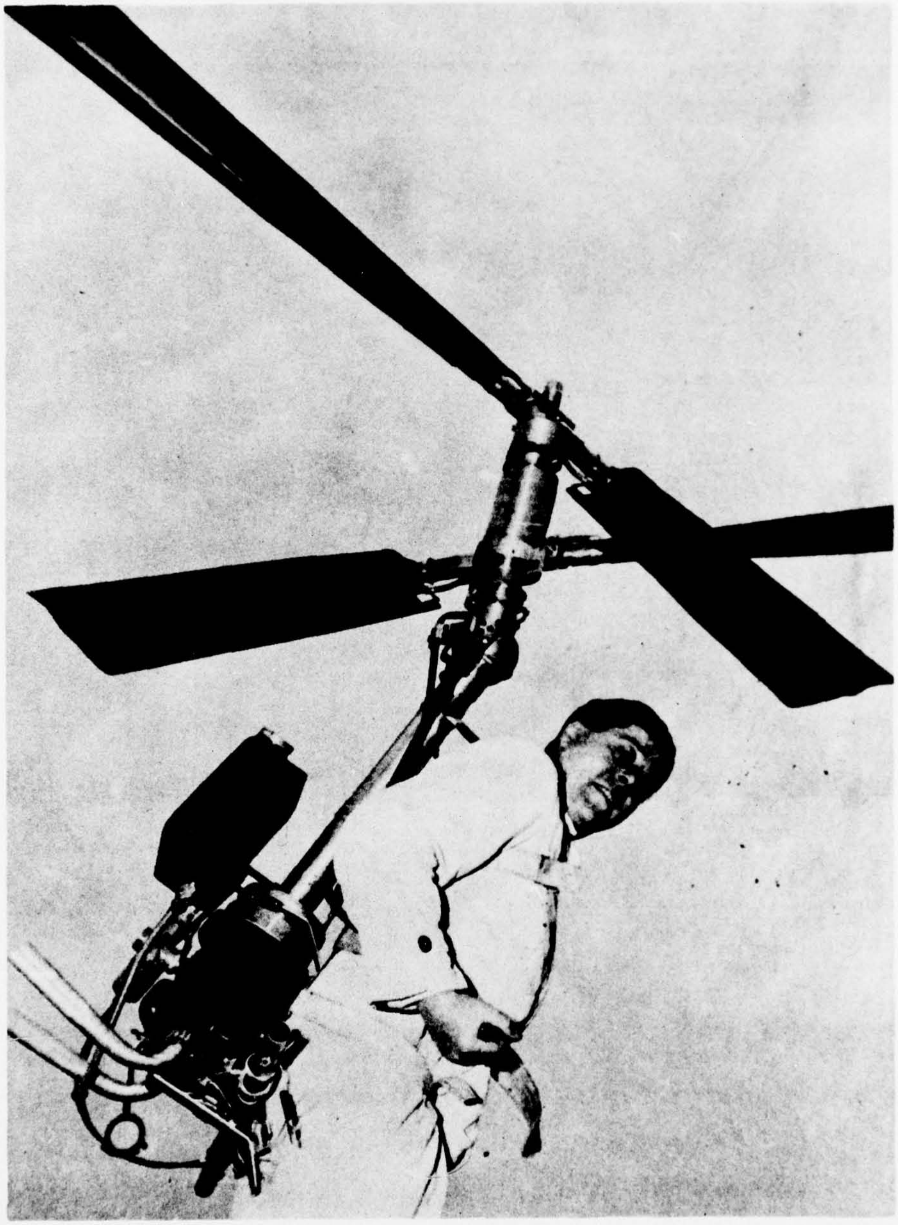
General type: Back-Pack Helicopter, two bladed coaxial

Rotor radius: - - -

Engine: 250 c.c., two stroke, 14 HP

Empty wt; Gross wt: 75 LBS, - - -

Remarks: Top speed 65 mph. No further information available.



Weihrauch's Coaxial Helicopter

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⑩ Martinus Maria Klijn

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The writer believes that there is a standing need for small, portable, strap-on backpack helicopters.

This paper describesthe history, the steps leading to the design and construction of a working prototype. The prototype has a single rotor blade, 12 feet long, balanced by a 4 foot spar supporting two counter rotating propellers. Specifications are given in the paper.

The helicopter described in this paper is not a device that fullfills the requirements for success. Recommendations are given for a future design.

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