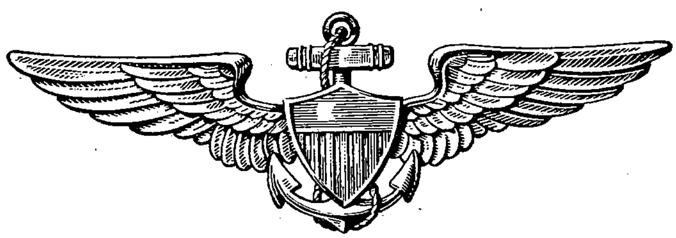
NAVAER 00-80T-41

HELICOPTER TRAINING MANUAL



ISSUED BY

THE OFFICE OF THE CHIEF OF NAVAL OPERATIONS

NAVAER 00-80T-41

HELICOPTER TRAINING MANUAL

NOTICE: This document contains information affecting the national defense of the United States within the meaning of the Espionage Laws, Title 18 U.S.C., Sections 793 and 794. Its transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law.

Reproduction of this document in any form by other than naval activities is not authorized except by special approval of the Secretary of the Navy or the Chief of Naval Operations as appropriate.

ISSUED BY

THE OFFICE OF THE CHIEF OF NAVAL OPERATIONS

U. S. NAVY 1952

REVISION PAGES

Date Issued	Date Inserted	No.	Inserted by (Signature)

FOREWORD

The Helicopter Training Manual has been prepared to help helicopter pilot and crewman trainees understand the background, theory of flight, and presently developed operating procedures for this comparatively new airborne vehicle.

The history of the helicopter is treated only from the standpoint of significant developments and therefore can not be considered to be complete in every detail. Many important persons may have been omitted. However, it does help demonstrate the trends in design and how we arrived at today's helicopters.

The basic theory of rotor blades, control, and rotor configurations, like other basic theory will remain valid for a long time. A good understanding of the principles outlined here can be quickly related to new designs and operating problems as they come along.

The Korean situation has given great emphasis to helicopter operations. Because almost every operation with a helicopter is a new one, to cover all of the problems with fixed doctrine at this time would be impractical. A knowledge of present operating procedures will be helpful in trying new ones.

The manual has been prepared under the direction of HTU-1 Naval Air Training Command, Pensacola, Florida; HU-2, Naval Air Station, Lakehurst, New Jersey; the Rotary Wing Design Branch, Bureau of Aeronautics; and DCNO (Air) Aviation Training Branch.

It is hoped that the helicopter student may find this a ready reference in his training, but because of the rapid advances in operations and helicopter performance, it is also important to keep abreast of all new material as it appears.

CONTENTS

Part I • History

PART I
HISTORY

Due to the extreme simplicity of the basic idea of vertical flight, it is not surprising that the use of power-driven whirling wings or "air screws" should have been advocated before the principles of horizontal flight were developed. It seemed evident, even to the earliest experimenters, that if whirling wings could be turned with enough power, they would support themselves in the air. Also, they could probably be made to develop enough surplus lift to support a framework, a pilot, and an additional load.

It was apparent that a successful machine that could rise vertically from the ground and also descend vertically would have a number of valuable features. And it seemed reasonable that if such a device could be produced, it could also be made to fly horizontally in response to the pilot's controls.

CHAPTER 1

WHEN THE HELICOPTER BEGAN

In its first form, the helicopter was conceived by Leonardo da Vinci, back in the middle ages, and a rough sketch with notes described his idea. (See Figure 1-1.) In his notes he used the Greek word "helix" meaning a spiral, and he is believed to have combined this word with "Pteron," meaning wing. It is from this combination of Greek words that our word "Helicopter" is derived.

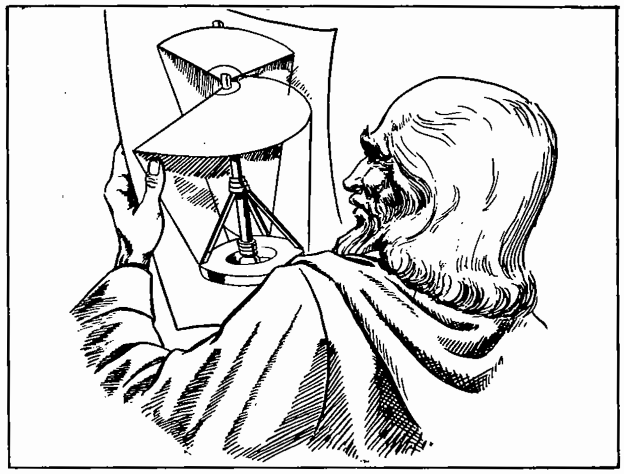


Figure 1-1

If the development of the idea of vertical flight had proved as simple as the idea itself, the helicopter would undoubtedly have been the first practical airplane in the field. But the development, instead of being simple, proved extremely complicated and difficult. Some of the early helicopters such as those of Cayley, (See Figure 1-2) Forlanini, Trouve and others, were made only as working models. Others, made up as full-sized machines, failed to provide sufficient lift to raise them off the ground. A few developed enough power to lift their own weight but did not have the extra lift necessary to carry the pilot. Even after the introduction of the internal combustion engine, lack of sufficient power was a common cause of failure. It took many trials and many failures to convince the early experimenters that the then existing 25 or 50 horsepower engines were not powerful enough to insure flight, even under the most favorable conditions.

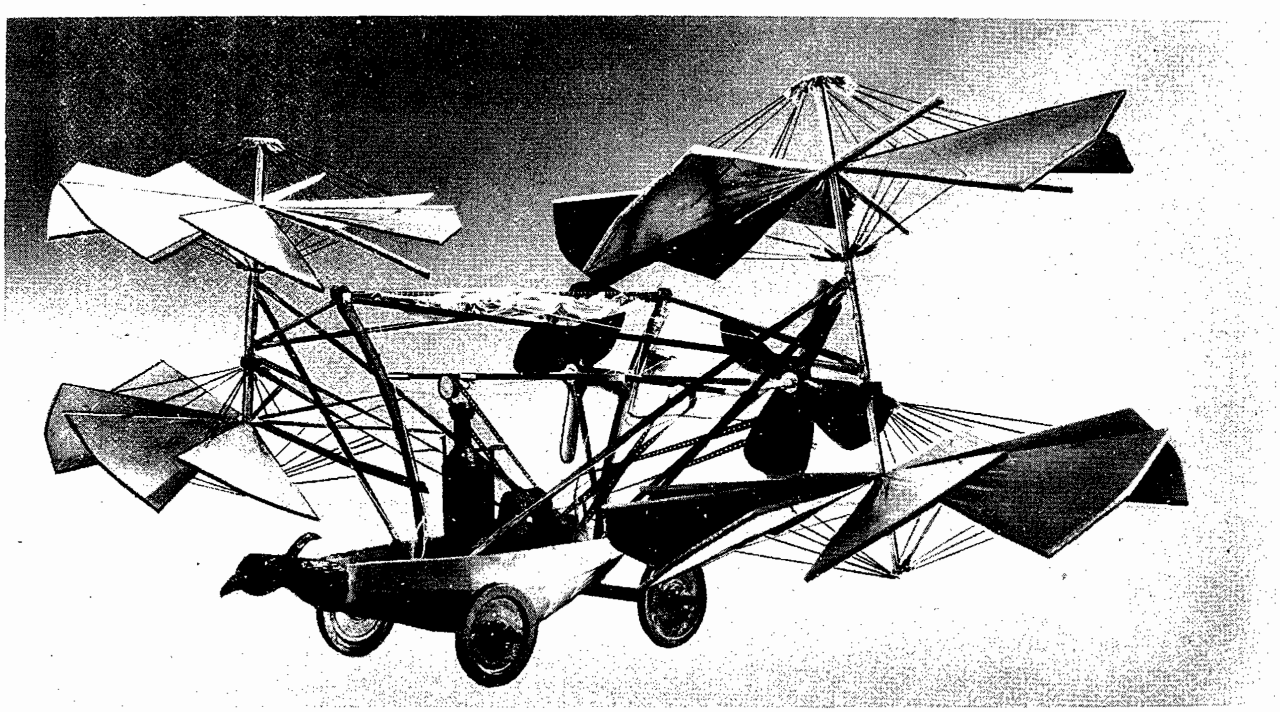


Figure 1-2. Model of a proposed aircraft designed by Sir George Cayley and described in an article in the Mechanics Magazine in 1843. This model was constructed in 1923 by the U. S. National Museum.

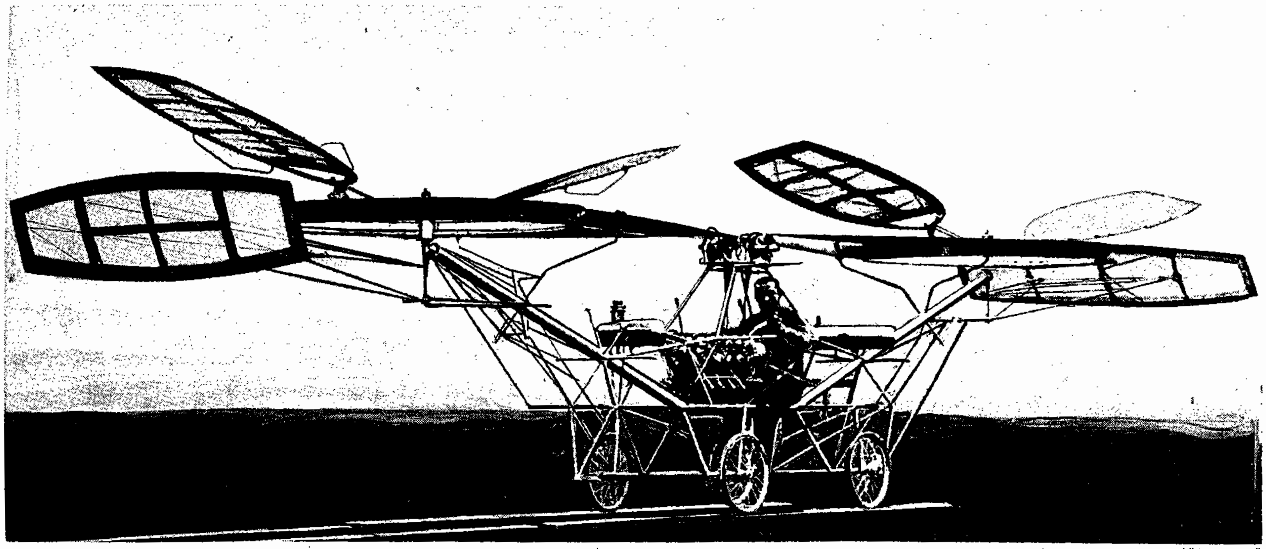


Figure 1-3

It was this lack of power that was responsible for the failure of Paul Cornu's two-rotor helicopter, which he built in France, in 1907. (See Figure 1-3.) It was powered by a 24-horsepower gasoline engine. With full power, Cornu was able to get the helicopter off the ground, supporting its own weight alone. With the weight of the pilot added, it could not be made to rise. Control was poor, and the machine could remain airborne for only about 20 seconds.

BREQUET—FIRST TO LEAVE THE GROUND

In 1907, the year of Cornu's experimental model, and four years after Wright's flight at Kittyhawk, a French engineer, Louis Brequet, succeeded in flying a helicopter of his own design. The machine was built in the form of a cross with a biplane rotor at the end of each arm. (See Figure 1-4.) It was powered by an engine with sufficient horsepower to enable the helicopter to lift itself with a pilot aboard. The machine was unstable, had no satisfactory means of control, and was not practical as a piece of apparatus for vertical flight. But its brief flight distinguished Brequet as the first man to leave the ground in a helicopter.

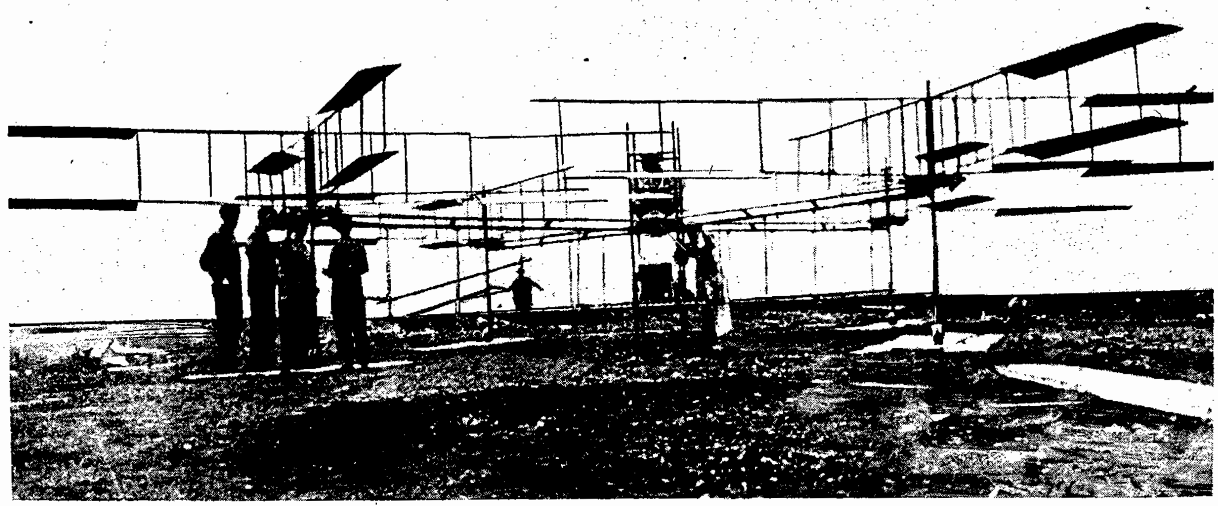


Figure 1-4

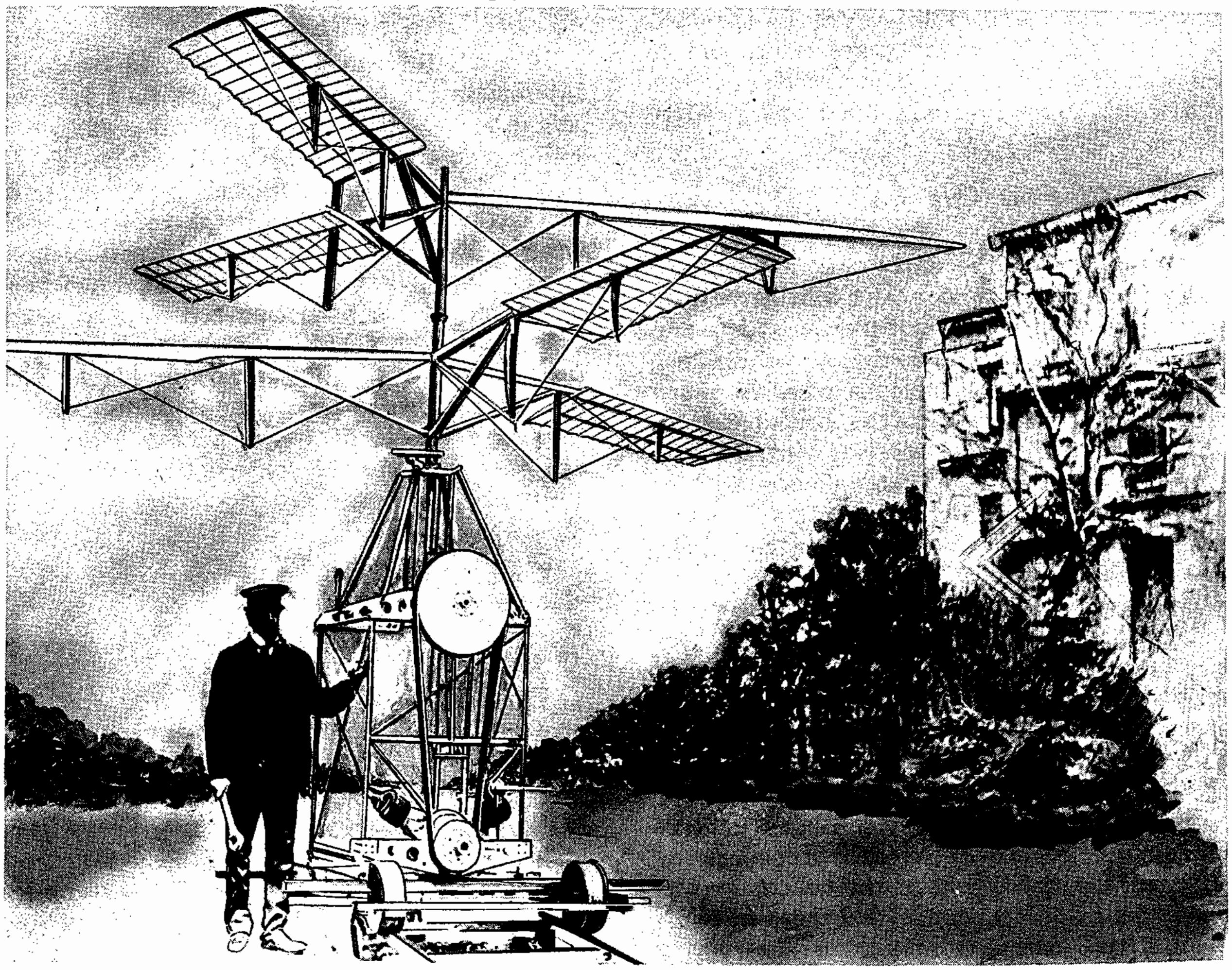


Figure 1-5. The first Sikorsky helicopter.

SIKORSKY ENTERS THE FIELD

The question of control was still unsolved when Igor Sikorsky entered the field in 1909. (See Figure 1-5.) He had followed the experiments of Wilbur and Orville Wright, and was convinced that he could make substantial contributions to the science of aviation. It was his belief, however, that the helicopter was a much more practical form of airplane than the type being developed by the Wright Brothers. Accordingly, he applied his efforts to vertical, rather than horizontal flight.

Sikorsky selected a 25-horsepower Anzani engine with which he had become acquainted while studying aviation in Paris.

This engine had already been used successfully in several light airplanes. His design included two lifting propellers. These propellers were mounted one above the other, and turned in opposite directions on the same axis (the rotor arrangement now known as the coaxial configuration). At the trial, the machine vibrated to an alarming extent and failed to raise even its own weight from the ground. By working over the design, the inventor was able to make the engine run with considerably more smoothness. Performance was improved so much that, with full power applied, the helicopter would lift itself into the air. Still there was not enough power to carry a pilot, and the addition of even a small weight would bring the machine back to earth. The inventor could find no immediate solution to the problem of securing greater lift without greater weight and abandoned his project. He then turned his attention to the conventional airplane. Igor Sikorsky was destined to return to the helicopter field a number of years later, and to find a solution not only to the question of greater lift, but to that of simplified and positive control.

PETROCZY AND THE CAPTIVE HELICOPTER

At the time of the early Sikorsky experiments, the captive balloon was considered necessary for observation, gunfire spotting, and other military use. It was only natural that the idea of replacing such balloons with the much discussed helicopter should be considered. In such an application the matter of control would be greatly simplified. The rotor blades could be placed at a fixed angle and the only control needed would be the throttle to provide more or less engine power as conditions required.

Proposed in 1915 by Lieutenant Petroczy of the Austrian Army, the concept of the captive helicopter was developed by Professor Theodore von Karman, who was then a professor of aerodynamics at Aix-la-Chapelle. The helicopter of his design was provided with coaxial propellers, turning in opposite directions. Power was supplied by three 120 hp Le Rhone engines which were connected to the propellers by shafts and gears. Weight of the helicopter was approximately 3,200 pounds, and there was sufficient lift to carry the pilot, an observer, a machine gun and fuel for an hour of flight. In tests carried on with this captive helicopter, several ascents were made to an altitude of approximately 150 feet. A feature of this helicopter was the position of the crew. They were to be stationed on top of the rotors, with full visibility above. The captive helicopter held promise as a replacement for the captive observation balloon, and appeared to be less vulnerable to fighter attack.

Tests of the captive helicopter were carried on for several months, but the inventors failed to find anybody who would serve as an observer. In its final ascent the engines began to misfire; the machine oscillated violently, and crashed to the ground. The destruction was complete and the idea of a captive helicopter was never revived.

In spite of the discouragements and failures up to this time there were many who still believed that the helicopter was the most practical form of airplane.

DE BOTHEZAT AND HIS THEORY OF LIFTING SCREWS

In 1921 the armed forces showed an active interest in the helicopter, which they believed might be developed into a practical machine for military use. With this belief, Major T. H. Bane, chief of the Engineering Division at McCook Field, entered into a contract with George de Bothezat to build a practical helicopter. (See Figure 1-6.) De Bothezat had published his theory of lifting screws two years before, and it was on the basis of his exact data for the design of helicopter rotor blades that the contract was signed. De Bothezat was to furnish complete drawings of the helicopter, and was to supervise construction and trials.

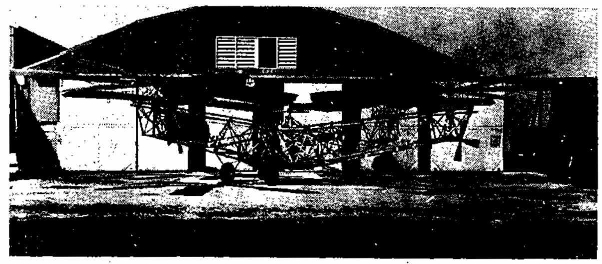


Figure 1-6

It was stipulated, in the contract, that de Bothezat was to be paid according to the performance shown in the test runs. The first trial was made with power supplied by a 180 hp Le Rhone engine. This engine was later abandoned in favor of a 220 hp engine capable of rotating the lifting rotors at 90 rpm. The six-bladed rotors were mounted on the ends of the arms of a cross-shaped framework. The pilot sat inside the framework of one of the arms. The structural part of the machine was 65 feet in width by 62 feet in length, and approximately 10 feet in height. Actually there were eight rotors in all on the de Bothezat machine: the four six-bladed lifting rotors, and two rotors turning in vertical planes to control horizontal motion. There were also two three-blade conventional propellers just above the engine.

Controls of the de Bothezat helicopter were considerably more complicated than those of a conventional airplane. The pitch of the rotor blades was controlled by a stick, and foot pedals. A wheel control, of the steering wheel type, regulated the pitch of the three-blade rotors. A larger wheel, rotating on the same center determined the pitch of the main blades. A standard throttle arrangement controlled engine speed.

A NEW RECORD FOR DISTANCE

The de Bothezat helicopter was first tested in December 1922; the duration of the first flight was slightly more than one and one-half minutes. The important feature of this aircraft was that for the first time the pilot was able to exercise an acceptable degree of control over the machine. The distance covered in this helicopter's first flight was approximately 300 feet, but some of the distance was the result of the wind. The pilot maintained good control, and he was able to make a fairly smooth landing at the end of the flight.

Tests on the de Bothezat helicopter continued into 1923. Trials included weight lifting, and the first helicopter passenger was carried. In spite of the good showing made by the machine, it failed to come up to the contract performance, and later in the year the Army decided to drop the project. Part of the failure was due to insufficient power and part to overweight and structural defects. The craft failed to attain sufficient altitude for sustained forward flight and complete tests for controllability were never carried out.

JUAN DE LA CIERVA AND HIS AUTOGIRO

It was shortly after the publication of de Bothezat's theory of lifting screws that Juan de Cierva of Madrid began to make an impression with his new method of using rotors. (See Figure 1-7.) Through his experiments, carried on from 1920 to 1928, he discovered autorotation,

Figure 1-7. Juan de la Cierva and his autogiro.

in which the movement of the craft through the air keeps the rotor turning, and dissymmetry of lift, or the difference in lift between the blade moving into the airstream and the one moving with the airstream. He had already built a conventional sportplane which had become popular in Europe. In a crash of one of these airplanes the pilot was killed, and de la Cierva began the development of an idea for an airplane which could fly safely at low speeds. Realizing that there was a critical value below which the lift of an airfoil is lost, he conceived the idea of using rotating airfoils instead of fixed wings. The plan he worked out caused the airfoils to rotate automatically and to act as wings for the plane.

De la Cierva's first autogiro utilized a system of counter-rotating rotors, but failed to fly because of the interference of one rotor with the other. In the year following his initial trial, he made another attempt, using a single five-bladed rotor. At this point de la Cierva ran into difficulties. He found that just before take-off, his machine developed a strong tendency to turn over and that the side which raised up was always the side on which the rotor blade was moving *into* the airstream.

As a result of his observation, de la Cierva developed a theory which is recognized by every helicopter engineer, and which is applied to every successful helicopter . . . the theory of "dissymmetry of lift."

FIRST AUTOGIRO FLIGHT

In 1928 de la Cierva built an autogiro with a four-blade, fully-articulated rotor, making use of the newly discovered principle. His aircraft was a complete success. As a result of his exhibits, he made an impression on engineers and scientists throughout the world. He started the trend in rotary-wing aerodynamics that gave a new impetus to the helicopter.

It was apparent that the autogiro had a number of advantages; it was excellent as a photographic airplane; it could be used, because of its slow speed, to pick up messages from the ground; and it gave splendid results on map-making projects. Structural weaknesses of the autogiro were met with and were overcome, but this airplane did not develop into a form that was practical for the armed forces. After extensive trials of the two models, the YG-1 and the YG-2, the decision was made that this machine was not the ultimate answer for the armed forces, as it lacked the lift and the space required for carrying the desired load.

EMILE AND HENRY BERLINER BUILD A HELICOPTER

In 1920, Emile Berliner, who held patents for several inventions, turned his attention to the helicopter and, working with his brother Henry, produced two models; one in 1920 and one in 1923. The first of these machines consisted of a small, heavy framework which served both as an engine mount and support for the coaxial rotors which he used. (See Figure 1-8.) With this machine, he attained a hovering height of about four feet. The second

Figure 1-8

model, built in 1923, had a dual (side by side) configuration of rotors. This aircraft was essentially a triplane, and the rotors were mounted on the tops of the right and left wings. This helicopter could rise to about 20 feet, hover briefly, maneuver in a 300 foot radius and proceed at about 40 miles per hour. It was powered by a 200 hp Bentley engine which drove the two rotors through shafting and gears, and also had a small controllable pitch rotor just forward of the rudder. This small rotor also turned in a horizontal plane. A feature never used before appeared in the Berliner Helicopter; this was the sets of vertical, adjustable vanes, or deflectors. There were four sets of these, located fore and aft of the left wing and fore and aft of the right wing, and in the downstream of the rotating blades.

In operation, the Berliner machine gained altitude by the lift of the two rotors over the wings. Then it proceeded to move horizontally by changing the pitch of the tail rotor. That is, if the pitch of the tail rotor was increased, it would raise the tail and incline the main rotors so that their downstream would give a forward push as well as the necessary lift, to the helicopter, and the machine would move forward. The helicopter was balanced laterally by controlling the shutter blades. The foot control turned the machine by moving the rudder. The triplane wings were used solely to increase lift when moving forward, and to provide support in the event of engine failure.

HELICOPTER DEVELOPMENT ABROAD

In the years that followed Berliner's experiments, work on the helicopter continued in several parts of the world. In France, Oemichen tried to combine a helicopter with a blimp; in Spain, Pescara had some success with a helicopter using counter-rotating rotors. In Holland von Banhauer, in 1930, built a helicopter with a single main rotor and a tail rotor . . . the configuration found in many helicopters today. In Italy, in the same year, d'Ascanio produced a coaxial helicopter which was able to remain airborne, and on one occasion remained in the air for 9 minutes. The first successful tandem rotor helicopter was flown in Belgium by Florine, also in the year 1930.

There has probably not been a single day in the past quarter century when aeronautical engineers have not been working on the helicopter, seeking new principles, testing out new designs, and trying to add in practical ways to the work of inventors, research workers and engineers who preceded them. But it was not until 1933, when the armed forces of the United States began to show a renewal of active interest in the helicopter, that substantial and continuous progress began.

By 1935 the helicopter had reached a point where its practical value began to be apparent. Louis Brequet had returned to the helicopter field in 1931. After one unsuccessful attempt, he built a large coaxial helicopter powered by a 350 hp engine. (See Figure 1-9.) It made use

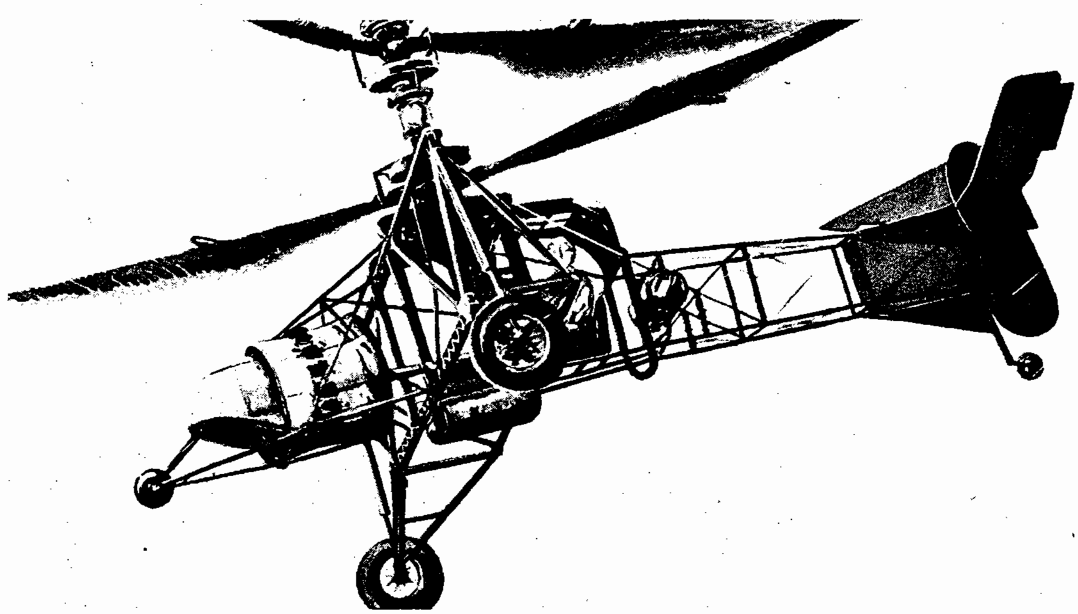


Figure 1-9

of many of the principles that had been discovered through experimentation with the autogiro. Trials made in 1935 proved that this new helicopter could take off vertically, that it could hover over a spot and that it was able to fly forward, backward or sideways. The machine could be readily maneuvered and could be landed at a selected spot. It not only reached an altitude of 500 feet, but on one occasion remained airborne for more than 45 minutes. It is credited with a forward speed of more than 50 miles per hour. Brequet's helicopter was overweight, and control at times was marginal, but the record shows that this machine in many ways was a useful and most practical helicopter. Based on the results of his experience with this model, Brequet prepared a scientific paper in which he proposed a gigantic transoceanic helicopter. Plans were never completed. In spite of the promising character of Brequet's development work he abruptly abandoned his efforts. There seems to be no record of any more Brequet helicopters.

FOCKE-WULF HELICOPTER SETS NEW RECORDS

Credit for the world's first really practical helicopter must go to Dr. Heinrich Focke of the Focke-Wulf Company, which produced the German FW-190 fighter plane. (See Figure 1-10.) Dr. Focke had obtained some experience in rotary wing aerodynamics when his company built a version of the de la Cierva Autogyro under license. And in 1937 he designed and built a dual-rotor helicopter which he designated as the FW-61.

With the FW-61, many early records were established.

Among these were:

Duration . . . One hour and twenty minutes
Distance . . . 143.069 airline miles
Altitude . . . . 11,243.416 feet
Speed . . . . . . 76.151 mph.

The machine was demonstrated in a number of European cities and caused wide comment. Its advantage of precision control was demonstrated. The FW-61 is generally considered the world's first practical helicopter, and the records set with it were not broken until Igor Sikorsky returned to the field and again began the development of the rotary wing airplane.

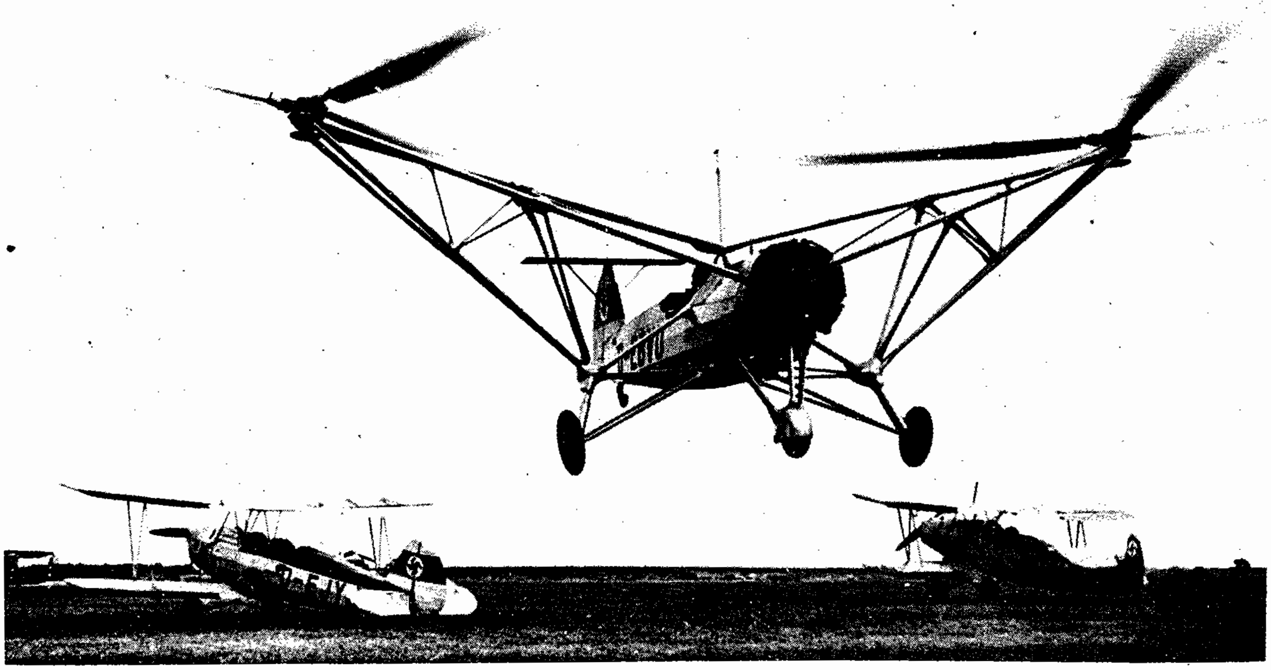


Figure 1-10. The Focke helicopter. The motor on the nose of the craft turned both the rotors which supplied the lift and forward motion. This helicopter could hover for minutes and go 76 miles per hour.

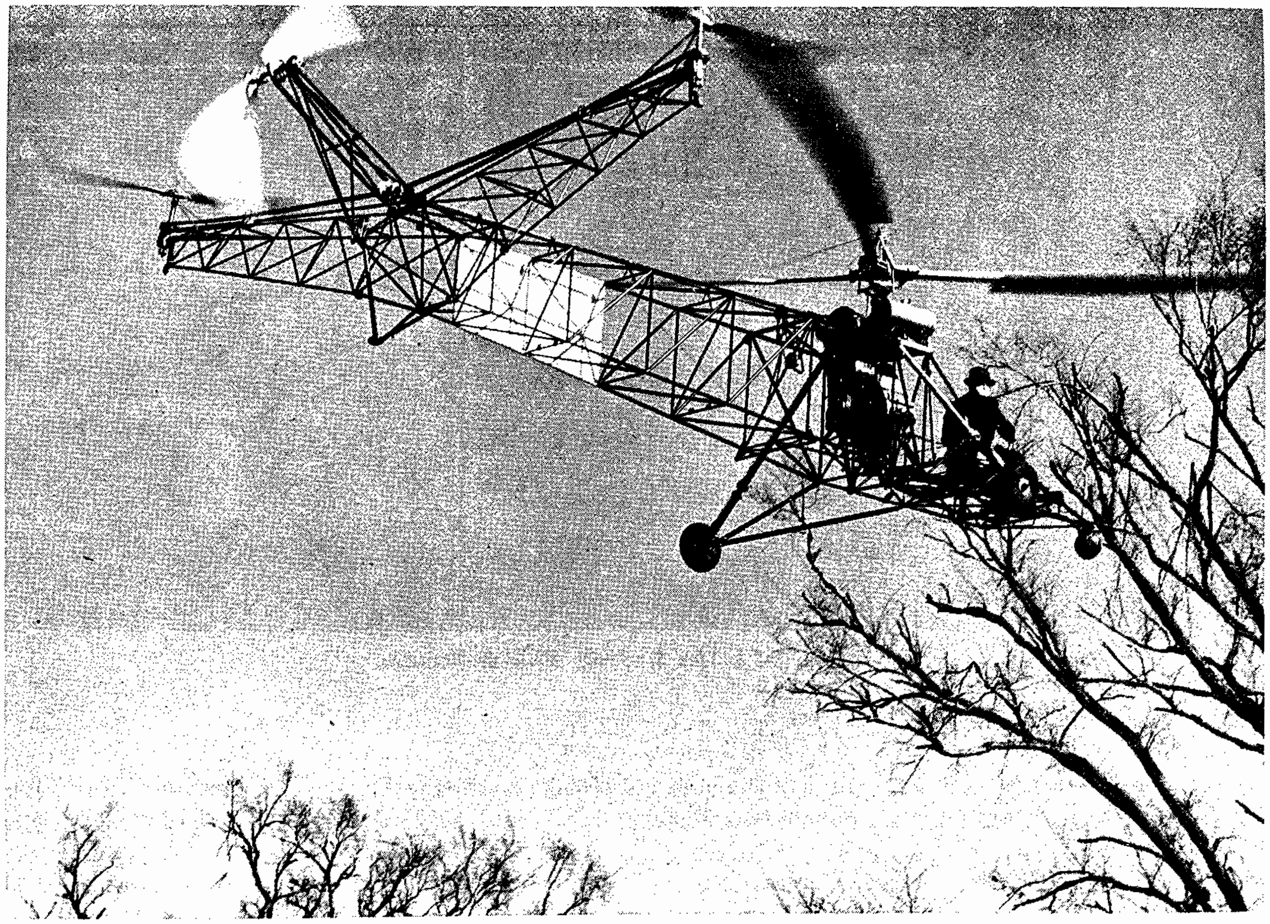


Figure 1-11. The Sikorsky helicopter VS-300 operating in close quarters.

SIKORSKY RETURNS TO THE HELICOPTER

When news of the accomplishments of the FW-61 reached this country, Igor Sikorsky made a trip to Germany to see the new helicopter and to talk with its designer. On his return to the United States, he immediately began work on the Sikorsky VS-300. On the 14th of September, 1939, this craft, which ranks as America's first practical helicopter, made its first flight.

In its initial form, the VS-300 was crude, construction was somewhat flimsy, and control was sometimes marginal. (See Figure 1-11.) But this machine was built for experimentation, and its design was changed many times. Eventually it was given a place of honor in the Edison Institute Museum. With this experimental model, Sikorsky utilized the principle of cyclic pitch control which had been patented by Pitcairn and Wilford. Sikorsky, in the course of his work, discovered many phenomena which are today part of the science of helicopter design. On May 6, 1941, this experimental model broke the world's helicopter endurance record, with a flight of 1 hour, 32 minutes, 26.1 seconds.

Taking full advantage of all the discoveries made with the VS-300, Sikorsky now began work on the XR-4, the prototype of the helicopter he was to build for the Army Air Forces. The army contract called for "a single-rotor helicopter with a small vertical propeller to offset torque and permit steering."

It was also specified that "the aircraft . . . will be demonstrated by the contractor at a flying field to be approved by the government, in the vicinity of the contractor's plant. Such demonstrations shall be conducted by the contractor at his expense and risk, and shall prove to the government the airworthiness and structural integrity of such craft."

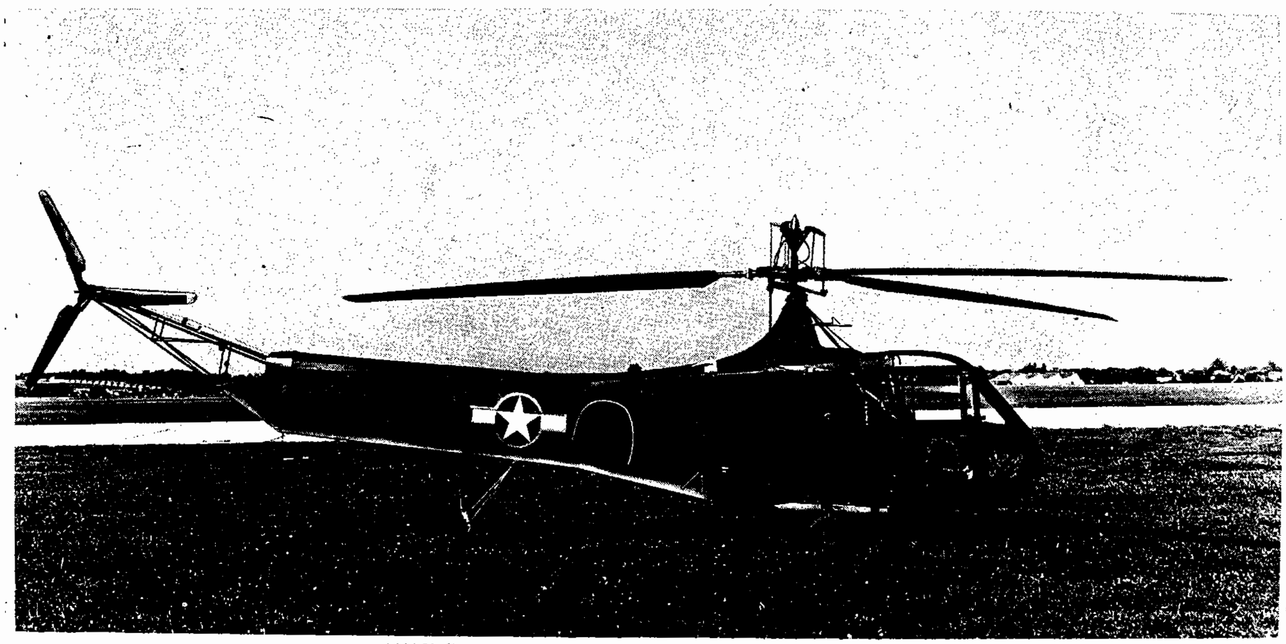


Figure 1-12. The Sikorsky XR-4 helicopter.

SIKORSKY HELICOPTER PROVES ITSELF

In the official trials, in 1942, the XR-4 made a vertical take-off, then hovered motionless and was put down vertically in the same spot. Next, forward, backward, and sidewise movements were made. As a result of these trials it could not be denied that the helicopter was thoroughly practical. (See Figure 1-12.) It was evident that there were many uses, and the Army at that time pointed out a number, among which were:

(1) Convoy duty, operating directly from the decks of ships being convoyed.
(2) Coastal and harbor patrol.
(3) Observation and fire control.
(4) Liaison and communications.
(5) Ambulance duty.

FIRST OVERLAND FLIGHT

As a final test of the airworthiness, it was decided to fly the XR-4 from the Sikorsky plant at Stratford, Conn. to Wright Field at Dayton, Ohio, the longest flight ever attempted in a helicopter.

The route selected for the flight to Dayton was not the most direct, but was laid out to avoid passing through mountainous country. It was felt that flight over open country was preferable even though the mileage was considerably greater. Stops were scheduled at Albany, Utica, Syracuse, Rochester, Buffalo, Erie, Cleveland, and several other points. The trip was made at an elevation of 1,000 feet at approximately 60 miles per hour. Approaching Buffalo, the pilot ran into a severe electrical storm. Believing it unwise to continue, he looked for a spot to land and selected a strip of green grass about 75 feet wide, between two plowed garden spots. Farm houses and trees left barely room for a vertical landing. The pilot brought the XR-4 in perfectly, landed and waited for the storm to die down. He then continued on to Dayton. This was a convincing demonstration of the ability of the helicopter to land on any small field, instead of searching for a prepared field as the pilot of a conventional aircraft would have had to do.

The XR-4 landed in Dayton on the 17th day of May, 1943, terminating the first successful cross-country flight ever made by a helicopter. The flight had taken five days and had covered 761 miles. It had included a total of 16 stops, and the flying time was 16 hours and 10 minutes.

The XR-4 became the Army's R-4, a modification of which became the HNS used by the Navy and the Coast Guard. It was the first helicopter to be accepted for the use of any military service. This aircraft was also the fore-

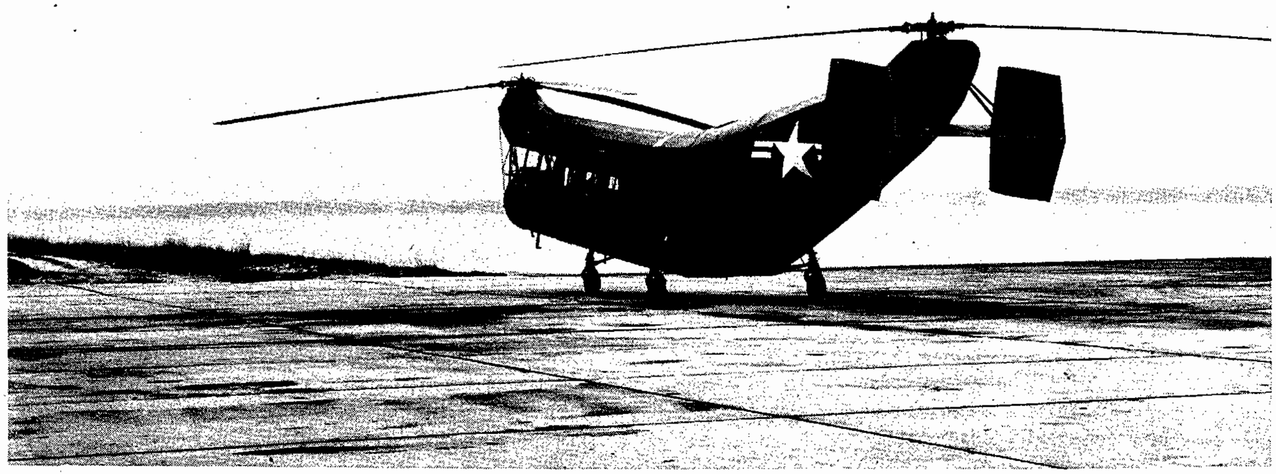


Figure 1-13

runner of the Navy's H03S-1, which is known in the Air Forces as the H-5.

While the Army was working with Sikorsky on the single rotor helicopter, the Navy was pushing the development of dual-rotor helicopters. Both Piasecki and McDonnell were given contracts to build variations of this type. The Piasecki HRP-1, better known as the "flying banana" came from this effort. (See Figure 1-13.) It was capable of carrying 10 combat ready troops.

MAIL DELIVERY BY HELICOPTER

On May 16, 1943, the helicopter was used for the first time in delivering mail, picking up a package of rush mail from the Capitol terrace and carrying it to the Washington Airport. Following the test, two helicopters made the trip from Washington, D. C. to Stratford, Conn., by way of Philadelphia. On the last leg of this trip the record for the longest non-stop flight of a helicopter was made; a distance of 140 miles.

The helicopters in use today still have their shortcomings, but new discoveries are being made nearly every day. New ways are being found to make rotors more efficient, and to make the controls easier and more effective. The autogiro has gone. There were things it could not do that are done well by the helicopter. But the helicopter might not be in today's practical form if Juan de la Cierva had not experimented and found the basic principles that have made his name outstanding in helicopter history: the principle of autorotation, and that of dissimilar lift of the rotor.

ONLY THE HELICOPTER CAN DO IT!

The helicopter of today might be compared to the conventional aircraft of 1920. The helicopter has demonstrated its value . . . it flies . . . it can be controlled . . . but there is still much to be done. Fixed wing aircraft, after World War I, had attained a speed of only 150 mph. In 1950, with the helicopter just beginning its useful history the tandem-rotor HUP-1 of Piasecki Helicopter Corporation made well over 135 mph. And there is nothing else that can make a vertical take-off, hover, fly forward, backward, or sidewise and make a safe vertical landing.

The leaders in rotary wing flight, among whom are Sikorsky, Hiller, Bell and Piasecki, have built hundreds of helicopters since the end of World War II. And though they employ different devices to secure directional flight, and to improve stability and control, the principles they follow are those so laboriously worked out by the pioneers in the field.

The helicopter has proved itself worthy of acceptance as a feature of the aviation program of the armed services. There is no other man-made vehicle in the air that can give the same performance . . . and it is certain that this performance will become even more dramatic as development proceeds.

NOTABLE HELICOPTER DATES

1452-1519—Leonardo da Vinci—Drawing only, Helix-Spiral Optera Wing.

1784—Launoy and Vienvenu—Toy with feathers for blades.

1907—Paul Cornu—24 hp engine, twin rotor helicopter.

1907—Louis Charles Brequet—First to leave the ground in a helicopter.

1909—Igor Sikorsky—25 hp coaxial.

1916—Lt. Petroczy and von Karman — 120 hp Coaxial rotors, captive helicopter.

1920—Emile and Henry Berliner — 2 models, one coaxial, one dual (side by side).

1923—Dr. Geo. de Bothezat—220 hp, 4 rotors, U. S. Army height 6 feet.

1924—Etienne Gemichend — 120 hp. 4 rotors, several minutes duration.

1926—Pescara—40 hp, coaxial, several minutes duration.

1920-1928—Juan de la Cierva—Flapping links, Autogyro.

1930—von Baunhauer — 80 hp., single 50 ft. main rotor and tail rotor.

1930—Florine—First tandem helicopter to fly successfully.

1930—D'Ascanio — 95 hp, coaxial duration 8 minutes, 45 seconds. Italy.

1935—Louis Charles Brequet — 4 rotor helicopter, 350 hp coaxial.

1937—Heinrich Focke — 160 hp, two rotors, German, 1 hour, 20 minutes, 49 seconds. Distance 143.069 miles. Altitude, 11,-243.416 ft. Speed 76.151 mph.

1941—Sikorsky breaks world's helicopter endurance record.

1942—XR-4 azimuth control.

1951—Kaman K-5—First helicopter to be propelled by a turbine engine.

PART II
THEORY

In the chapter on the history of the helicopter, it was pointed out that the development of the helicopter covered many centuries and involved many men. One of the most important contributors to the development of the helicopter was Juan de Cierva. His autogiro was the culmination of many experiments which resulted in conclusions that proved why other helicopters had been impractical. Although the autogiro has now passed from the picture because the light plane gradually achieved equivalent performance, a review of the features which distinguish it from a helicopter is desirable.

CHAPTER 2

DEVELOPMENT OF THE ROTOR AND ROTOR CONFIGURATIONS

AUTOGIRO

The autogiro (See Figure 2-1) had a conventional aircraft fuselage with the engine and propeller on the nose. Early models had stub wings but these were eliminated in later models (See Figure 2-2.) The propeller pulled the autogiro in the same manner as the propeller on a fixed wing aircraft. A mast on the top of the fuselage mounted a rotor similar to the one on a helicopter. However, there was no connection mechanically between the engine and the rotor. The rotor was a freewheeling device. Airflow over the rotor blades due to relative motion of the autogiro through the air caused the rotor to turn of its own accord or autorotate. The autorotation was fast enough to create lift which supported the aircraft just as the wings do on a conventional aircraft. The autogiro could not hover at a zero air speed with no wind because there would then be no relative motion of air over the rotor. The passage of air through the rotor was always from below up through the rotor system.

Figure 2-1

Figure 2-2

Figure 2-3. Sikorsky — HRS

HELICOPTER

In the helicopter (See Figure 2-3), there is no propeller for forward motion. Both lift for support and thrust for translational motion come from the overhead rotor or rotors which are driven directly by the engine. The airflow through the rotor of the helicopter is always down during powered flight. If the engine fails, the rotor can be made to autorotate, in which case the direction of the airflow through the rotor changes from down to up.

De CIERVA'S DEVELOPMENTS

De Cierva was trying to develop an aircraft in which the air speed of the sustaining surfaces would be independent of the speed of the aircraft itself. By this means he hoped to design a craft that would not stall in the common sense of the word. His use of a rotor solved this problem since the rotating airfoils would always have sufficient air speed regardless of the forward speed of the aircraft. However, in spite of all of the experimenting on helicopters, it was apparent that no one had carefully analyzed the problems of rotating airfoils up until this time. De Cierva began detailed studies on the shape of such airfoils and the means of rotating them.

The significant result of these studies was the discovery of autorotation. De Cierva found that at certain angles of attack, there is a component of the resultant force of the airfoil that causes it to move forward at the same time that lift is being generated. (See Figure 2-4.) This condition sometimes occurs in conventional aircraft. It is the force which causes spinning.

It must be observed that autorotation is possible only at low angles of attack. High angles increase the drag to such an extent that there is no forward component of the resultant force in the plane of rotation. (See Figure 2-5.) For this reason it is important in helicopter operation that the collective pitch lever be put in low pitch immediately if it is necessary to autorotate in an emergency.

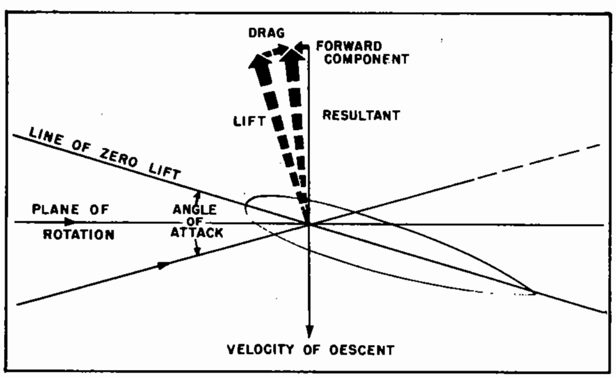


Figure 2-4

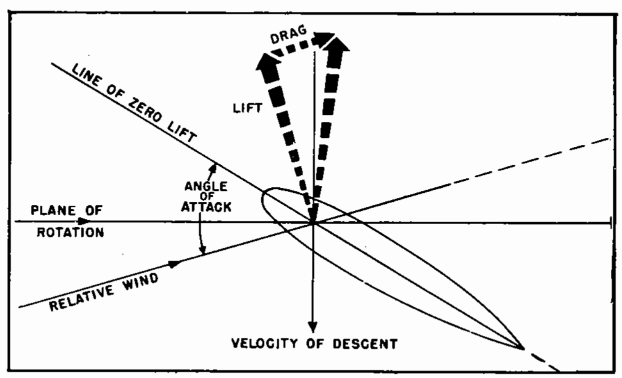


Figure 2-5

After establishing the principle of autorotation, De Cierva decided that just replacing the wings of the conventional aircraft with a free turning rigid rotor was his answer to a slow flying, safe airplane that could be flown by any qualified pilot with very little additional instruction.

Such an aircraft was built and gave evidence of operating as planned. But every time this machine approached take-off speed it had a tendency to overturn. Since this action was always in the same direction, that is, it tended to tip toward the retreating blade, (See Figure 2-6) de Cierva reasoned that he still had missed some basic principle. He tackled this problem and came up with the theory of the dissymmetry of lift.

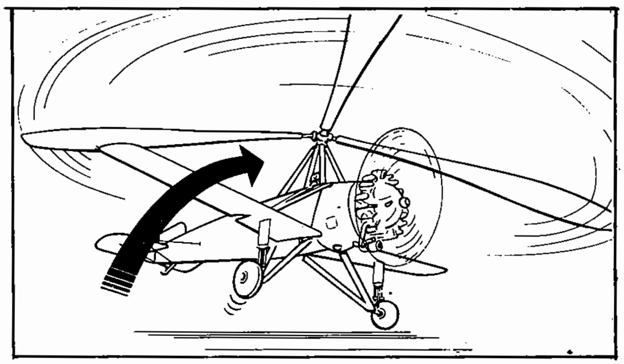


Figure 2-6

DISSYMMETRY OF LIFT THEORY

The lift on any blade element has been demonstrated to be $L=\frac{1}{2}C_LPV^2A$ where L is the lift, A the area of the blade element, V is the velocity of the air in miles per hour, P is the air density, and C_L is the lift coefficient of the blade element. Assuming the blade element in this case to be the tip of the rotor, the lift will be the same on all blade tips if all of the blades are moving at the same angle of attack in still air.

In order for an autogiro to become airborne, however, it must have a forward speed to give a relative wind over the rotor blades. De Cierva reasoned that the relative wind over the advancing blade was the rotational velocity plus the forward speed of the autogiro itself. By the same reasoning, the retreating blade would have a velocity equal to the rotational velocity minus the forward velocity of the aircraft.

Assuming equal angles of attack on each blade, and therefore the same lift coefficients, equal areas of the blade elements, and the same air density, then the only factor in the lift on the two blades that is different is the velocity.

Since velocity in the formula instead of being directly proportional is squared, the difference in velocity on the two blades changes the available lift appreciably.

To see what effect there is, assume three different conditions: zero relative speed; a translational speed of fifty miles per hour; and a translational speed of 100 miles per hour. In all cases assume that the rotor velocity is 300 miles per hour at the tip. With no wind, tip speed is the same at all points and therefore the lift is the same on both blades. (See Figure 2-7.)

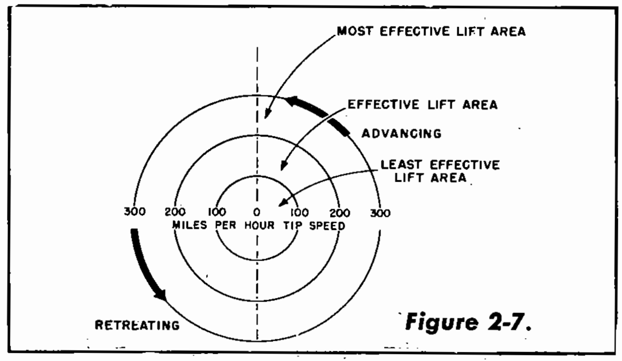


Figure 2-7.

Zero Relative Speed, Tip Speed of 300 miles per hour.

With a forward speed of fifty miles per hour, the advancing blade has a velocity of 300 + 50 or 350 mph while the retreating blade had a velocity of 300 — 50 or 250 mph. (See Figure 2-8.)

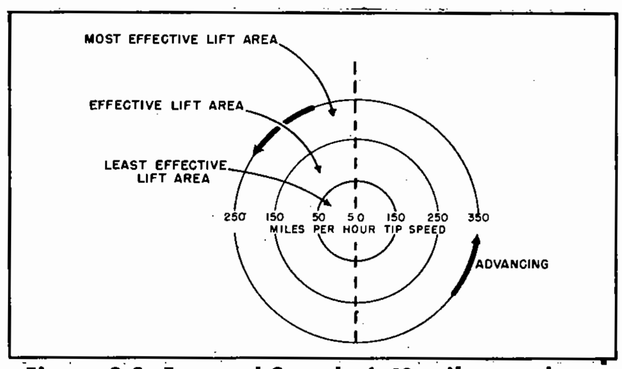


Figure 2-8. Forward Speed of 40 miles per hour.

The ratio of lift on the two blades is then 350^2 to 250^2 or 1.96 to 1. This means that the lift on the advancing blade tip is almost twice the lift on the retreating blade tip.

With a forward speed of 100 mph, the advancing blade tip has a velocity of 300 + 100 or 400 mph. (See Figure 2-9.) The speed of the retreating blade tip is 300 — 100 or 200 mph. The ratio of lift in this case is 400^2 to 200^2 or 4 to 1.

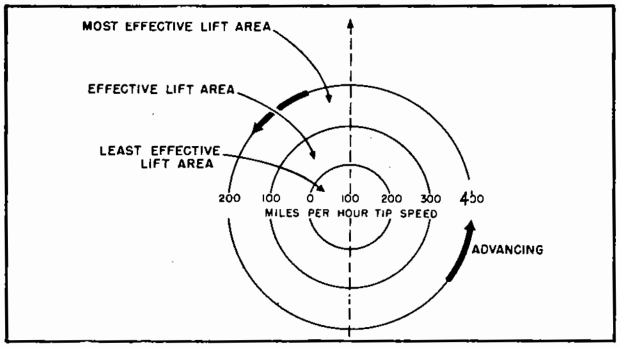


Figure 2-9. Forward Speed of 100 miles per hour.

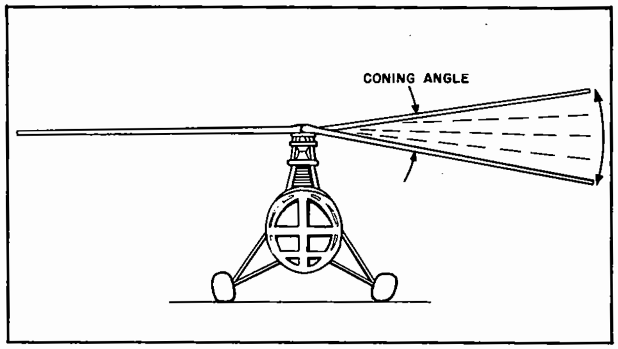


Figure 2-10

When he recognized this problem, de Cierva realized that a rigid rotor would always have this upsetting unbalance.

His work on this disturbing feature led to the development of the "flapping hinge." This means that the individual blades are hinged at the rotor hub so that each one can move up and down independently in a vertical plane. (See Figure 2-10.)

With this type of rotor, the advancing blade will have greater lift which causes it to increase its coning angle or flap upward. The retreating blade will have less lift and will decrease its coning angle or flap downward. It can be seen that when the blade flaps upward, the relative wind will have a downward component which will reduce the angle of attack and therefore the lift. (See Figure 2-11.) The downward flapping blade will have a greater angle of attack and therefore greater lift.

This type of rotor head, therefore, tends to even out the lift. Also if there is no offset to the "flapping hinges" an upsetting moment is not transmitted to the rotor head.

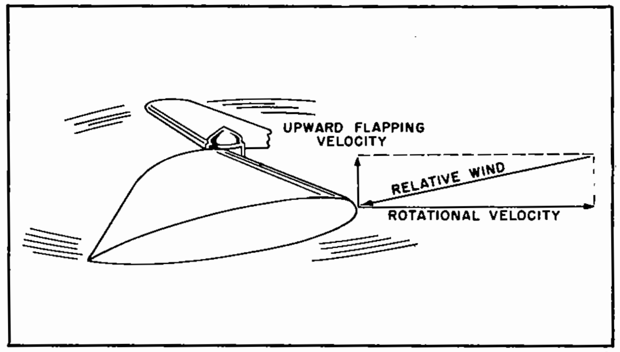


Figure 2-11

ROTOR HEADS

De Cierva fitted his autogiro with a flapping hinge rotor head and the machine performed exactly as he predicted.

This type of rotor head is in common use today on helicopters (See Figure 2-12) and is known as the fully articulated rotor head.

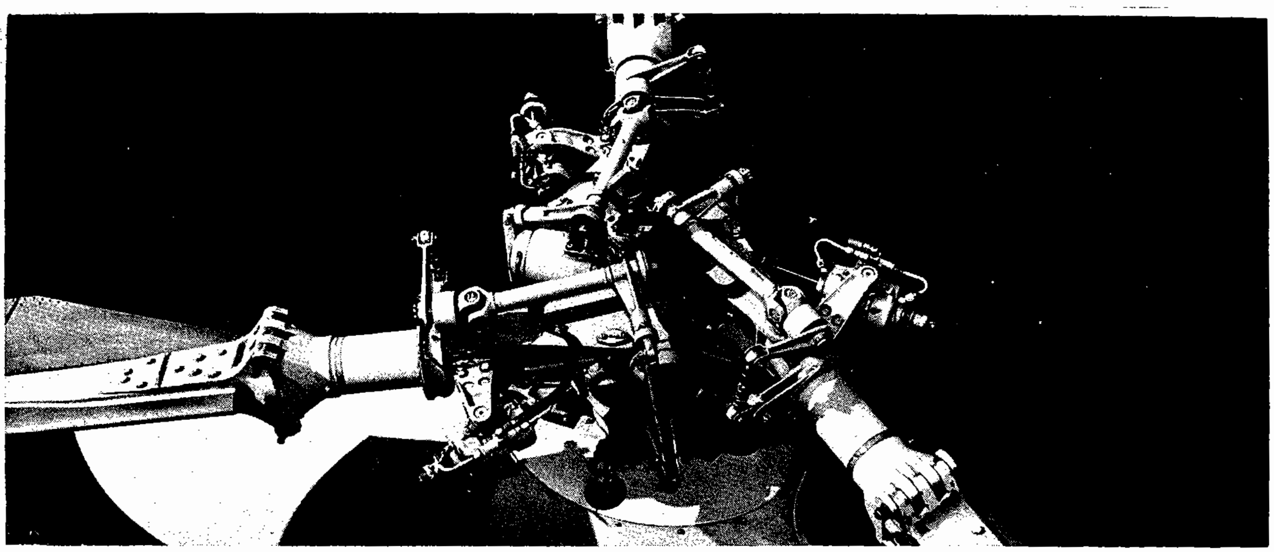


Figure 2-12

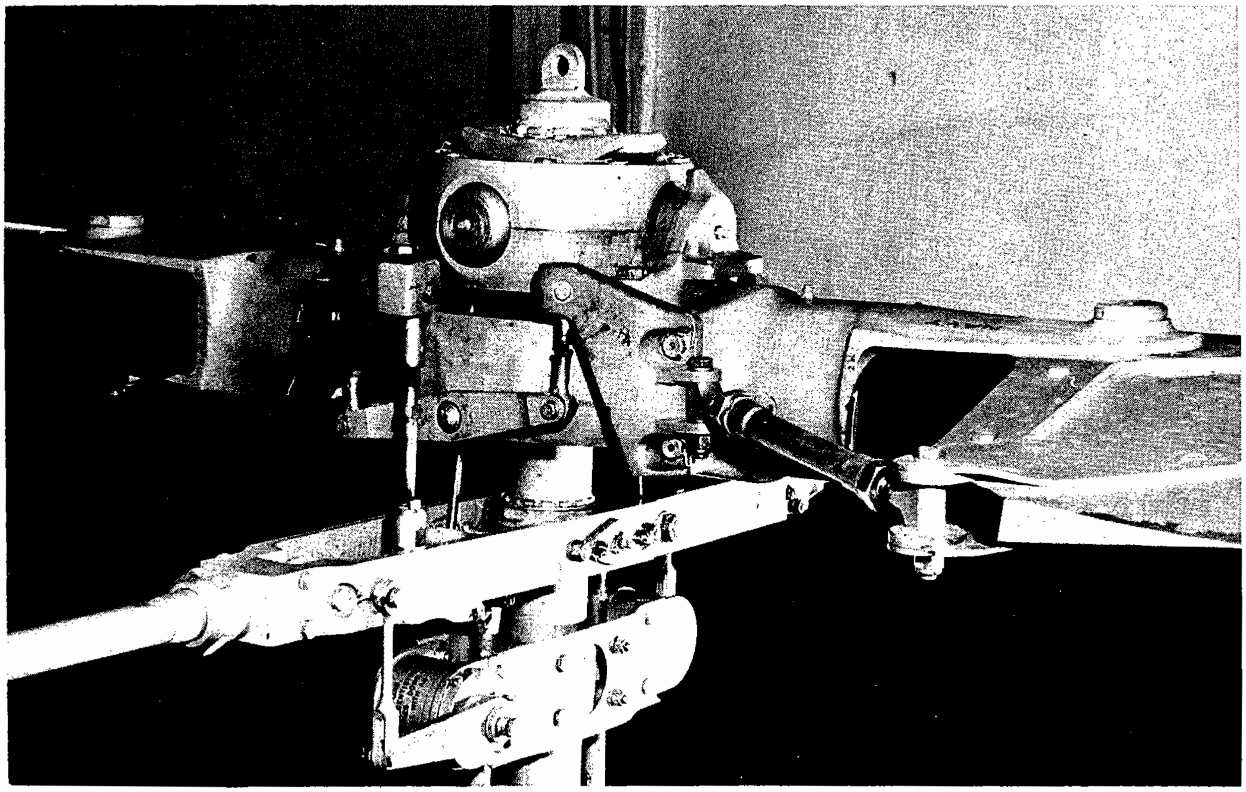


Figure 2-13. The semi-rigid rotor head used on the Bell helicopter.

A simpler type of rotor head called a semi-rigid head (See Figure 2-13) may be used with a two bladed rotor. In this case, both blades are on the same transverse axis and rock up and down together about the rotor hub. The angle of attack of the advancing blade decreases as it rises due to excess lift.

The angle of attack of the retreating blade increases as it is depressed by the rising advancing blade. This type of rotor balances out the load on the two blades aerodynamically.

CYCLIC PITCH CONTROL

Another development that came about with the autogiro was cyclic pitch control. This made it possible to vary the angle of attack of the rotor blades as they rotated about the mast. This type of control was first used on the Wilford Gyroplane and Kellett Autogyro and did the tail rotor through a power take-off, a longer

As had been said, the autogiro was just a stop gap in the development of the helicopter. With the theory of dissymmetry of lift worked out, the flapping hinge rotor head designed, and the development of cyclic pitch control it took only the solution of applying power to the rotor system efficiently to result in a successful helicopter.

In the few years since the flight of the first successful helicopter, many different types of helicopters have been produced.

ROTOR CONFIGURATIONS

A generally used method of distinguishing between various types of helicopters is on the basis of the number and placement of the rotors which supply the lifting and translational forces for their operation. This is commonly spoken of as the "configuration" of the helicopter. Every helicopter pilot should be familiar with the most generally used configurations. Well established configurations are:

(1) Single rotor
- a. Engine driven
- b. Jet driven

(2) Multi-rotor
- a. Coaxial rotors
- b. Tandem rotors
- c. Lateral, with parallel masts
- d. Synchropter, lateral with converging masts

Figure 2-14. The Bell HTL single-rotor helicopter.

(1) SINGLE ROTOR HELICOPTERS (See Figure 2-14.)

a. Engine Driven. This is the basic type helicopter. One rotor supports the entire weight of the helicopter. In this configuration, if the rotor is engine driven through a shaft, it is necessary to have a vertical rotor at the end of the tail section to provide directional control. Power is supplied to the main rotor through a short shaft and transmission. It is carried to the tail rotor through a power takeoff, a longer shaft and gearing. Bell, Sikorsky, and Hiller are examples of the single-rotor engine driven helicopter. This configuration has the advantages of simplicity and effective control. A disadvantage is that power must be diverted from the main rotor to drive the tail rotor.

b. Jet Driven. The jet-driven helicopter also belongs in the single-rotor configuration. (See Figure 2-15.) In this type helicopter the rotor may be driven either by ram jet engines or those of the pulse jet type. In either case the jet engines are attached to the rotor blades at their tips. Since power is supplied directly to the rotor blades rather than from the fuselage there is no tendency for the fuselage to rotate, and no need for a vertical tail rotor. There are two weaknesses of this type of helicopter. First, the engines used are less efficient than reciprocating engines; and, second, the burners on the blade tips interfere with autorotation when the power is off.

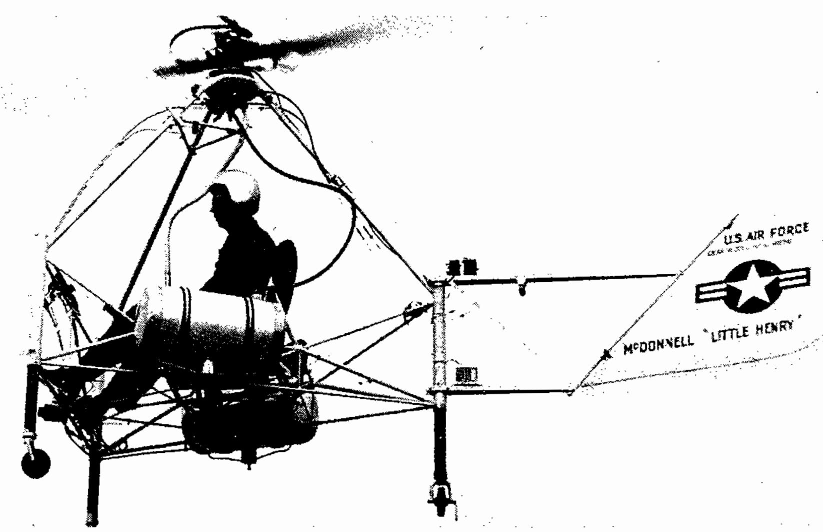


Figure 2-15. The jet-driven single-rotor helicopter, McDonnell "Little Henry".

Figure 2-16. Coaxial rotor helicopter built by Gyrodyne.

(2) MULTI-ROTOR HELICOPTERS:

a. COAXIAL ROTORS: (See Figure 2-16.) Early advocates of the coaxial rotor recognized the tendency of a single rotor to rotate the helicopter fuselage in a direction opposite to its direction of rotation. They reasoned that this tendency could be compensated for by mounting a second rotor to turn on the same center and to rotate in the opposite direction thus balancing out the torque of the first rotor.

Mechanically, this arrangement is not as simple as is the single rotor configuration, and the control mechanism is somewhat more complicated. The lifting qualities are good, although there is a certain amount of interference between the two rotors, because the lower one is always operating in disturbed air. Coaxial rotor systems have good ground clearance and are easy to maneuver. The principal advantage is that one rotor compensates the tendency of the other to make the helicopter rotate around its vertical axis. The excessive height of the structure is sometimes an objection, and there are problems of stability.

Figure 2-17.

b. TANDEM ROTORS: In this configuration, one rotor is placed forward, and the other is located in the after section of the helicopter. (See Figure 2-17.) These rotors are driven synchronously from the same engine. The rotor blades may or may not be in the same plane, and they may or may not intermesh. This configuration has a number of readily apparent advantages. Its longitudinal stability is fair, as the structure is literally "hung" at fore and aft points. For this reason the center of gravity is less critical than in either the single or dual rotor lateral configuration. It also has a small frontal area and a short span. A disadvantage is its rather complex system of drive and control.

c. LATERAL ROTORS: (Parallel Masts) (See Figure 2-18.) This configuration was one of the first types tried. The Berliner helicopter now in the Smithsonian Museum in Washington was an early example of this type. The rotors were spaced at equal distances to the right and left of the longitudinal axis and were mounted on the top unit of each of the triplane sets of wings. In this configuration, the two rotors turn synchronously in opposite directions and thus exert no turning force on the body of the helicopter. The two rotors may or may not intermesh. One of the principal advantages of this configuration is that the full power of the engine is available for lift. There is good lateral control and fair directional control,

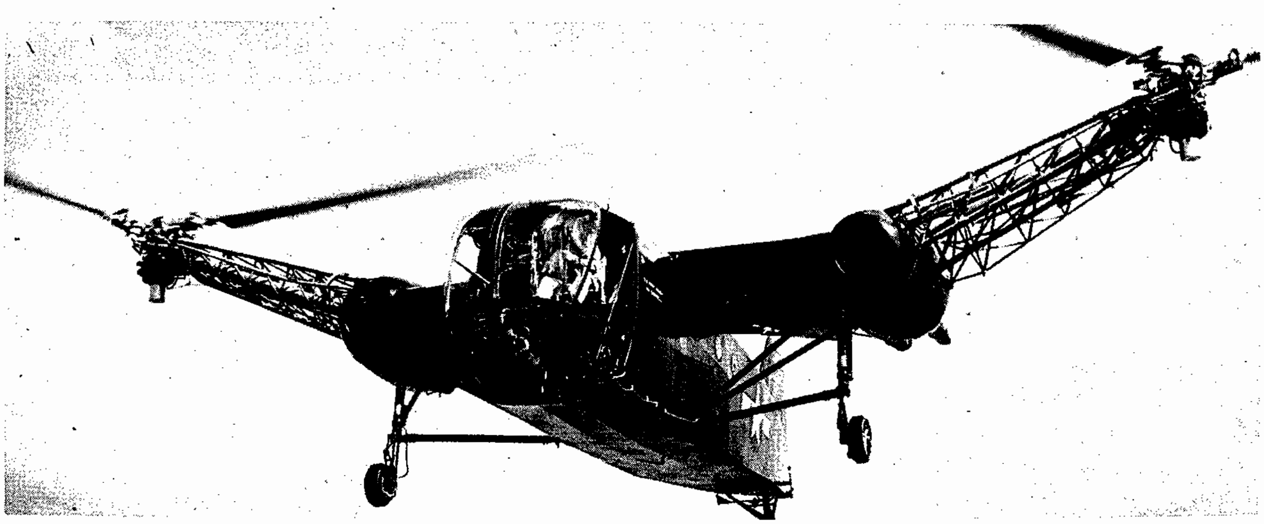


Figure 2-18. McDonnell XHJD-1

Figure 2-19. Kaman Synchropter

through change in the pitch of the rotor blades of the two rotors. The length is short as no tail section is necessary. There is also small induced loss in forward flight. As the pylons may be designed as wings they can be made to contribute to the lift, especially at higher speeds.

d. SYNCHROPTER: (Converging Masts) (See Figure 2-19.) In this configuration the rotors are carried by masts set at equal angles and equally spaced to the right and left of the longitudinal axis of the helicopter. These rotors are deeply intermeshed and must operate synchronously. The short distance between the center of the two rotors is a factor in compactness. Drive shafts are shorter and consequently lighter than in the dual configuration with both rotors mounted laterally in the horizontal plane.

Figure 2-20. The designation HUP-1 stands for the first model, general purpose helicopter made by the Piasecki Company.

MANUFACTURERS AND DESIGNATIONS

Designations of helicopters follow the same system as is used for other aircraft. The letter H stands for helicopter. (See Figure 2-20.) The letters T for training, O for observation, U for general purpose, C for crane, S for Anti-submarine Warfare, and R for transport are the same as in conventional aircraft. The letters indicating the manufacturer are the same in the case of fixed wing aircraft builders. In the case of companies like Piasecki who have not previously built Naval Aircraft the letters are new.

COMMONLY USED NAVAL HELICOPTERS

BELL, HTL-1, 2, 3, 4 and 5. A single rotor helicopter with a vertical tail rotor for directional control. The main rotor is a two-bladed semi-rigid moving rotor on a gimbal joint in the mast. This permits see-saw movement of the blades as a unit.

BELL, HSL-1. A tandem rotor helicopter in which each rotor is a two-bladed rotor with a stabilizer bar similar to single rotor on HTL.

SIKORSKY, H03S-1. A single rotor helicopter with a vertical rotor in the tail for directional control. Rotor has three blades, fully articulated, so they can move up and down in flapping action.

SIKORSKY, H04S-1. Similar to the H03S-1 but with larger rotor and more powerful engine. Has four-wheel landing gear.

SIKORSKY, HRS-1 and 2. Same as other Sikorskys in configuration, but larger in size and capacity.

PIASECKI, HUP-1 and 2. A tandem helicopter with one rotor over the cockpit and the other on a tail pylon. Directional control is provided by control of the two rotors through the rudder pedals. Rotors overlap.

PIASECKI, HRP-1 and 2. Same configuration as the HUP-1 except rotors do not overlap.

KAMAN, HTK-1. Synchropter type—two-blade rotors. Control is effected by the movements of small servo airfoils which warp the blades, changing their pitch as desired.

KAMAN, HOK-1. Same configuration as model HTK, but with more power and carrying capacity.

HILLER, HTE-1 and 2. Single rotor, two-bladed semi-rigid rotor system. Tail rotor is used for directional control.

CHAPTER 3
BASIC PHYSICS AND AERODYNAMICS AS RELATED TO THE HELICOPTER

INTRODUCTION

An understanding of the basic principles of physics and aerodynamics pertaining to fixed wing aircraft makes it easier to understand the principles of rotary wing aircraft. A review of these basic principles relating them to rotary wing aircraft will be covered first.

Air has weight, and therefore it has mass. Because air has mass, its action can be predicted by applying the physical laws pertaining to fluids.

NEWTON'S LAWS OF MOTION

Three of the physical laws which are most useful in explaining aerodynamic results are Newton's Laws of Motion. Simply stated they are:

(1) Every body continues in its state of rest or uniform motion in a straight line unless compelled by external force to change that state.

(2) Rate of change of momentum is proportional to the force acting, and the change takes place in the direction in which the force acts.

(3) To every action there is an equal and opposite reaction.

According to the first law, every particle of air (the body in this case) will remain stationary unless some outside force such as a wing or rotor blade (which is the outside force) causes the particle of air to move. Or a particle of air already moving in a straight line will continue in a straight line motion until it is deflected by an outside force.

If the wing or rotor blade acts on a particle of air, according to the second law, the air will be deflected in the direction of the force applied by the wing or blade. Also, the rate of change of momentum of the air will be proportional to the force applied by the wing or blade. The momentum of the air is its mass times its velocity.

Then according to the third law of motion, if the wing or rotor deflects the air downward, the reaction of this downward action, is a force upward on the wing or rotor. (See Figure 3-1.)

AIRFLOW

In order to simplify the explanation, let's slice through the wing or rotor blade and consider the action on this one cross section which is known as an airfoil.

If a particle of air moves past an airfoil from one point to another in a smooth, continuous path, its path is called a streamline. Conventionally, the streamline flow around an airfoil is shown like this. (See Figure 3-2.)

If the airfoil is slightly inclined to the airflow, the airflow below the wing is deflected downward. The airflow over the upper surface of the airfoil follows the contour of the airfoil and is deflected downward where it rejoins the flow below the airfoil.

Since the air is given an acceleration in the downward direction, and the air has mass, the result is a force (mass times acceleration) on the airfoil with a reaction in the upward direction. The airflow is also decelerated by the wing which causes a backward force to act on the wing. The upward and backward force on the wing is known as the resultant force. The component of this force perpendicular to the undisturbed airflow or relative wind is the lifting

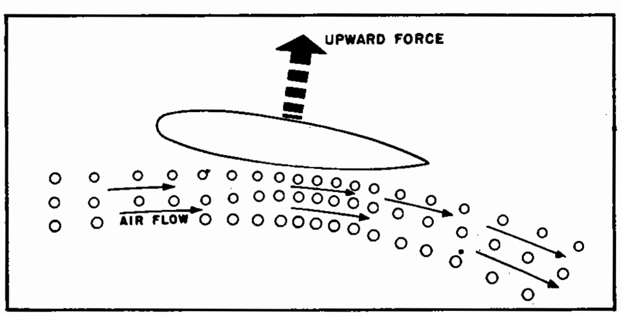


Figure 3-1

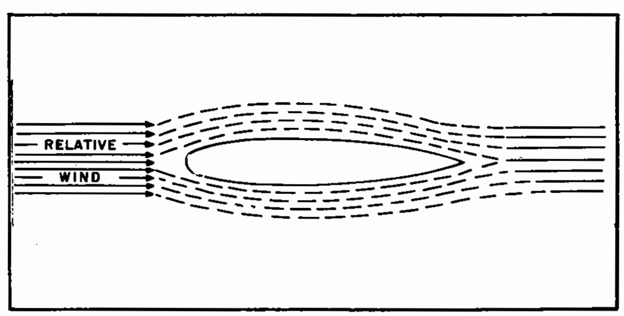


Figure 3-2

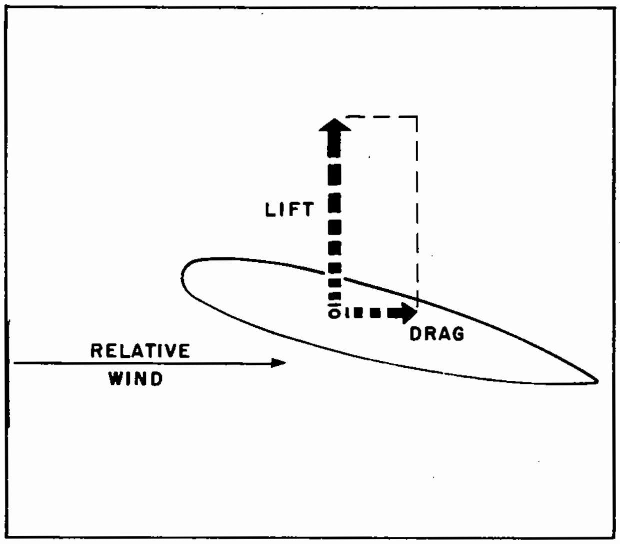


Figure 3-3

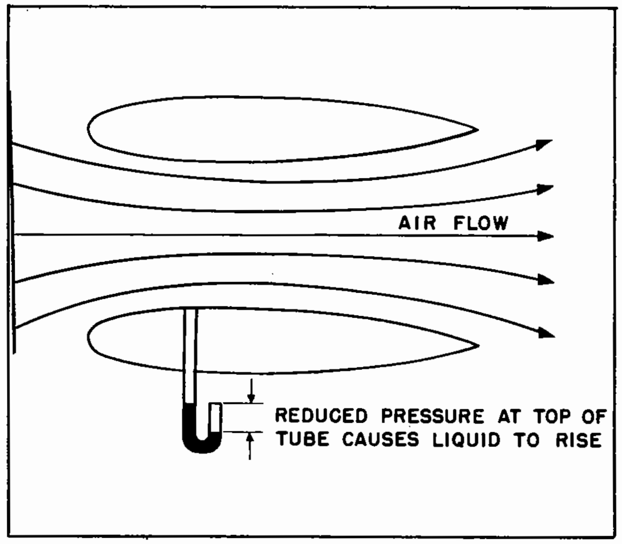


Figure 3-4

force or LIFT. (See Figure 3-3.) The component of the resultant force acting parallel to the relative wind is the drag force or DRAG.

BERNOULLI'S THEOREM

There is another principle of physics which also accounts for the lifting force on an airfoil. It is known as Bernoulli's theorem. According to this theorem, as can be demonstrated in a venturi tube, an increase in velocity of a fluid results in a reduction of pressure. (See Figure 3-4.) If an airfoil is used as one wall of the venturi, it is apparent that the velocity above the wing must be increased to maintain a smooth flow with the airflow going a shorter distance, below the airfoil. This will decrease the pressure above the airfoil and result in additional lift. (See Figure 3-5.)

At subsonic speeds, and all rotors as yet developed operate below the speed of sound, the lift on the upper surface is approximately two thirds of the total.

Experiments show that as the angle of the airfoil increases in relation to the relative wind, the lift increases. This angle is known as the angle of attack. When this angle gets to around 15 degrees, however, the airflow is no longer smooth over the upper surface. (See Figure 3-6.) The flow, in other words, is not streamline flow but turbulent. At this angle, known as the stalling angle, the lift no longer increases. In fact, at any angle greater than the stalling angle the lift decreases.

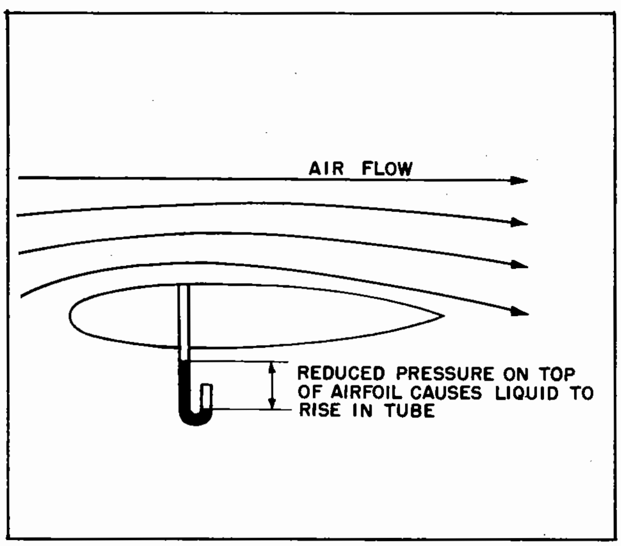


Figure 3-5

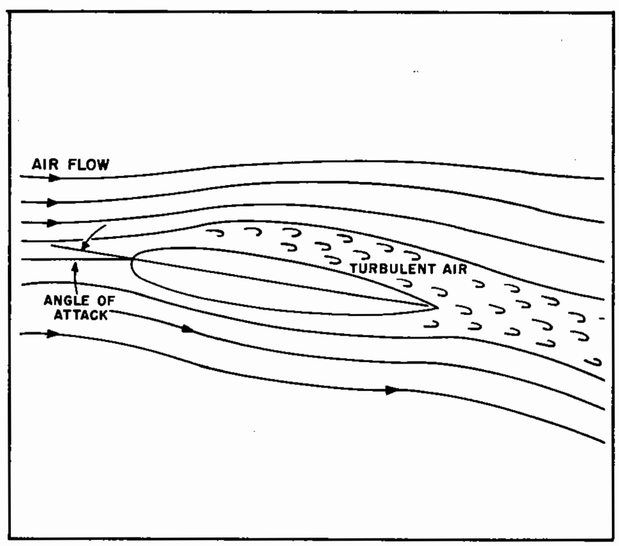


Figure 3-6

AIRFOILS

What the stalling angle is depends on the shape of the airfoil. We have shown a symmetrical airfoil, since this is the common shape for rotor blades. The airfoil used on the Sikorsky H03S-1 is an NACA.0012. The National Advisory Committee for Aeronautics has classified many combinations of airfoil shapes and then tested them in the wind tunnel. The first two places in the number denote the amount of camber or curvature of the centerline of the airfoil. Since this is a symmetrical airfoil, the camber is zero. The 12 denotes that the maximum thickness of the airfoil is 12% of the chord. (See Figure 3-7.)

The wind tunnel tests not only determine the stalling angle, but also the lift coefficient of the airfoil. This is a constant factor at any given angle of attack for a specific airfoil shape.

In addition to the lift coefficient, wind tunnel tests also determine the drag coefficient, or the constant factor used in determining the amount of drag of any given airfoil.

Lift coefficients and drag coefficients are normally plotted as characteristic curves (See Figure 3-8.) for each airfoil. The coefficients are plotted against angle of attack.

Actually, of course, the lift on the wing is a summation of all of the individual forces of the single air particles. Although these individual forces are distributed over the entire airfoil, they are assumed to act at one point on the airfoil called the Center of Pressure or C.P. (See Figure 3-9.)

FORCES ON THE WING

Lift and drag can be plotted as vectors in which the length represents the amount of the force and the direction indicates the direction of the force. These vectors then can be added as vectors to give the resultant force. (See Figure 3-10.)

As the angle of attack changes, the distribution of the individual forces over the surfaces of the airfoil changes. This causes the resultant to act at a different location or C.P. (See Figure 3-11.) With the airfoils normally used on fixed wing aircraft, changes in angle of attack result in a rather large Center of Pressure travel. This is not a serious problem with fixed wings. However, in the case of rotor blades which are rather flexible, a shift of the center of pressure

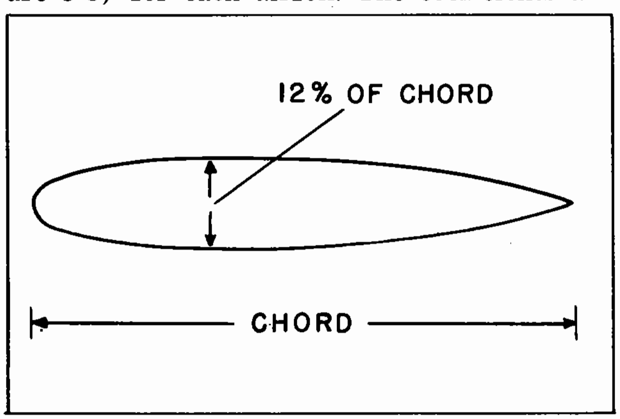


Figure 3-7

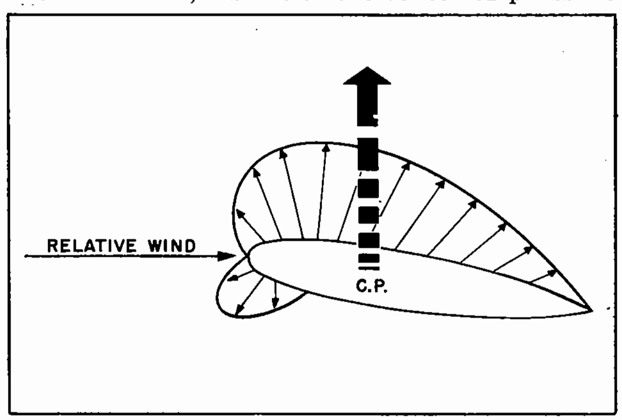


Figure 3-9

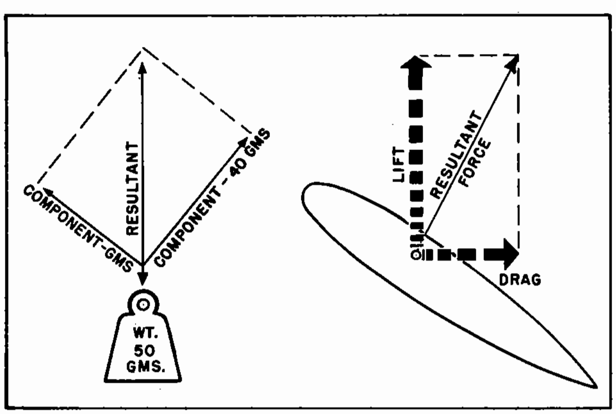


Figure 3-10

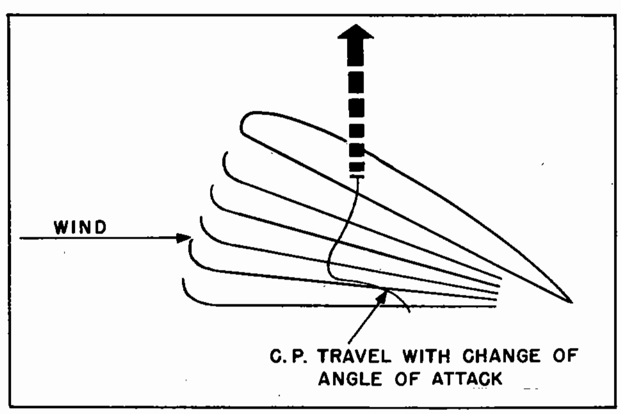


Figure 3-11

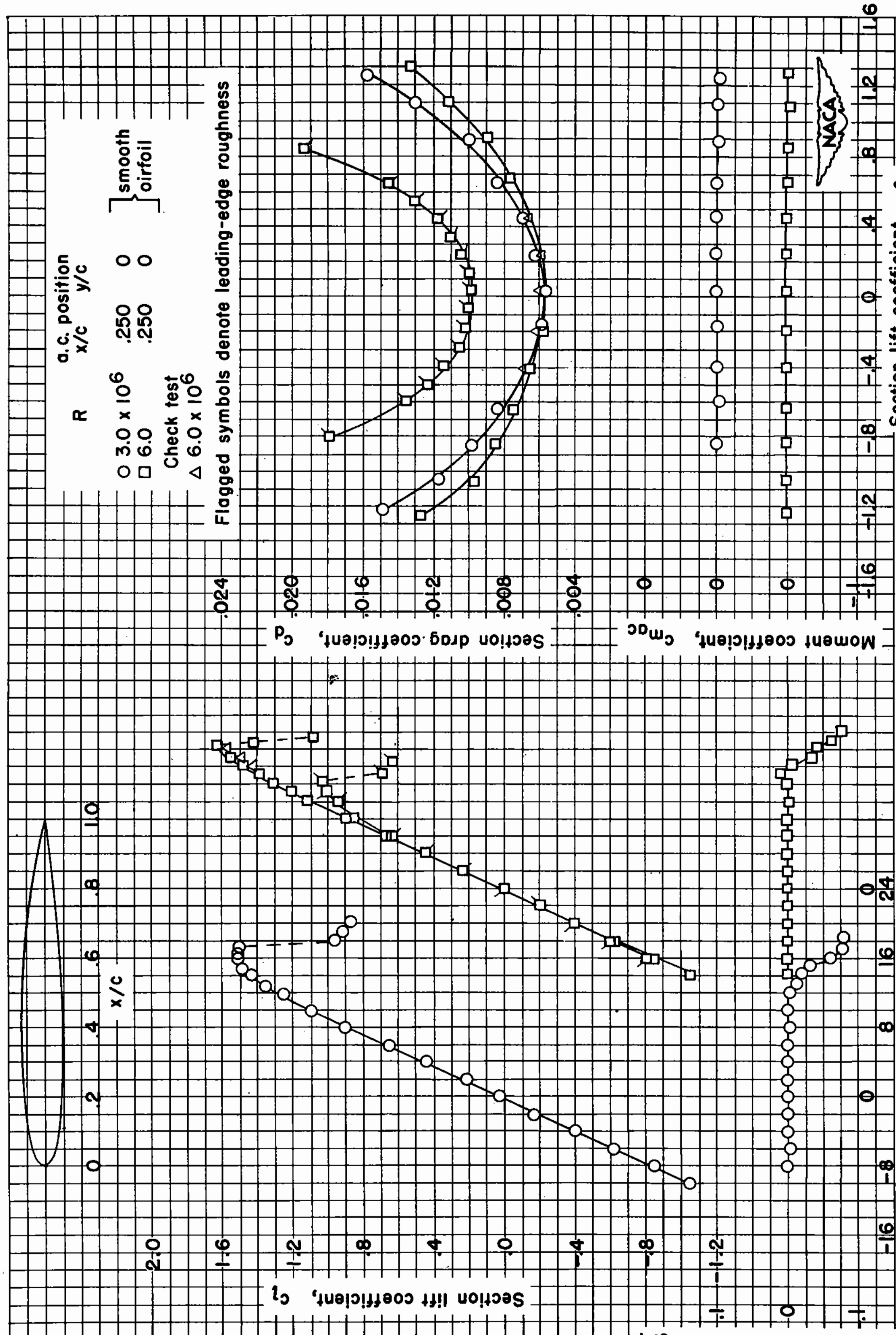


Figure 3-8. Section lift, drag, and pitching-moment characteristics of NACA-0012 airfoil section.

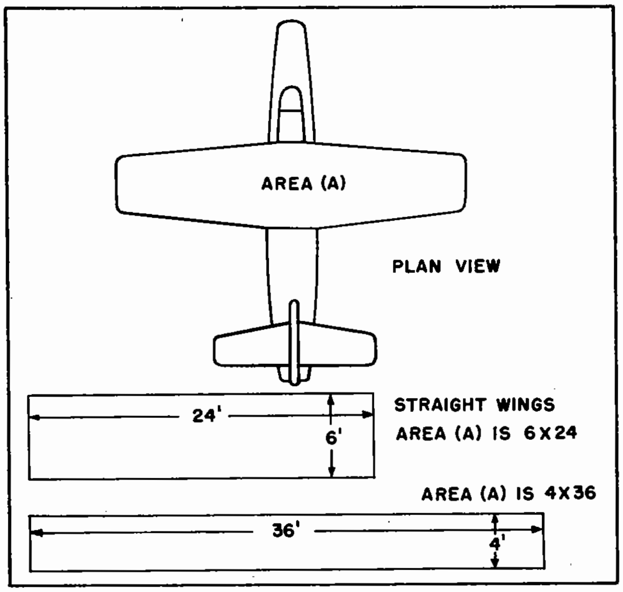


Figure 3-12

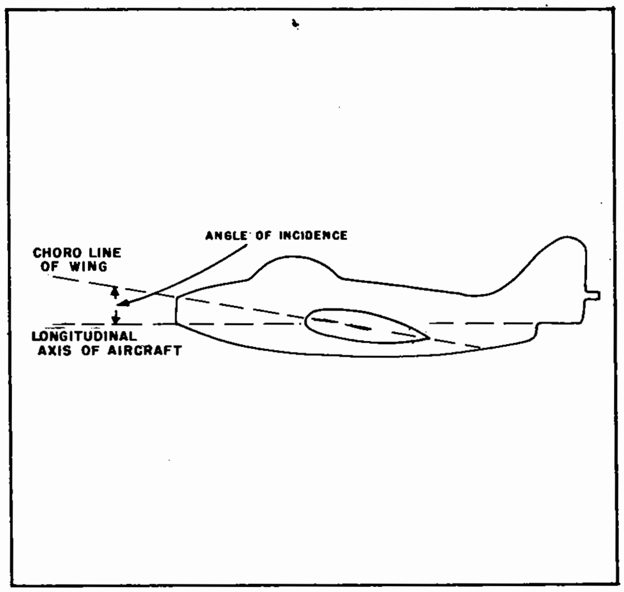


Figure 3-13

would make control very difficult since it introduces moments on the blade which are different at different positions as the blades rotate. Most rotor blades have a symmetrical airfoil because this type airfoil has a minimum of C.P. travel.

Up to this point, the discussion has been confined to the aerodynamics of the airfoil. This could be the cross section of a fixed wing or the cross section of a rotor blade. When these effects are then related to a wing or rotor system, certain differences occur.

First consider the wing of a fixed wing aircraft. To find the amount of lift it can produce, the individual factors can be multiplied together to get the total.

One of these factors, as has been explained, is the lift coefficient which is dependent on the shape of the airfoil and the angle of attack.

Another is the density of the air since this is directly related to the mass of the air which causes the lifting force. As the altitude increases, the density decreases. Also, when the temperature increases, the density decreases. Temperature and altitude are both serious considerations in heavily loaded aircraft. This is especially true of helicopters. Density is usually indicated by the Greek letter Rho (ρ).

In order to determine the total mass of air contributing to the lifting force, the area (A) of the wing becomes a factor. The area of the wing is considered to be a projection of the wing plan. (See Figure 3-12.) In the case of straight wings, the area is simply the span times the chord.

The other factor affecting the lift is the velocity (V) of the air acting on the wing. Actually the lift is proportional to the square of the velocity. Because of this, doubling the velocity makes the lift four times as great, and tripling the velocity increases the lift nine times. With fixed wing aircraft it must be remembered that the velocity of the air creating lift is always identical to the velocity of the aircraft itself. In a helicopter the velocity over the rotor will be different from the velocity of the helicopter itself. Putting all of the factors together, the formula for lift on a fixed wing is:

$$L = C_L \frac{\rho}{2} A V^2$$

Although all the factors affecting the lift are the same for fixed wings and rotary wings, the local relative velocity which varies from a minimum near the hub of the rotor to a maximum at the tip of a blade makes the problem of computation more difficult. This will be covered later.

Another consideration for fixed wings which differs from that for rotors is the so-called angle of incidence. This is the angle between the chord of the wing and the longitudinal axis of the aircraft. (See Figure 3-13.) In most fixed wing aircraft this angle is built right into the airplane and therefore does not change in flight. This is not true of helicopters, another point that will be discussed later.

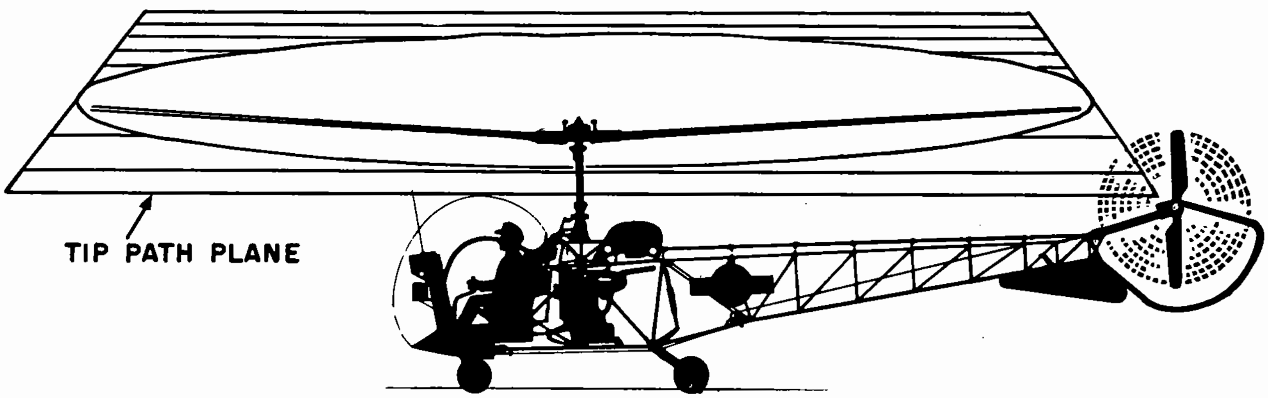


Figure 3-14

ROTARY WING TERMS

In order to describe some of the problems of rotary wings more simply, there are several definitions of terms required which are peculiar to rotary wing aircraft.

The TIP-PATH-PLANE is the plane which includes the tips of the rotor blades as they pass through the cycle of rotation. (See Figure 3-14.) In a vertical take-off with no wind, the tip-path-plane would be in a horizontal position. The tip-path-plane will be tilted away from horizontal in any other condition of flight in a helicopter.

The VIRTUAL AXIS is an imaginary line which passes through the center of the rotor and is always perpendicular to the tip-path-plane. The lift is presumed to act along the virtual axis.

As the rotor goes around, there will be a force acting on it that is not common to fixed wings, that is, the centrifugal force or force which tends to make the blades fly off into space. This force is considered to act at the center of gravity in the spanwise direction of the individual rotor blades. As the rotor goes around, the center of gravity of each blade describes a circle

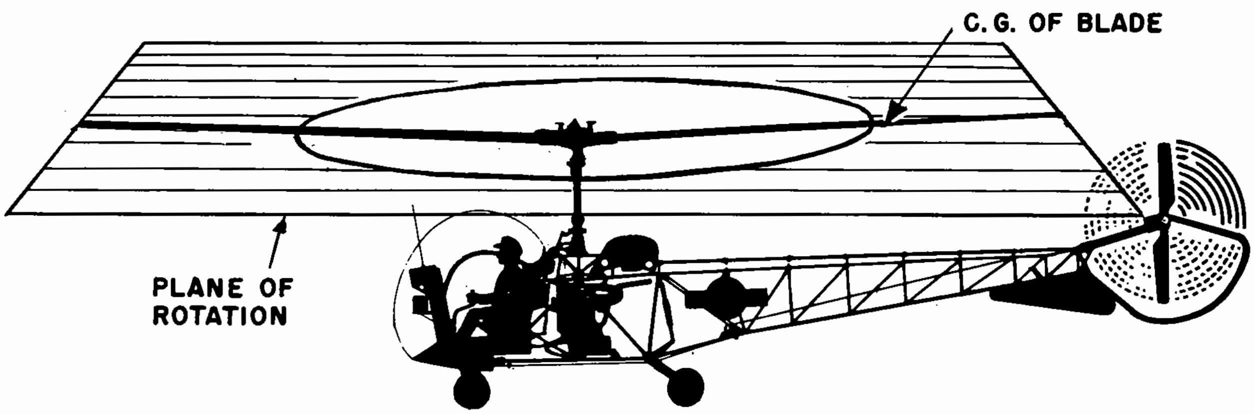


Figure 3-15

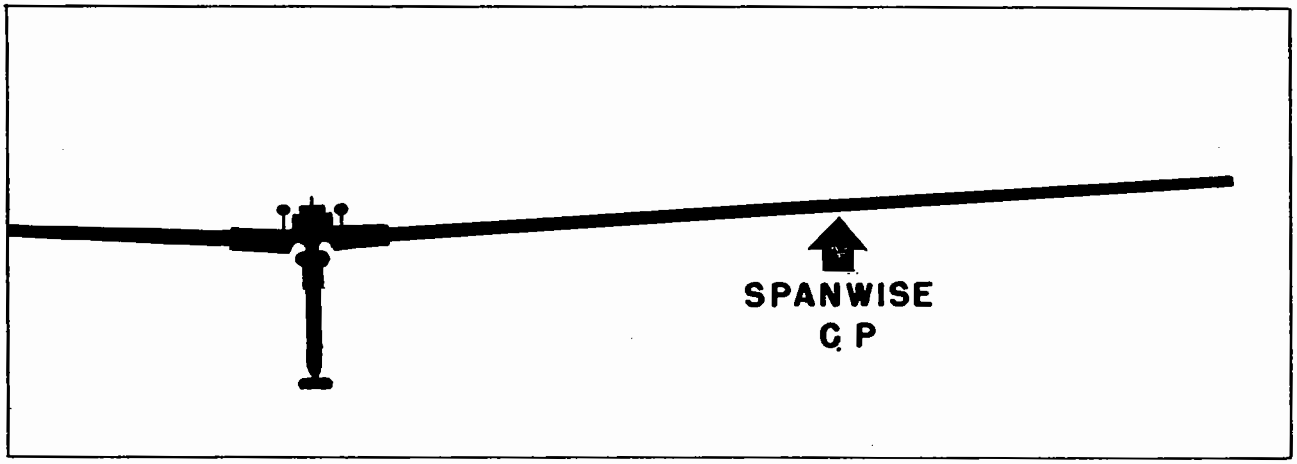


Figure 3-16

which is known as the PLANE OF ROTATION. (See Figure 3-15.)

In fixed wing aircraft, the center of pressure was considered only along the chord of the airfoil. With rotary wings, the center of pressure of the rotor in the spanwise direction is also important. (See Figure 3-16.)

In a fixed wing in normal flight, this, of course, would be at the center of the area of each wing. On a straight wing, it would be at the mid-point of each wing. In a rotor blade, however, the location along the span will depend on the rotational velocity, the shape of the blade, and the angle of attack along the blade. The combination of these elements generally puts the spanwise C.P. out past the mid-point of the blade.

The lift is assumed to act at the spanwise center of pressure. The resultant force between the lift and the centrifugal force will be along the rotor blade. The angle the blade makes with the plane of rotation is called the CONING ANGLE. (See Figure 3-17.) It can be seen that if the rotational speed of the blades remains the same, the greater the lift, the greater the coning angle.

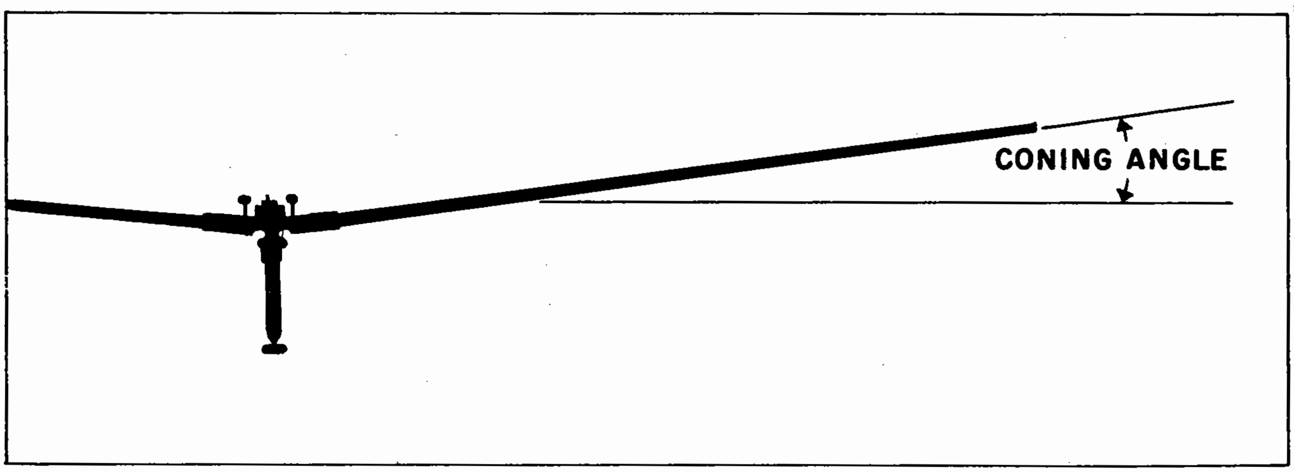


Figure 3-17

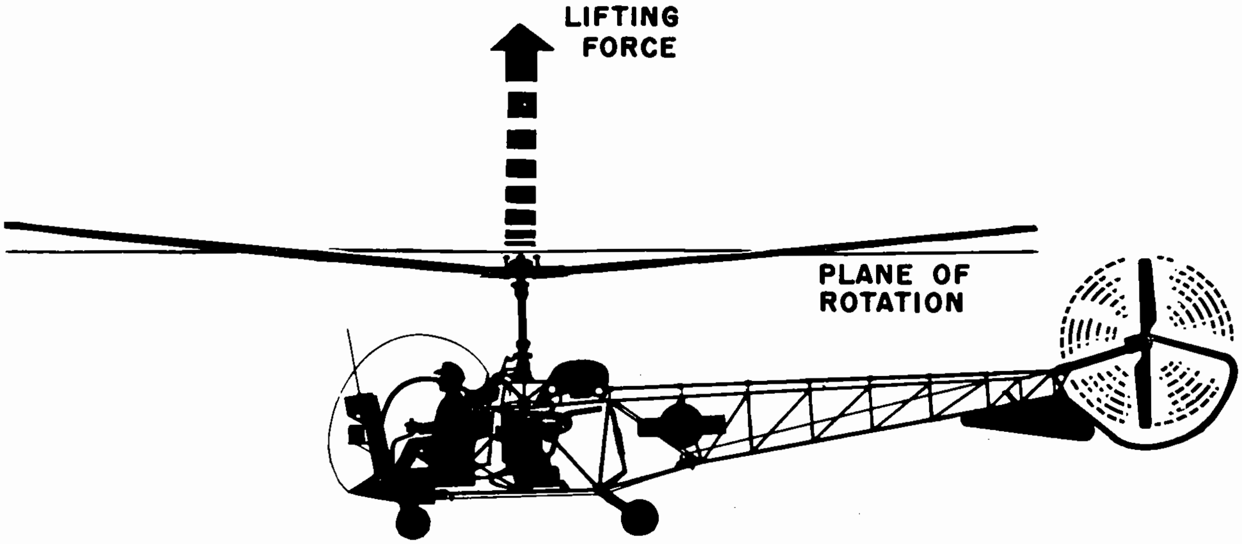


Figure 3-18

BLADE ELEMENT THEORY

With the geometry of the rotor disc well in mind, it is possible to explain the lifting action. There are several theories advanced on the lift of rotor blades. Following the conventional explanation of lift for fixed wing aircraft, however, it seems that the blade element theory is the easiest to follow.

According to this theory, the air flow over any airfoil section or blade element of the rotor blade acts just as it does on a fixed wing.

The same lift coefficient is used and the velocity at that element is used. Air density has the same effect. The total lift is arrived at by integrating or summing up the lift of the individual blade elements over the length of the blade and then adding the lift of each blade together. In the case of a fixed wing with equal air velocity and equal angle of attack throughout the length of the wing, this becomes a rather simple summation. In the case of a rotor, the fact that the velocity at each element is different and that there may be differences in angle of attack, makes this a more complicated problem. The actual calculations may be left to the mathematicians, but an understanding of some of the effects that change the calculations should be helpful to anyone operating a helicopter.

If the rotor is operating in a hovering condition with no wind, the plane of rotation will be parallel to the ground. This makes the local relative wind parallel to the ground also and the angle of attack on any blade element will be the same throughout the cycle of rotation. The lifting force will be perpendicular to the plane of rotation. (See Figure 3-18.)

However, if the helicopter is rising, there is a component of velocity parallel to the axis of the rotor and the relative wind is then a resultant of the rotational velocity and the vertical velocity of the helicopter. (See Figure 3-19.)

Since lift is considered to act perpendicular to the relative wind, and the relative wind is no longer parallel to the plane of rotation, the lift is not acting perpendicular to the plane of rotation. (See Figure 3-20.) The vertical thrust then, or the force acting to overcome gravity, is slightly less than the lifting force.

So far, all discussion has been confined to the forces in the vertical direction which support the helicopter but do not give it any horizontal

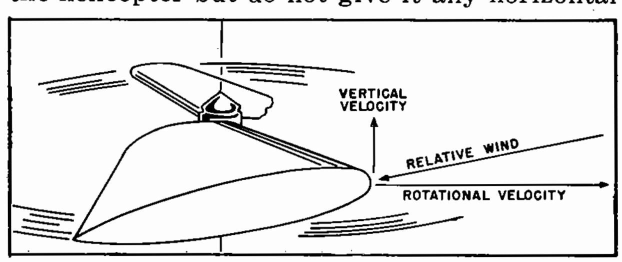


Figure 3-19

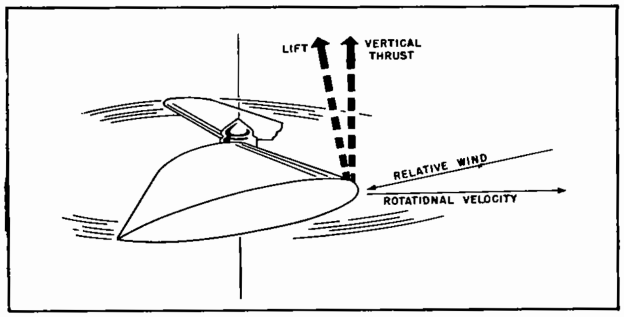


Figure 3-20

motion. Even so, two different velocities have already entered the picture. This is one of the points that must be kept clear in any discussion of principles of flight of the helicopter, the particular velocity being considered must be specified. This also applies to such things as torque, drag and other forces since there will always be at least two sets of forces which may be quite different from one another. One set will relate to the rotor disc itself, while the other is related to the entire helicopter. To some extent this is true of the wing and the complete airplane of a fixed wing aircraft, but in that case the direction and magnitude of the forces will always be in the same proportions and in the same direction.

For example, you can never have lift on the wing with a zero velocity of the aircraft. With the helicopter, lift on the rotor blade with zero horizontal velocity is quite normal. In fact, rpm of the rotor or the rotational velocity of the rotor blades is the equivalent of air speed to the fixed wing pilot.

Before going on to the principles of aerodynamics related to horizontal flight in the helicopter, the practical factors affecting the amount of lift furnished by the rotor will be considered.

FACTORS AFFECTING LIFT

In general, the practical factors affecting the lift of a helicopter are:

(1) Rotor area
(2) Power supplied to rotor
(3) Pitch of rotor blades
(4) Solidity ratio of rotor
(5) Density altitude
(6) Smoothness of rotor blades

(1) ROTOR AREA. In figuring the lift of a rotor, one simple assumption which is generally made is that the lift is dependent upon the entire area of the rotor disc. The rotor disc

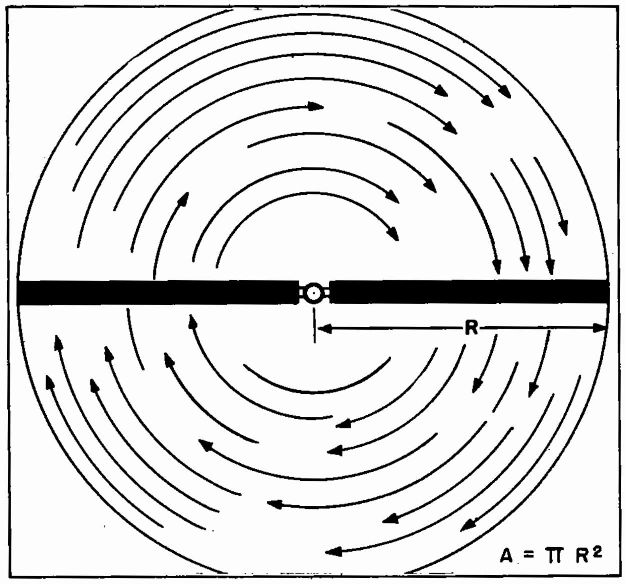


Figure 3-21

area is the area of the circle whose radius is equal to the length of the rotor blade, or $A=\pi R^2$ (See Figure 3-21.) From this it can be seen that the lift of a rotor increases not in direct proportion to the length of the rotor, but in proportion to the square of the length of the rotor. Thus the lift of a rotor with a 20 foot blade would be 77.8% greater than the lift of a rotor with a 15 foot rotor blade, rather than 33⅓% as might be expected. The desirability of large rotor disc areas is readily apparent. But it must be kept in mind that the greater the rotor disc area the greater the drag with the result that power requirements increase sharply also.

(2) POWER APPLIED TO ROTOR. The amount of power applied to the rotor will affect the lift. There are only three ways of getting more power to the rotor: One is to install a larger engine to produce larger power output. Installing a larger engine, of course, is being used in the design of larger and larger helicopters. Just installing a larger engine in a small-sized helicopter adds weight which does not increase the over-all efficiency. Another method is to use a more efficient engine, but this increase in efficiency is difficult to achieve. The third method of getting more power is to reduce losses that take power away from the main job of turning the rotor. It has been found recently that transmission losses amount to 8%, cooling losses 7%, and power taken by the tail rotor 5 to 10%. (See Figure 3-22.) The importance of cutting down these losses assumes a

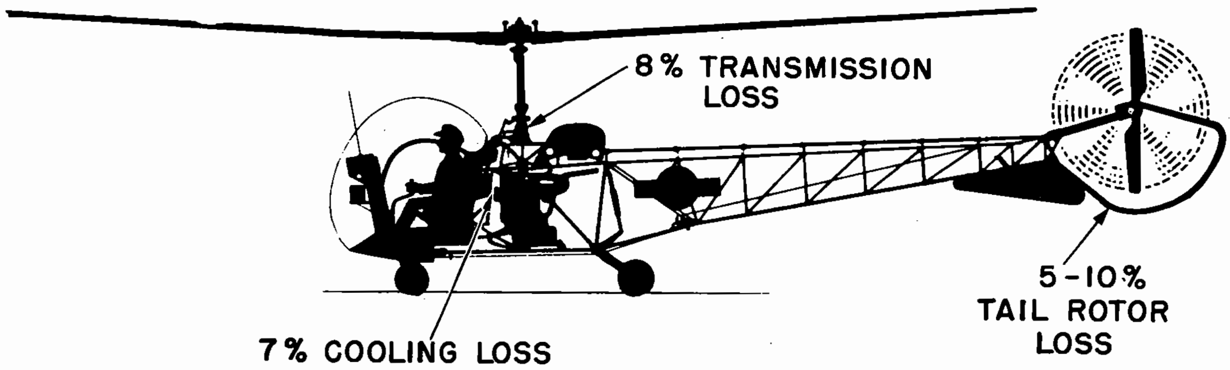
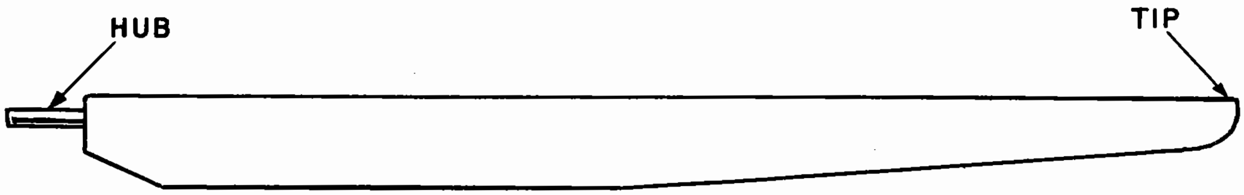


Figure 3-22



PLAN VIEW OF ROTOR BLADE

Figure 3-23

place of first importance. If each of the three losses shown could be decreased by 50%, there would be approximately a 12% increase in power available at the rotor without the addition of a pound of increased weight. Because of the 5 or 10% power required by the tail rotor, there is considerable effort expended on the design of helicopters which will not require a tail rotor. However, elimination of tail rotors by using different rotor configurations introduces other drag factors which in turn require additional power. So simply eliminating the tail rotor does not give a gain of the entire 5 to 10%.

(3) PITCH OF ROTOR BLADES. If the rotor were to be operated at zero angle of attack or zero pitch, no lift would result. When the pitch increases, the lifting force increases until the angle of attack reaches the stalling angle. In order to even out the lift distribution along the length of the rotor blade, it is common practice to twist the blade so that a smaller angle of attack results at the tip than at the hub. Another means of getting even lift distribution across the length of the blade is to have a greater blade chord near the hub. (See Figure 3-23.)

(4) SOLIDITY RATIO OF THE ROTOR. Another factor which affects the lift of a helicopter is the solidity ratio of the rotor. By solidity ratio is meant the ratio of the total blade area to the disc area. To see how solidity ratio is figured, assume the rotor has two blades with a radius of 20 feet and the blades are 1.5 feet wide throughout their entire length. (See Figure 3-24.) The entire rotor disc area is πR^2. In this case

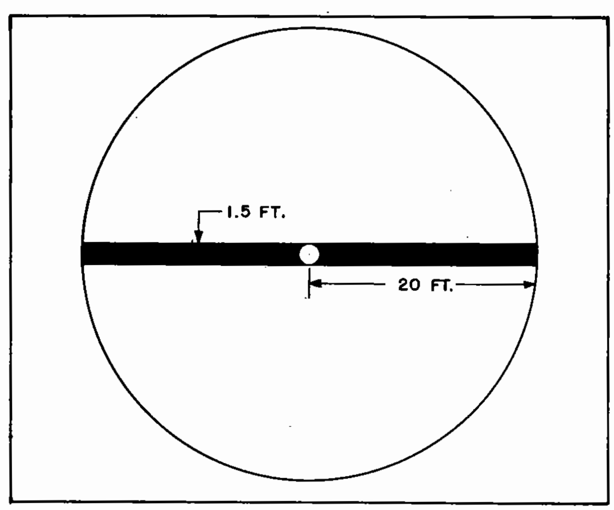


Figure 3-24

$A = \pi 20^2 = 3.14 \times 400 = 1256$ square feet.

The total area of the blades is the length times the chord times the number of blades. $A_B = 20 \times 1.5 \times 2 = 60$.

The solidity ratio is then

$$\frac{60}{1256} = 0.048$$

In conventional nomenclature, solidity is expressed by the small letter sigma σ. The letter b is used for the number of blades, c designates the blade chord. The capital letter R stands for rotor blade radius. Using this nomenclature solidity can be defined by the formula

$$\sigma = \frac{bcR}{\pi R^2}$$

R, the radius of the blades can be cancelled out so that

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

The aspect ratio of rotor blades is the radius divided by the *blade* chord $\frac{R}{c}$

If there were no induced velocity, then the thrust and torque of a rotor would be directly proportional to the solidity since the thrust is proportional to the total lift, particularly in hovering. It would seem from this that the greater the solidity, the greater the lift available from the rotor. However, since one blade operates in the downwash of the preceding blade, it is best to keep the solidity as low as possible since this makes the blade operate at its optimum angle of attack. Flight tests have shown that reducing solidity will increase the performance in hovering. For this reason, the choice of solidity ratio must be a compromise between a low solidity for maximum performance in hovering and a high solidity for maximum lift of the rotor system.

It has been found that most helicopter designs have a solidity ratio of from .05 to .08. Good efficiency has been demonstrated, however, by a few helicopters with ratios of as low as .035.

(5) DENSITY ALTITUDE. It has been shown in all of the formulas for lift and drag, whether of fixed wing aircraft or rotor blades, that the density of the air is an important factor. This is true since the mass or density of the air reacting in a downward direction causes the upward force or lift which supports the helicopter.

Density is dependent on two things. One is the altitude, since density varies from a maximum at sea level to a minimum at high altitude. The other is atmospheric changes. Due to the atmospheric changes in temperature, pressure or humidity, density of the air may be different, even at the same altitude from one day to the next or one location in the country to another.

The two things that affect air density, give the helicopter pilot two problems. Because he can hover at his take-off point with a certain load does not mean that he can hover at a higher altitude. And although the helicopter pilot may be able to hover with a certain load on one day, he may not be able to hover with the same load the next day or even at a different time of the same day if there has been a change in the pressure, temperature or humidity at the take-off point. Therefore, the important thing to the pilot is not just the actual altitude above sea level but the so-called density altitude.

Helicopter performance is figured under ideal conditions, that is, at sea level air pressure with dry air at a temperature of 59 degrees F.

Any difference in density due to nonstandard barometric pressure will establish a new equivalent altitude for the operation of the helicopter. This is known as the pressure altitude. Then correction for nonstandard temperature and humidity conditions determines the density altitude.

If the density of the air is lower either because of altitude or because of moisture or temperature differences, the lifting power of the helicopter is materially decreased. In other words, the density altitude may be much higher than the actual altitude of the aircraft. Thus a helicopter pilot, taking off from a field with a 1,000 foot elevation on a hot day, may easily have only the performance equivalent of taking off from a field with a 2,000 foot altitude. Such a condition may be dangerous unless the pilot makes allowance for this difference in operating conditions. Because the helicopter in hovering flight has such a small amount of excess power available compared to conventional aircraft, density altitude is much more important to a helicopter pilot than it is to a pilot of standard aircraft. The difficulty is compounded in many helicopters because the engines are not supercharged. This means that in addition to less lift, the engine will not develop as much power, because the reduced amount of oxygen available reduces the power output of the engine.

The conditions which affect air density are pressure, temperature, and proportion of water vapor. If temperature and water content remain unchanged, the increase in pressure will decrease the density altitude. In other words, if the barometric pressure increases with no change in temperature or humidity, the helicopter is capable of lifting a greater load. If pressure and water vapor remain the same, and the temperature increases, the density will decrease. Also, if the pressure and temperature remain the same, but the water vapor increases, the density will be lower. From this it is seen that either high temperature or high humidity will lower the density and therefore raise the density altitude or the effective altitude at which the helicopter is operating. Total pressure is always the sum of the air pressure plus the pressure of the water vapor. Water vapor displaces air. The density of water vapor is less than the density of air. So, an increase in water vapor or humidity will result in a decrease in the average density of the mixture of water vapor and air. The greatest change in density altitude, however, will generally result from a change in temperature. When low temperatures prevail, the relative humidity has only a minor effect on the performance of the helicopter.

But when both temperature and relative humidity are high, the effect is considerable. Regardless of the combination of factors which may combine to increase density altitude such an increase means that the useful load carrying capacity of the helicopter is decreased. The helicopter pilot is provided with a chart (Figure 3-25) so he can establish what the density altitude is. Then he can compute the useful load which the helicopter can carry.

It is necessary to know the pressure altitude to determine density altitude from this chart. Pressure altitude has already been corrected for barometric changes. It must be remembered that density altitude may change materially within a few hours. This chart is calculated to cover altitudes from below sea level to 19,000 feet above sea level, and from —50° C. to 30° C.

First locate the desired pressure altitude, shown by the slanting curved lines. Then follow the vertical line indicating the outside air temperature. The intersection point is opposite the Density Altitude value indication at the left of the chart.

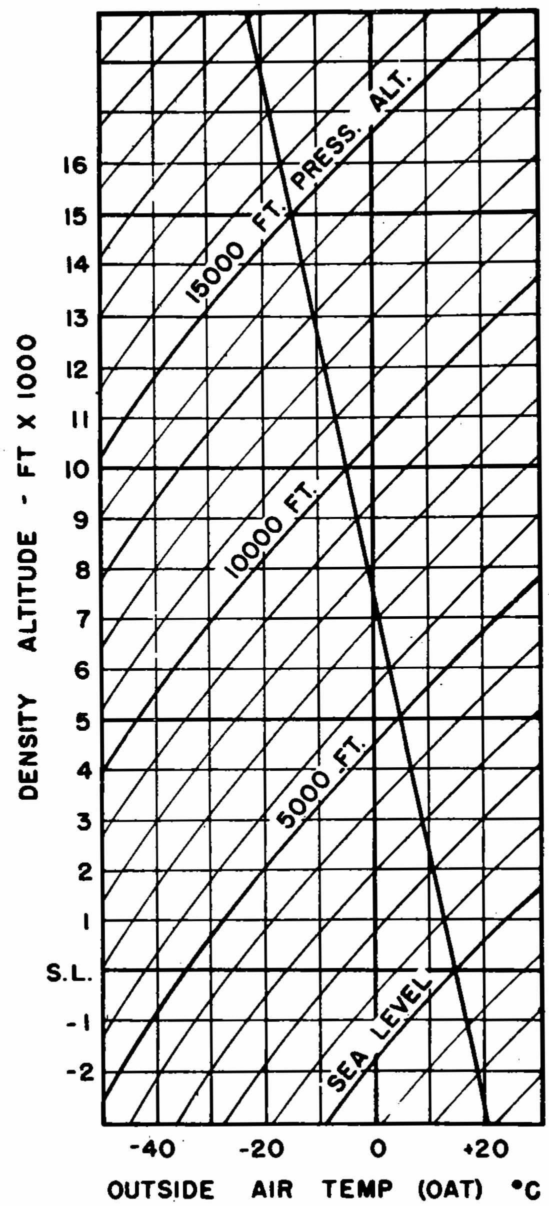


Figure 3-25. Density Altitude Chart.

EXAMPLE

If pressure altitude is 6000 ft. and temperature is 20° C. find the density altitude. Intersection of the two lines indicates a density altitude of slightly less than 8000 ft.

Pressure altitude is 9500 ft. and OAT is 5° C. What is the density altitude? Intersection of two lines shows it to be 10,500 ft.

(6) SMOOTHNESS OF ROTOR BLADES. Experiments and tests have proved that the lift of a helicopter can be materially increased by polishing the rotor blades to a mirror-like surface. By making the rotor blades as smooth as possible, the parasite drag can be reduced.

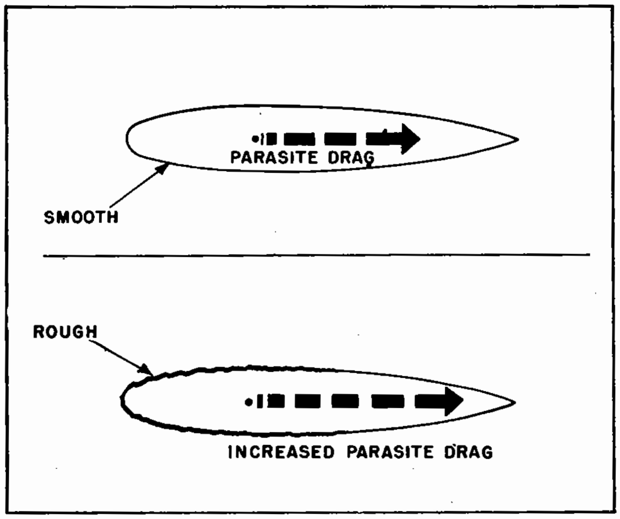


Figure 3-26

Reducing the parasite drag increases the power available for turning the rotor blades. (See Figure 3-26.) This increased power to the blades is directly related to the lift. Careful polishing of the rotor blade surfaces has resulted in increases in lift of as much as 10%. This not only indicates the desirability of making the blades as smooth as possible to start with, but of maintaining this smoothness during normal operations. Any dirt or grease or abrasions on the rotor blades themselves may be a source of increased drag with the resultant decrease in lifting power of the helicopter

PILOT CONTROL OF LIFT

Six factors which enter into the amount of lift available in helicopter operation have been covered. Generally speaking, the pilot himself has control of only two of these.

One is the pitch angle of the blades. The other is the power delivered to the rotor, or, as the pilot knows it, the rpm of the rotor. The pitch angle or angle of attack of the blades can be controlled by the pilot by use of the collective pitch lever, usually operated by the pilot with his left hand. Through this lever, the pitch of all blades is increased or decreased simultaneously as implied by the name collective pitch.

The amount of power delivered to the rotor which is indicated by the rotor rpm is controlled by the motorcycle type grip on the end of the collective pitch lever. (See Figure 3-27.) The more power, the greater the amount of lift available. As will be repeated many times, the rpm of the rotor is the critical thing in helicopter operation, since it determines the air velocity over the rotor blades. This factor is as important to the helicopter pilot as air speed is to the conventional aircraft pilot. Since this is true, it might be supposed that the answer is to use as much rpm as possible. However, as the rpm increases, the centrifugal force increases. Centrifugal force varies as a square of the velocity. For this reason, a 25% increase in rpm would not result in a mere 25% of centrifugal force. The increase would actually be more than 56%. As an example, at 190 rpm, which is the normal operating condition for the rotor of the HO3S-1, the centrifugal force in a blade shaft is approximately 2800 pounds. If the rotor is speeded up to 225 rpm the centrifugal force increases to 3930 pounds.

The chart (Fig. 3-28) indicates how rapidly centrifugal force increases as speed increases. If the rotor speed is allowed to go too high, the rotor head will be subjected to severe strains. If the rotor speed is too low, centrifugal force will drop rapidly with the result that coning will be excessive.

Excessive rotor speeds might also put the tips into the range of transonic speeds and cause stress conditions and aerodynamic loads not anticipated.

It can be readily seen that it is essential to keep the rotor rpm within the designed specification limits in order to avoid either over speed or under speed difficulty.

Figure 3-27

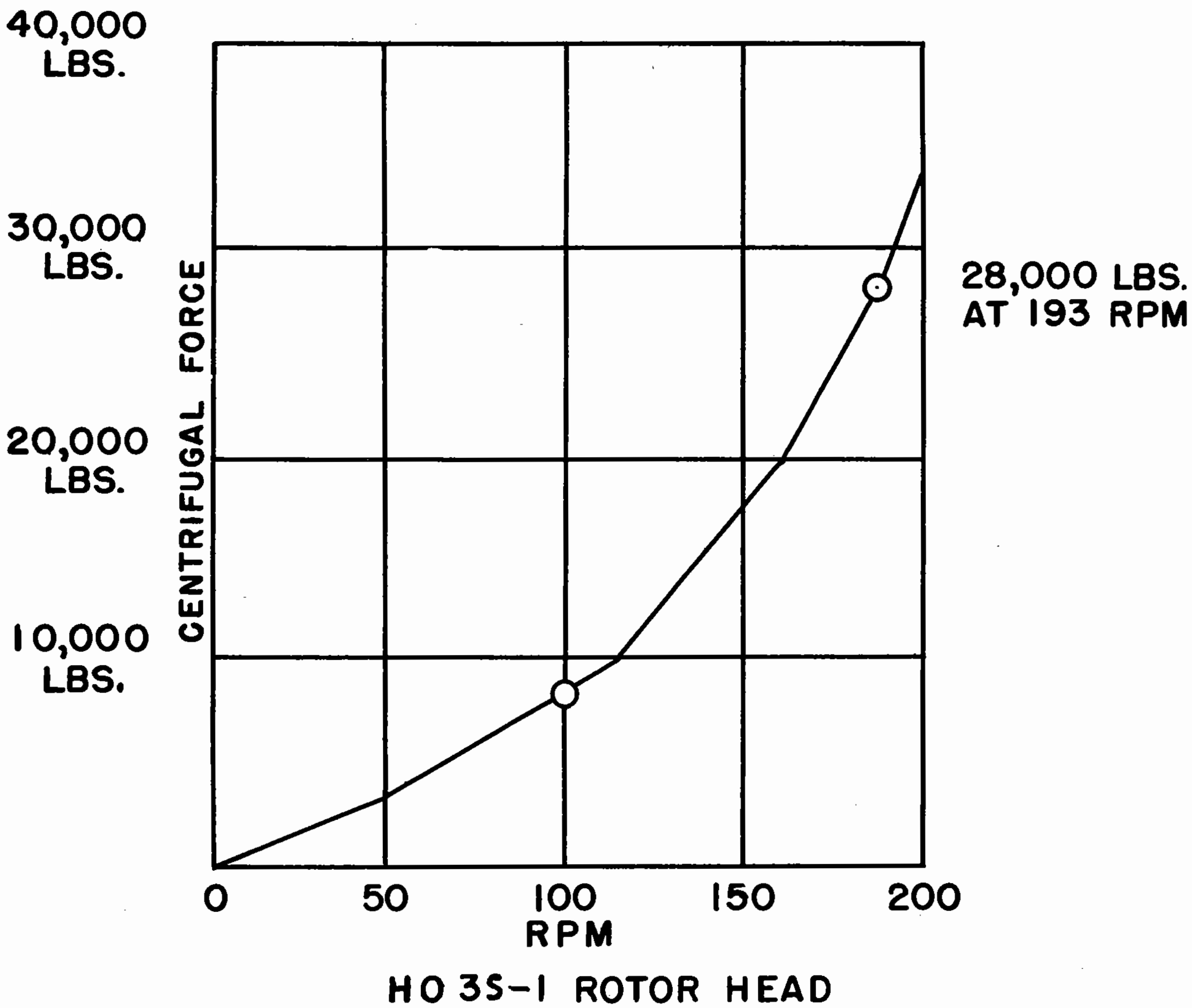


Figure 3-28

CONCLUSION

Basic principles of physics and aerodynamics as they relate to the lift and drag forces on the helicopter rotor have been discussed in this chapter. With only these forces involved the helicopter could climb vertically and hover but could not move in translational flight. This would result in a rather impractical vehicle. In the next chapter some of the preliminary problems of translational flight will be discussed.

CHAPTER 4
FORCES ON THE HELICOPTER

FORCES ON THE AIRPLANE

A quick review of the over-all forces on a conventional fixed wing aircraft will simplify the understanding of the forces on the helicopter.

Lift is assumed to act perpendicular to the relative wind. In a fixed wing aircraft, the lift component overcomes the gravity force or the weight of the aircraft. In level flight lift will equal weight. (See Figure 4-1.) If there is an excess of lift over weight the aircraft will rise.

The thrust furnished by the propeller or jet airstream is counteracted by the drag of the aircraft. The drag of the aircraft is a combination of the drag of the wing and tail surfaces and the drag of the fuselage. When the thrust is equal to the drag, the aircraft will be in uniform motion in forward flight. (See Figure 4-2.) If the thrust exceeds the drag, there will be an acceleration until the increased drag at the new speed equals the thrust again. The flight will then continue at uniform speed.

Since the lift component does not act at the center of gravity it will cause a moment about the center of gravity tending to upset the aircraft.

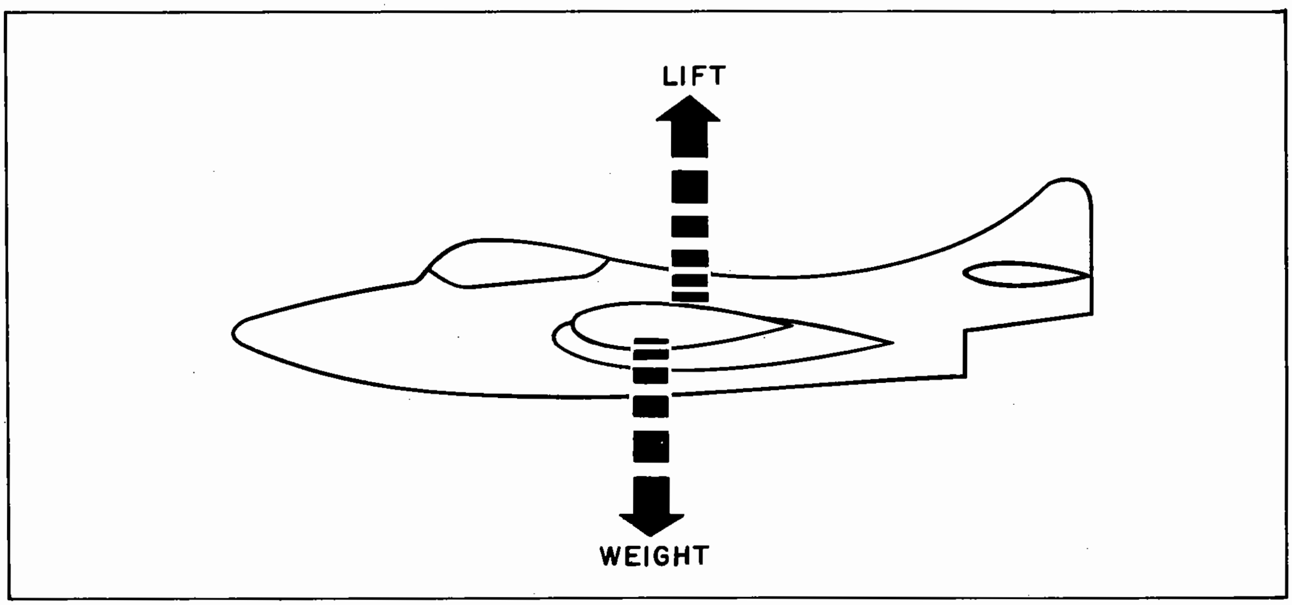


Figure 4-1

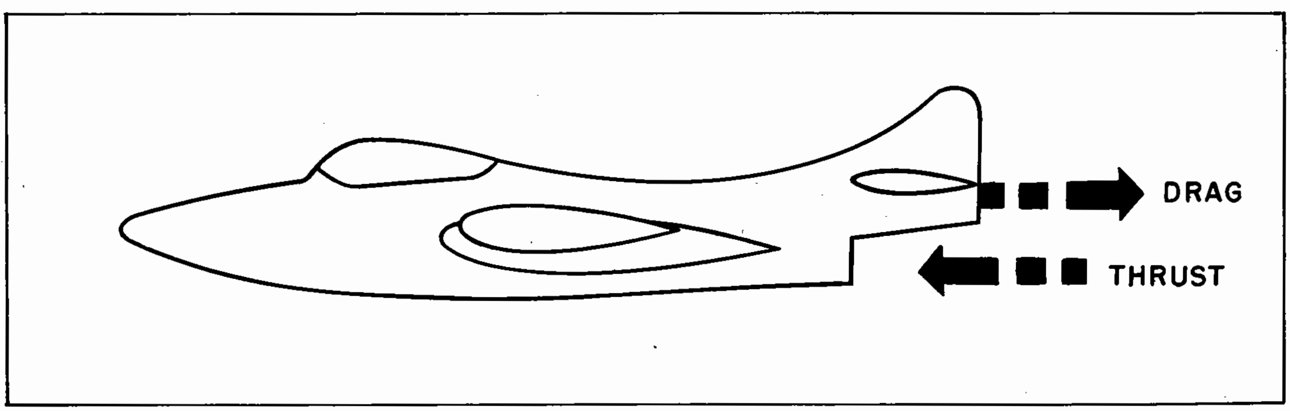


Figure 4-2

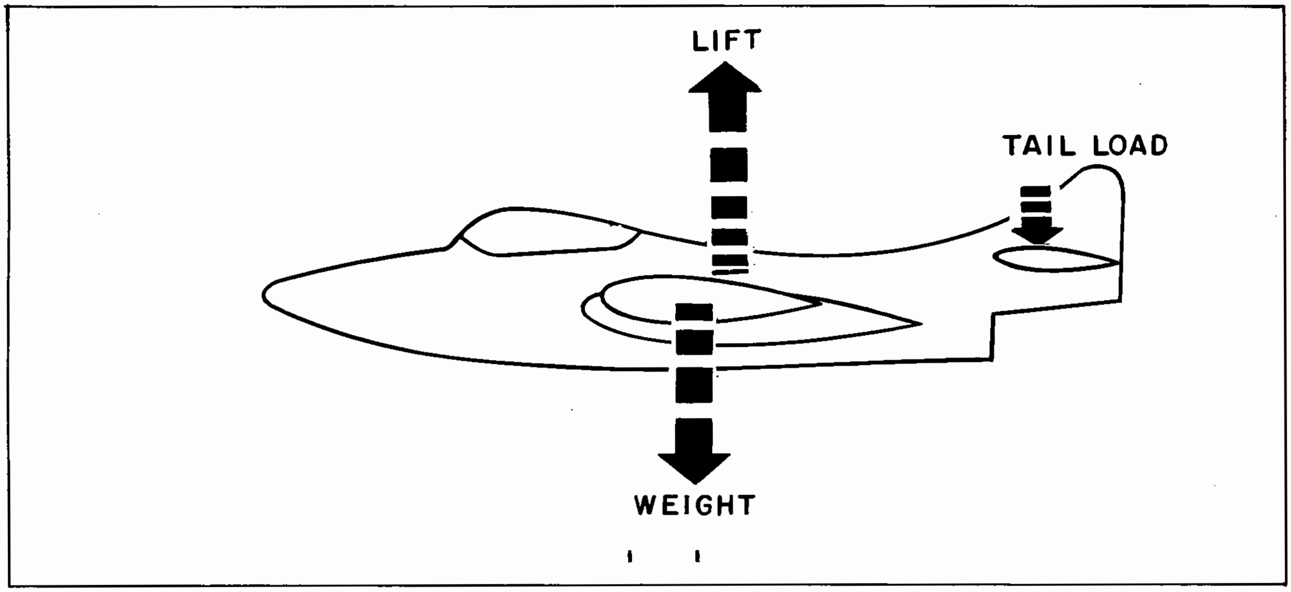


Figure 4-3

In fixed wing aircraft, this upsetting moment is generally balanced by an airload on the tail surfaces. The tail load is usually a down load. The lift must then be equal to the weight plus the tail load. (See Figure 4-3.) Under these conditions all forces are in balance.

Another force on the airplane is the torque or twisting effect created by the reaction of the turning propeller. Because the wing is long and heavy in respect to the propeller, a slightly greater lift on one wing than the other will easily counteract this torque reaction. (See Figure 4-4.) Since lift on the wing is always available when torque is a problem, counteracting the torque in this manner is acceptable.

All of these forces have counterparts in the helicopter.

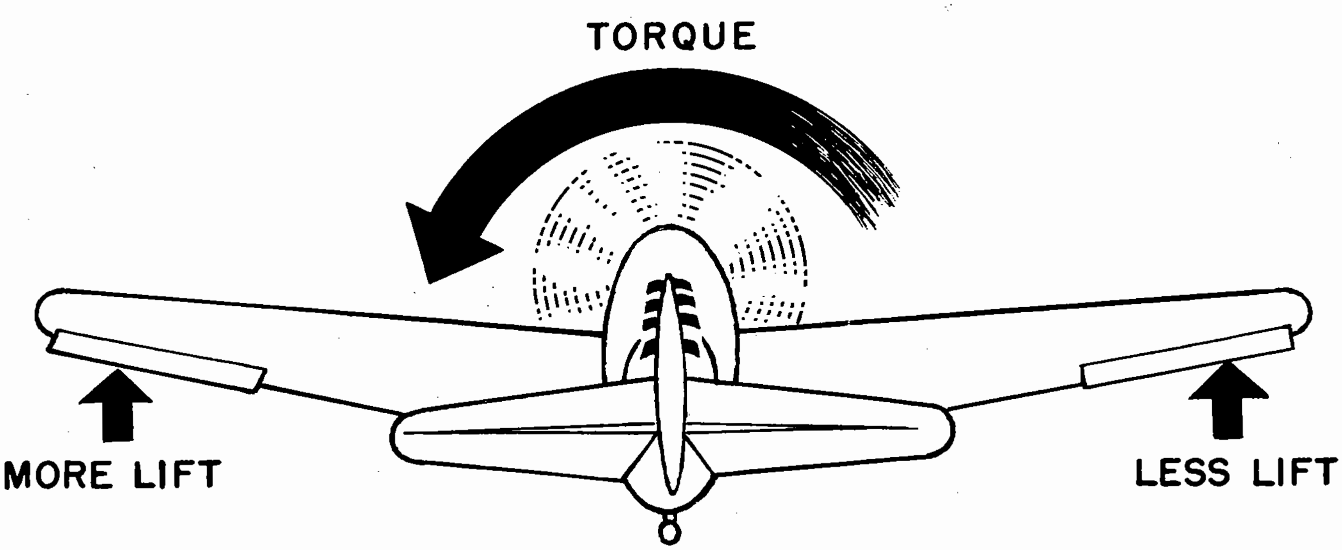


Figure 4-4

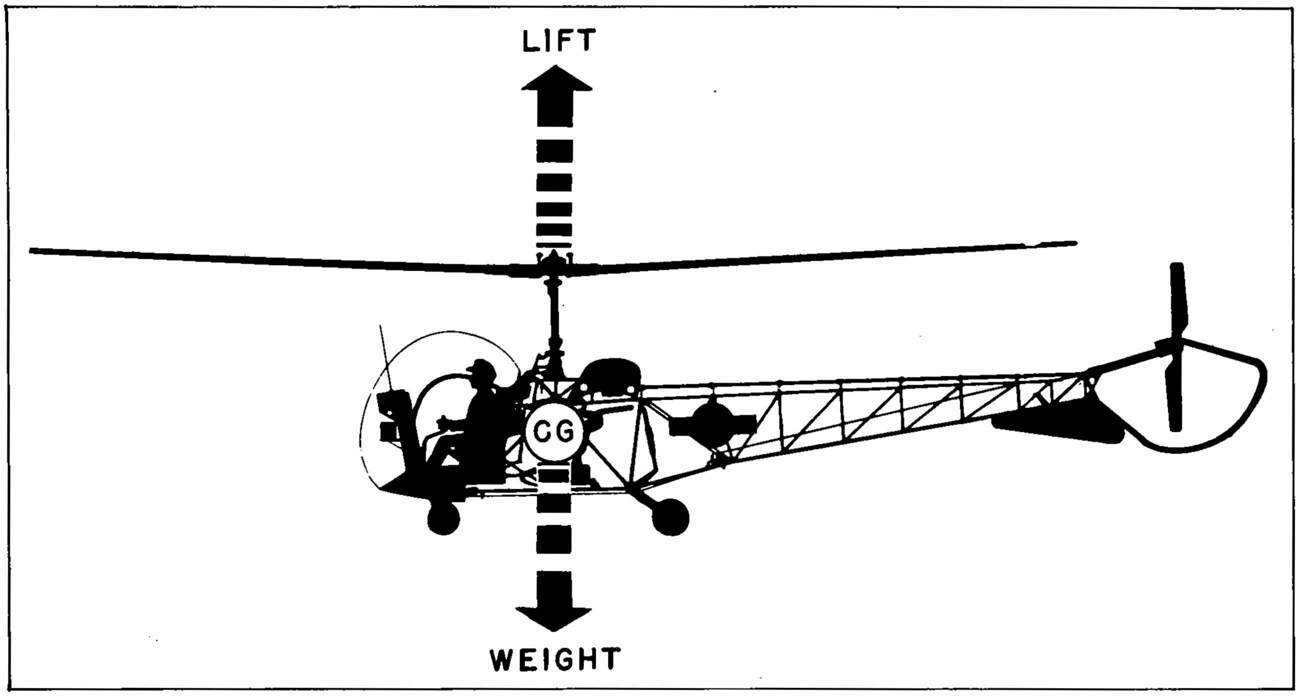


Figure 4-5

FORCES ON THE HELICOPTER

It has been shown that in a no wind hovering condition, the lift and therefore the thrust of the rotor is straight up. When this lift equals the weight, the helicopter will hover. (See Figure 4-5.) If the lift is greater than the weight of the helicopter, the helicopter will rise. (See Figure 4-6.) When the lift is less than the weight, the helicopter will go down. In the condition of hovering, there is no translational motion, so there is a zero horizontal force and therefore zero drag in the horizontal direction.

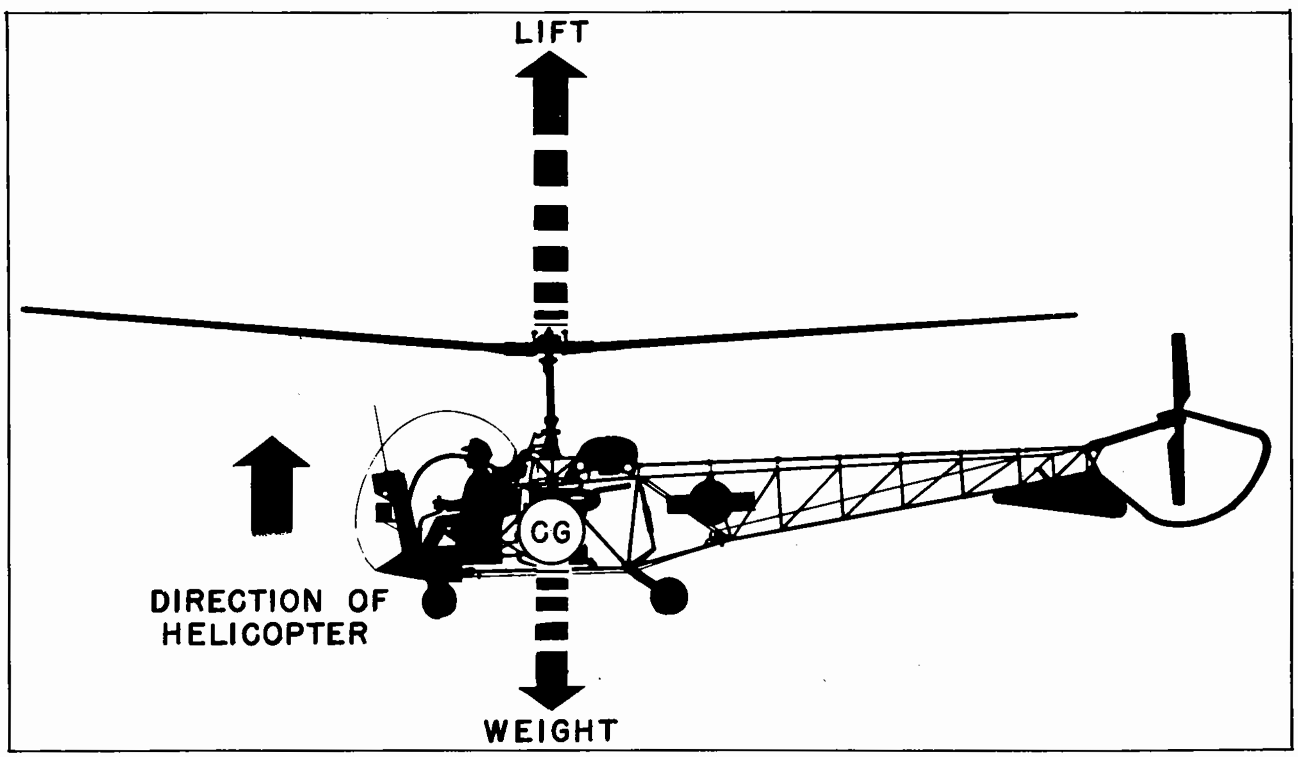


Figure 4-6

If the tip-path-plane of the helicopter is tilted from horizontal, the lift component, which always acts perpendicular to the tip-path-plane or along the virtual axis, is also tilted. If the lift is then resolved into components perpendicular and parallel to the ground, there will be a vertical thrust component to support the helicopter and a horizontal thrust component or horizontal force which will cause translational motion. (See Figure 4-7.) The helicopter will move in whatever direction the tip-path-plane is tilted. This may be forward, backward or sidewards.

An example will be used to show how this force created by the rotor blades can be resolved into the horizontal force acting in a horizontal direction and the lifting force acting in a vertical direction. This can be done either graphically or by trigonometry.

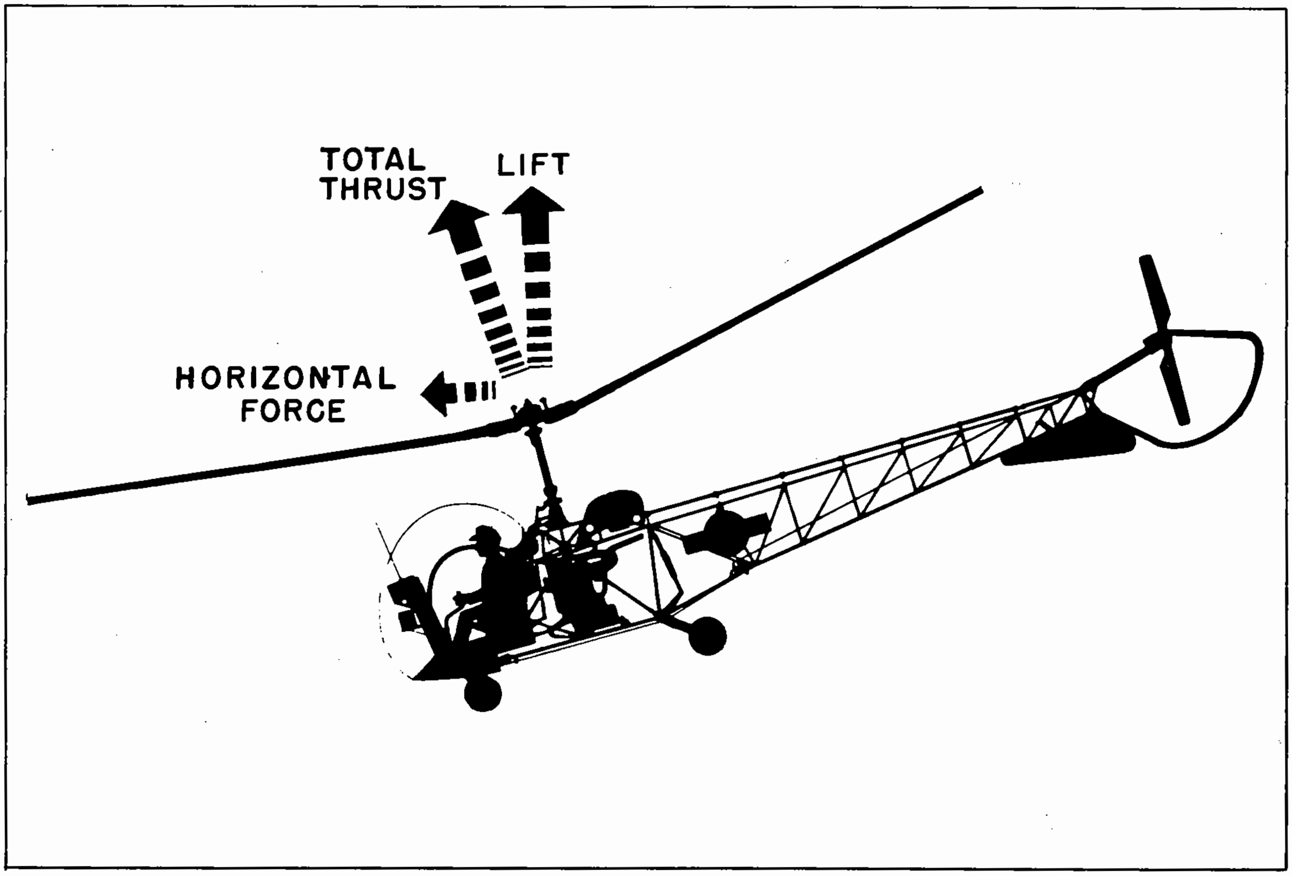


Figure 4-7

EXAMPLE OF LIFT AND HORIZONTAL FORCE

(1) GRAPHIC SOLUTION. Assume that the force created by the rotor is 5000 pounds, and that the tip-path-plane of the rotor is inclined at 15° to the horizontal. The virtual axis then is inclined at 15° to the vertical. The problem is to find how much of the force is exerted in lift . . . and how much is applied to translational movement.

To solve this problem graphically, (See Figure 4-8) lay off the 5000 pounds, ED, on a line 15° off vertical. Then measure the vertical and horizontal components according to the same scale. It will be found that the vertical line DF, representing the component of lift will scale to approximately 4800 pounds, while the horizontal component FE, representing the forward translational force will have a value of about 1200 pounds.

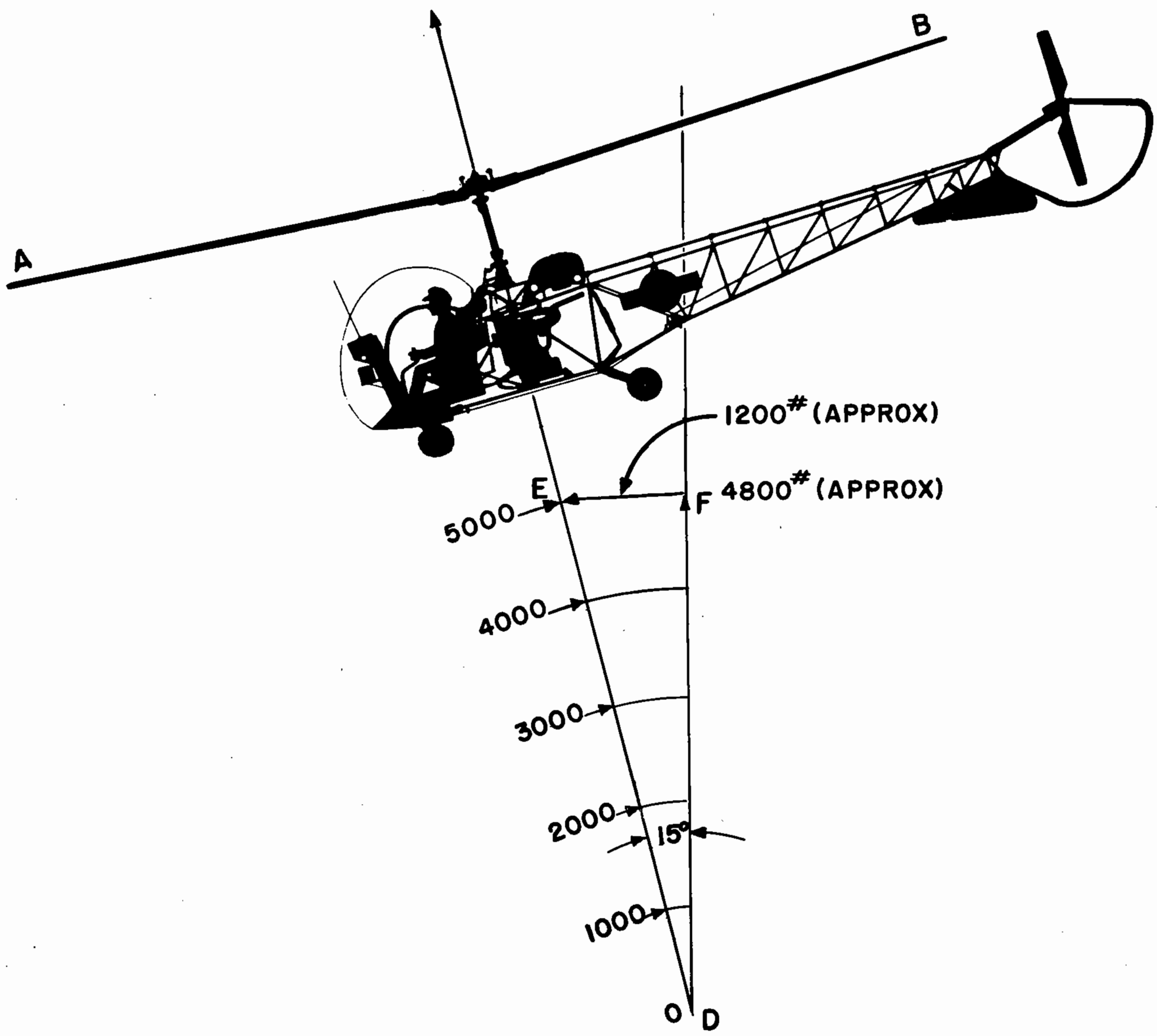


Figure 4-8

(2) TRIGONOMETRIC SOLUTION. The same problem can be solved more accurately and just as quickly by trigonometry (See Figure 4-9.) In this solution the formula would be:

$$\text{Lift} = 5000\ (\cos 15°)$$

$$\text{Horizontal force} = 5000\ (\sin 15°)$$

OR

$$\text{Lift} = 5000\ (0.966) = 4830 \text{ lbs.}$$

$$\text{Horizontal force} = 5000\ (0.259) = 1295 \text{ lbs.}$$

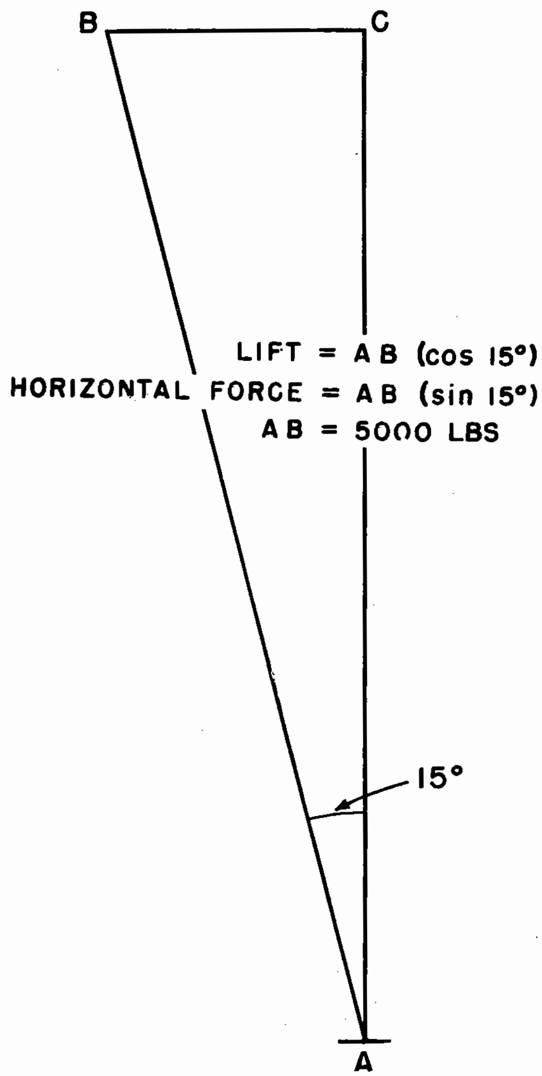


Figure 4-9

It is apparent from both the graphic and trigonometric solution of the lift-horizontal force triangle, that the greater the tilt of the tip-path-plane the greater the horizontal force and the smaller the lift component. (See Figure 4-10.)

Conversely, the smaller the tilt angle of the tip-path-plane, the less the horizontal force and the greater the lift.

It must also be noted, that in changing from hovering to translational flight there will be a decrease in lift, at least momentarily, unless allowance is made for this change.

The force component of the rotor in a horizontal direction is counteracted by the total drag of the helicopter. As long as the horizontal force is greater than the drag, there will be an acceleration in the horizontal direction. When the drag of the helicopter increases due to the increased speed, it will eventually equal the horizontal force and uniform speed will result. (See Figure 4-11.)

TORQUE REACTION

With rotors turned by a shaft in the fuselage, there will be a torque reaction applied to the fuselage just as there is in a fixed wing aircraft. However, in the case of the helicopter it is applied in a horizontal plane rather than in a vertical plane. Also, since the rotor is long and heavy in respect to the fuselage, the reaction will be appreciable.

In the helicopter, compensating for torque is complicated by the fact that forward speed is not always available to correct the twisting effect, and the means must be effective at all speeds from zero to the maximum.

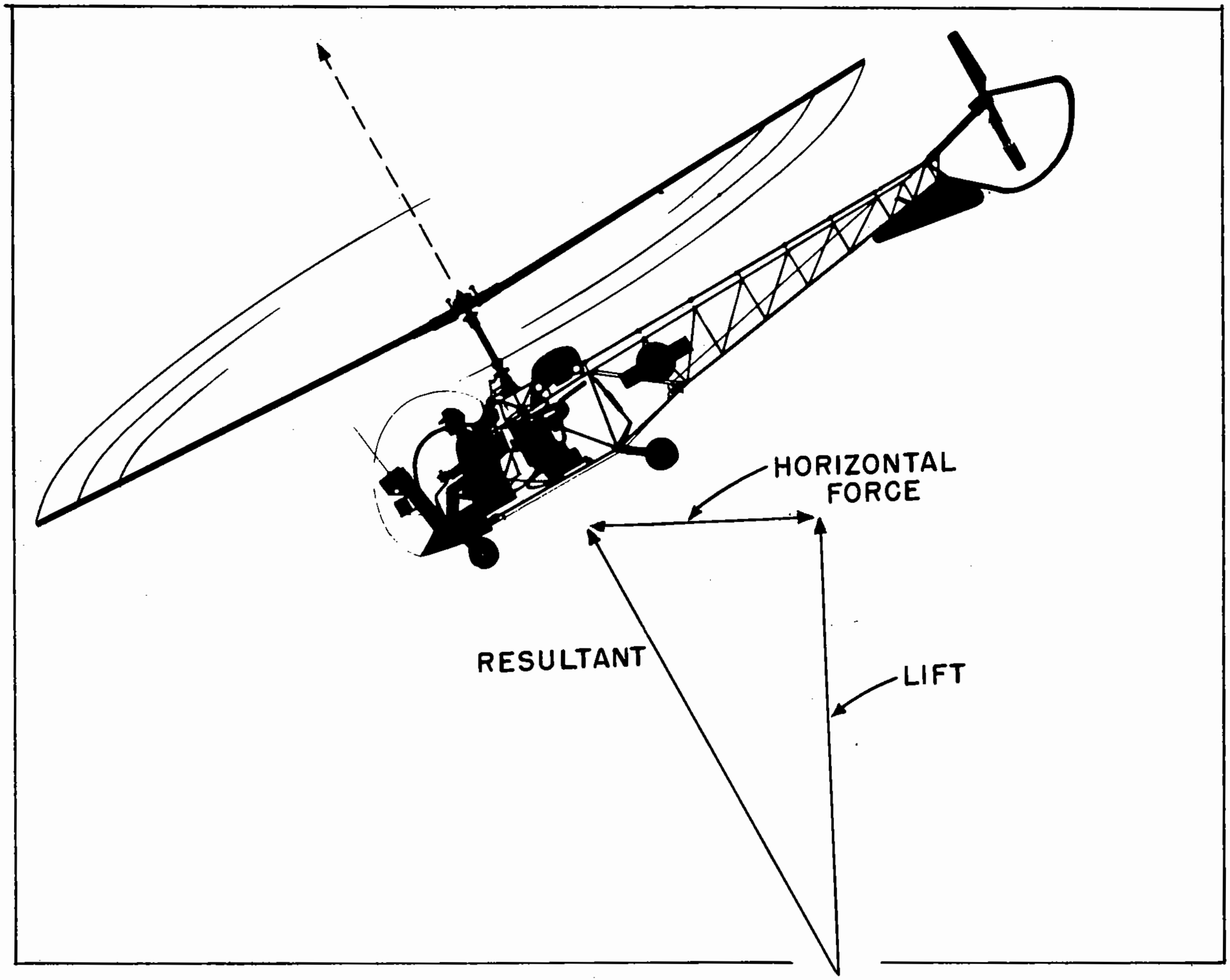


Figure 4-10

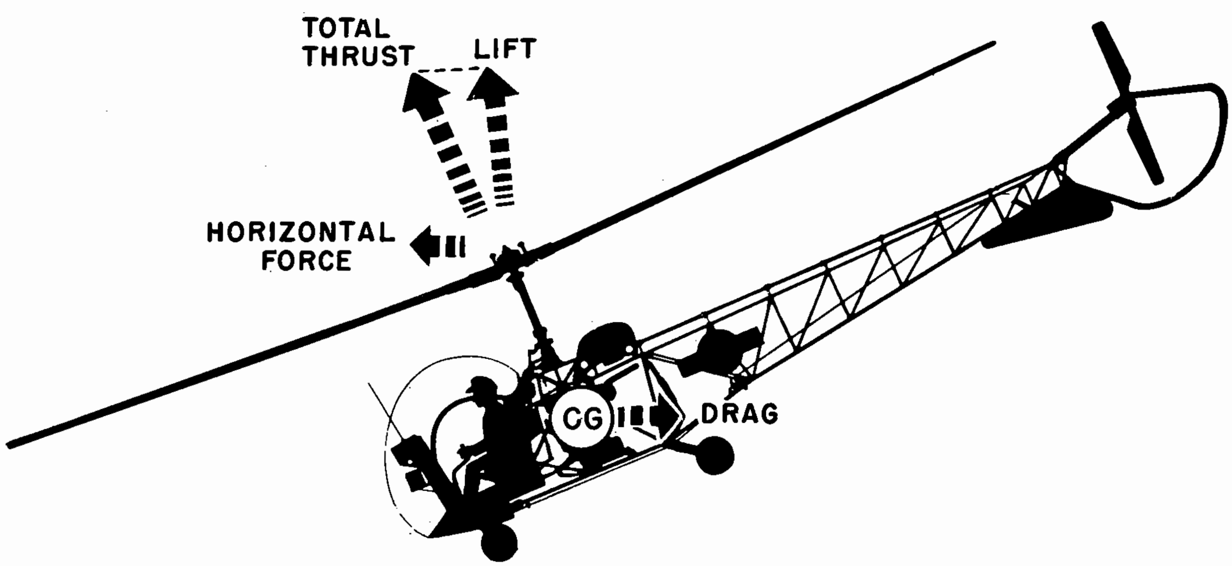


Figure 4-11

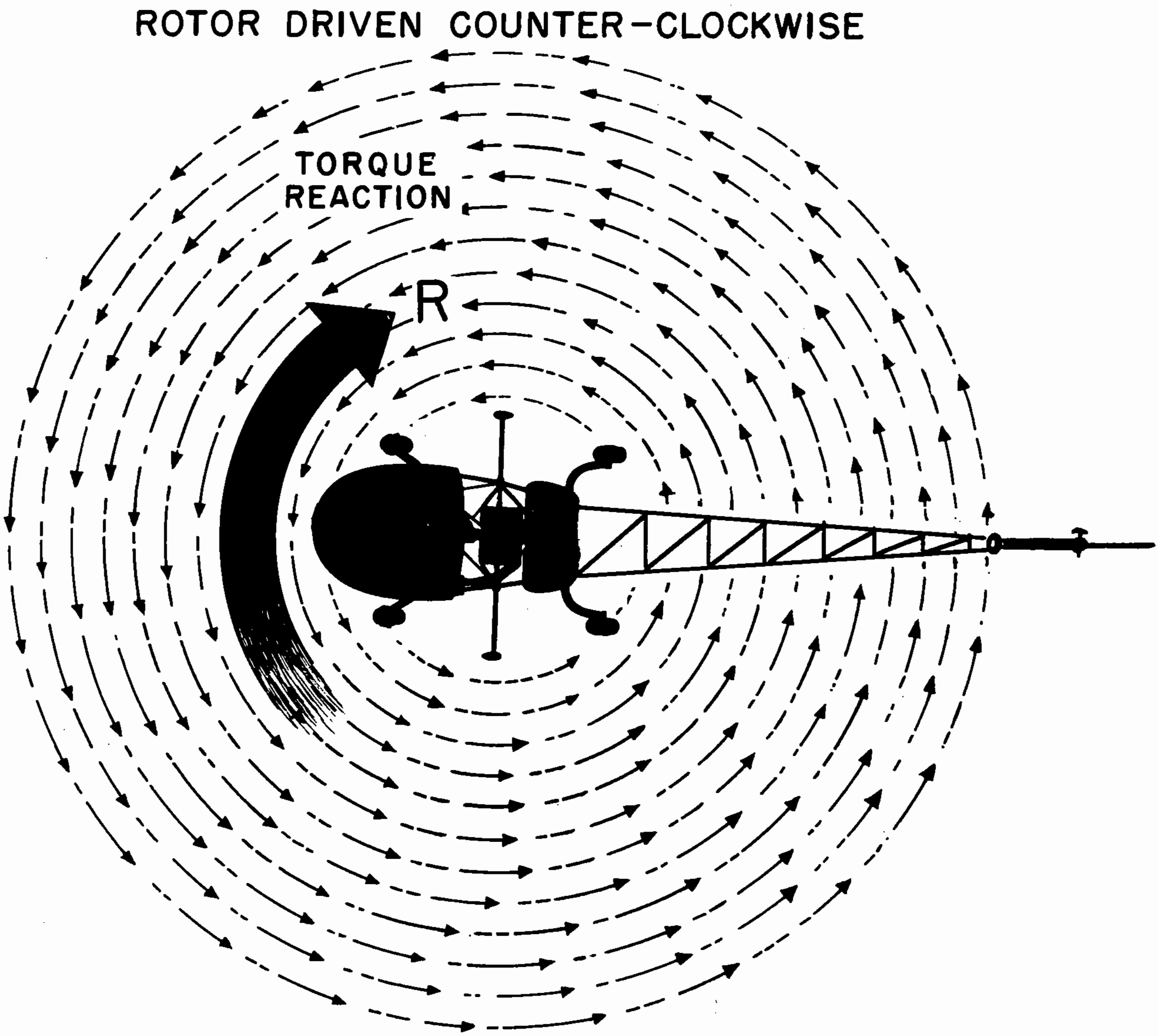


Figure 4-12

In Figure 4-12 a single-rotor helicopter is seen from above. The rotor is being driven in a counter-clockwise direction by the engine in the fuselage. According to Newton's third law of motion, "For every action there is an equal and opposite reaction"therefore the fuselage tries to turn in a clockwise direction. And it would turn, and keep on turning, unless some force were applied to offset this action.

ROTOR DRIVEN COUNTER-CLOCKWISE

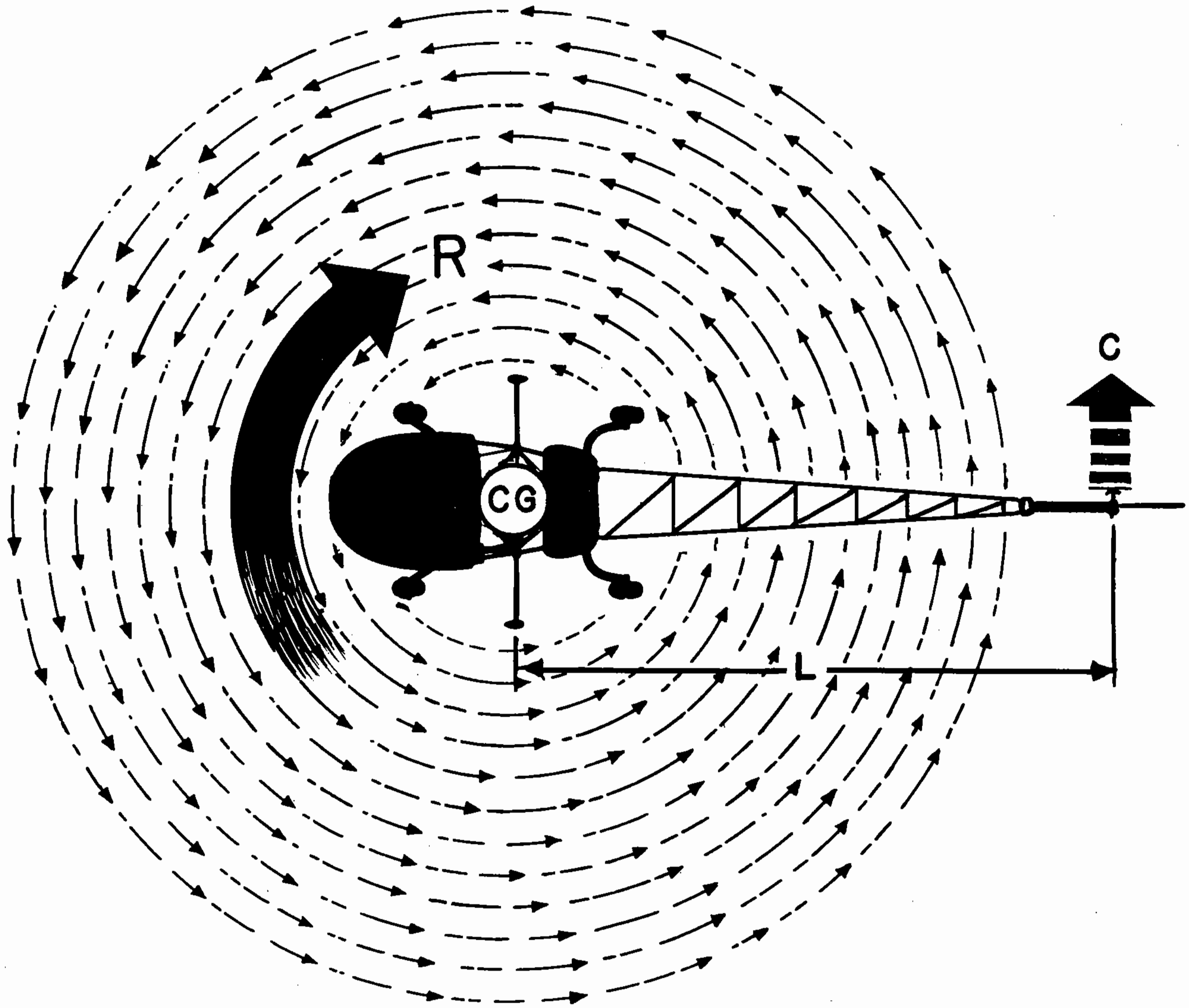


Figure 4-13

The force generally applied is through an engine-driven tail rotor, which supplies a force C. (See Figure 4-13.) The force C acting at the distance L from the center of gravity gives a moment CL which is equal and opposite in its effect to the torque R which is trying to rotate the fuselage clockwise.

There is an important difference in the moment supplied by the tail rotor and the torque effect of the rotor.

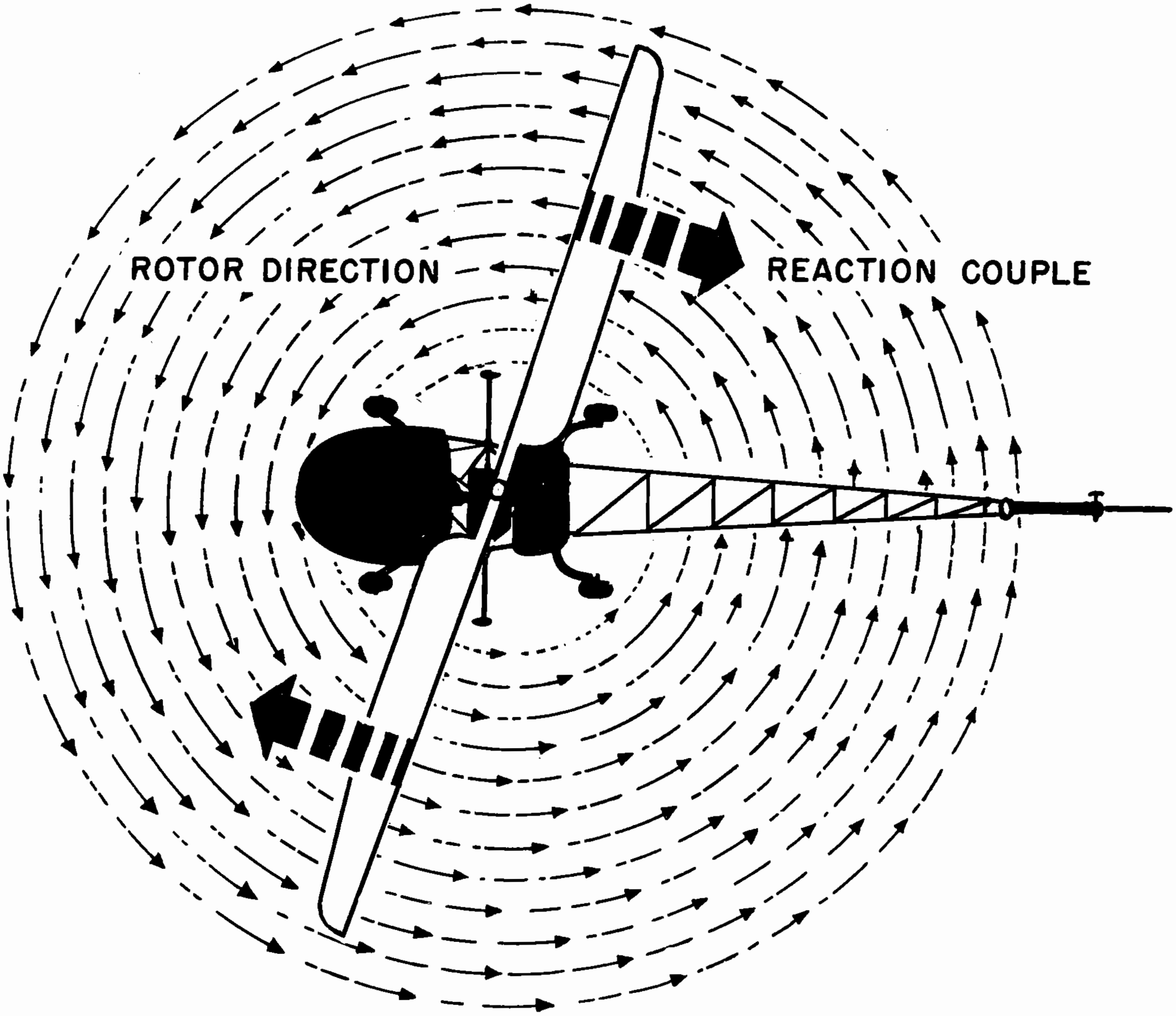


Figure 4-14

The torque effect is the reaction of the rotor blades to the driving force of the engine. The reaction of each blade being equal in magnitude and opposite in direction and acting at the same radii from the point of rotation, form what is known as a couple. (See Figure 4-14.) A couple has rotation effect only. It has no unbalance to cause a translational motion.

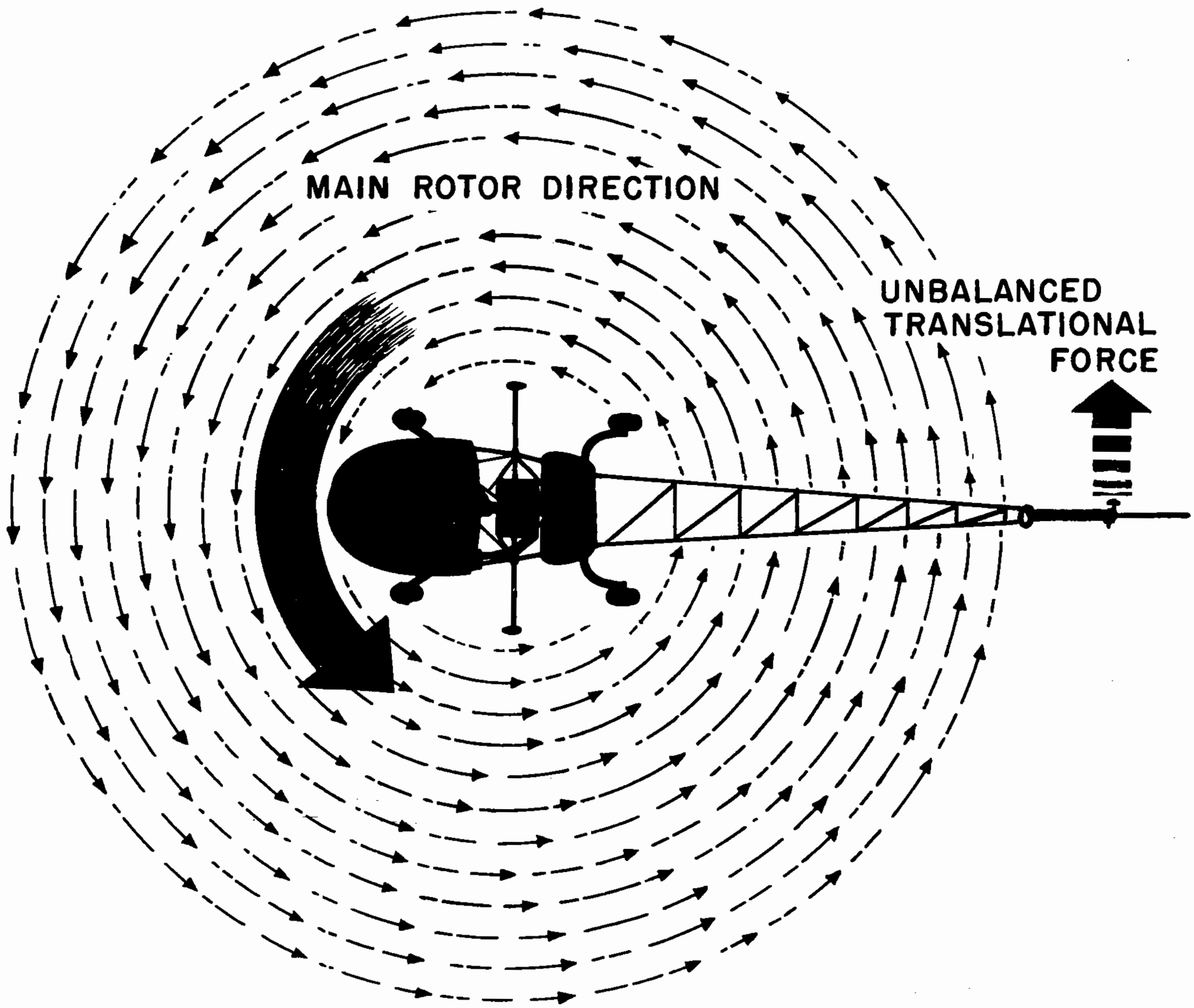


Figure 4-15

On the other hand, the force of the tail rotor acting around the center of rotation of the rotor has a rotational effect and an unbalanced translational force. (See Figure 4-15.)

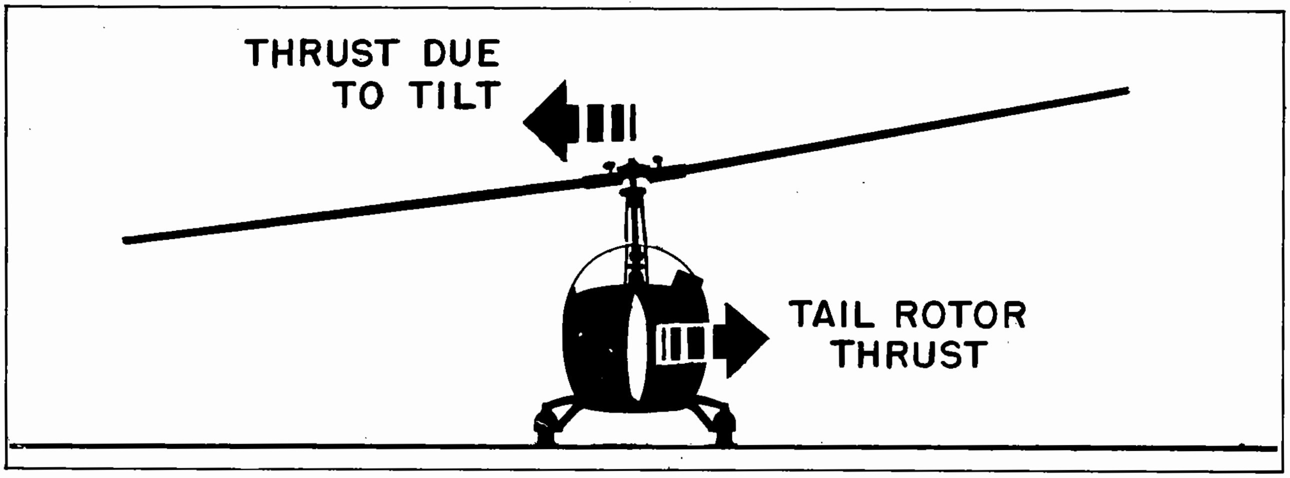


Figure 4-16

Thus the tail rotor also tends to move the entire helicopter in the direction in which it is swinging the tail of the aircraft. This motion is spoken of as "drift." By inclining the rotor mast slightly to the side, the tip-path-plane has a built-in tilt. This gives a horizontal thrust component which compensates for the drift effect. (See Figure 4-16.) This inclination of the mast is usually to the left to compensate for the pull of the tail rotor to the right. This would be true of any single rotor with a counter-clockwise direction of rotation.

In many helicopters, overcoming drift is achieved by rigging the cyclic control to give the required amount of tilt to the tip-path-plane.

ACTION OF THE TAIL ROTOR

The tail rotor of the single rotor helicopter could be driven independently of the main rotor if desired, but the simplest method is to drive it through a power take-off from the main rotor transmission. In most designs there is no disconnect, and the tail rotor turns whenever the drive-shaft of the main rotor turns. As there is no means of shifting gears, it runs at a speed having a fixed ratio to the speed of the main drive-shaft.

Directional control is achieved by changing the pitch of the tail rotor blades. (See Figure 4-17.) In low pitch, the tail rotor delivers less thrust than is required to overcome the torque effect of the main rotor. This allows the tail to swing around, just as it would be if a tail rotor were not provided. In medium pitch, the tail rotor equals the torque of the main rotor. In high pitch, the tail moves in the same direction of rotation as the main rotor.

Actually, most tail rotors are also capable of producing thrust in the same direction as the rotation of the main rotor. This is required in order to turn to the right while in autorotation since under this condition of flight the drag of the transmission tends to pull the fuselage around to the left in the same direction as the main rotor is moving.

Control of tail rotor pitch, and, therefore, directional control of the helicopter, is provided by the rudder pedals in the cockpit. These are in the conventional position, and give the same yawing effect as the rudder pedals in a conventional aircraft. Pressure on the left rudder increases the pitch of the tail rotor blades, overcompensating and swinging the nose of the helicopter to the left. Pressure on the right rudder decreases the pitch and therefore the thrust, causing less compensation. The reaction of the main rotor then swings the helicopter nose to the right.

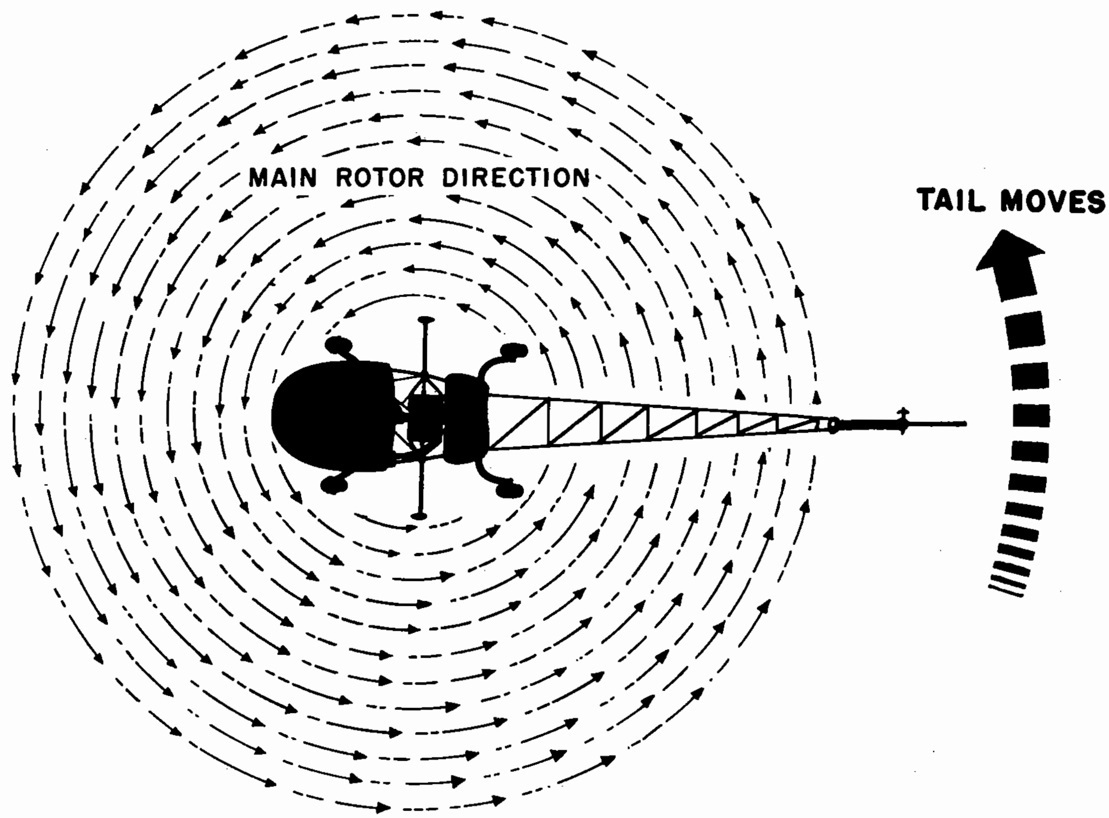
So far, three of the helicopter controls have been covered:

(1) COLLECTIVE PITCH CONTROL, or the change of all blades simultaneously and by the same amount.

(2) THROTTLE CONTROL, to keep engine speed constant, regardless of the increase or decrease in blade pitch.

(3) TAIL ROTOR CONTROL, controlling the direction in which the nose of the helicopter is pointed.

The fourth of the helicopter controls effects the translation or the direction, in azimuth, of helicopter flight.


MAIN ROTOR DIRECTION
TAIL MOVES

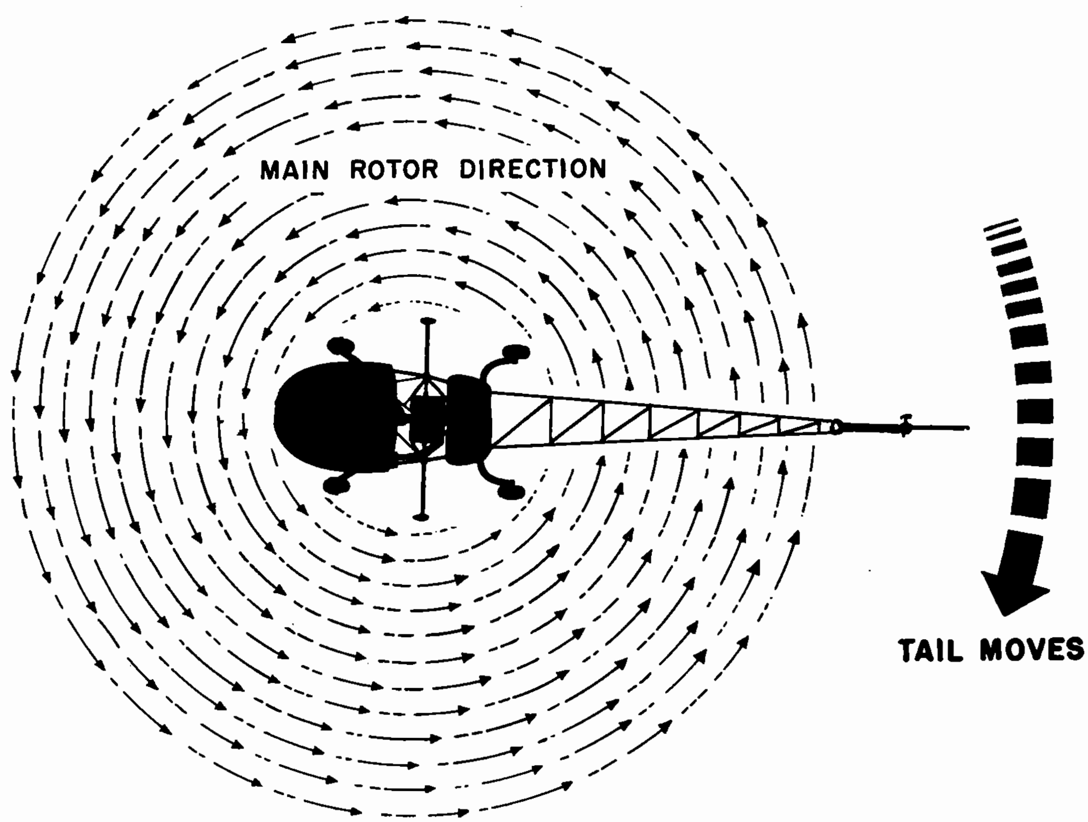

MAIN ROTOR DIRECTION
TAIL MOVES

Figure 4-17

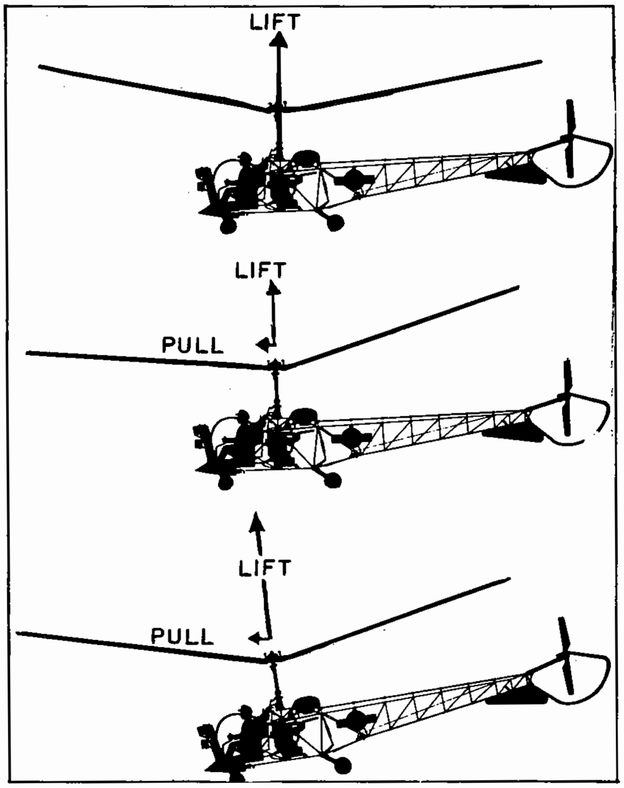


Figure 4-18

TRANSLATIONAL FLIGHT

It has been shown that translational movement of a helicopter in one direction or another is accomplished by tilting the tip-path-plane.

Although the mechanical linkages used to tilt the tip-path-plane are different in different makes and models, the principle is fundamental in helicopter design

In all models, tip-path-control is exercised through a control stick directly in front of the pilot. This stick is known as the **cyclic pitch control stick.** This is the fourth and last of controls required for helicopter operation. This control gets its name from the fact that cyclic changes in angle of attack, achieved with this control, are used to tilt the tip-path-plane. (See Figure 4-18.) The direction in which this stick is moved determines the direction in which the helicopter moves. Forward movement produces forward flight; movement to the side moves the helicopter in the direction in which pressure is applied. Backward movement tends to stop forward flight and to produce flight in a rearward direction.

GYROSCOPIC PRECESSION

Before going into a discussion of translational control, it is necessary to understand one force on the helicopter which affects the design of all control mechanism. This is gyroscopic precession.

When the rotor blades get up to speed, the rotor disc becomes a first-class gyroscope. Any tilting action of the rotor system results in a rotating force acting in a plane at right angles to the plane of rotation.

What this means is that if the rotor disc were rigid to the hub and the hub were moved to tilt the disc forward, the gyroscopic precession would tilt the plane of rotation sidewards instead. (See Figure 4-19.)

Since the forces would be too great to tilt

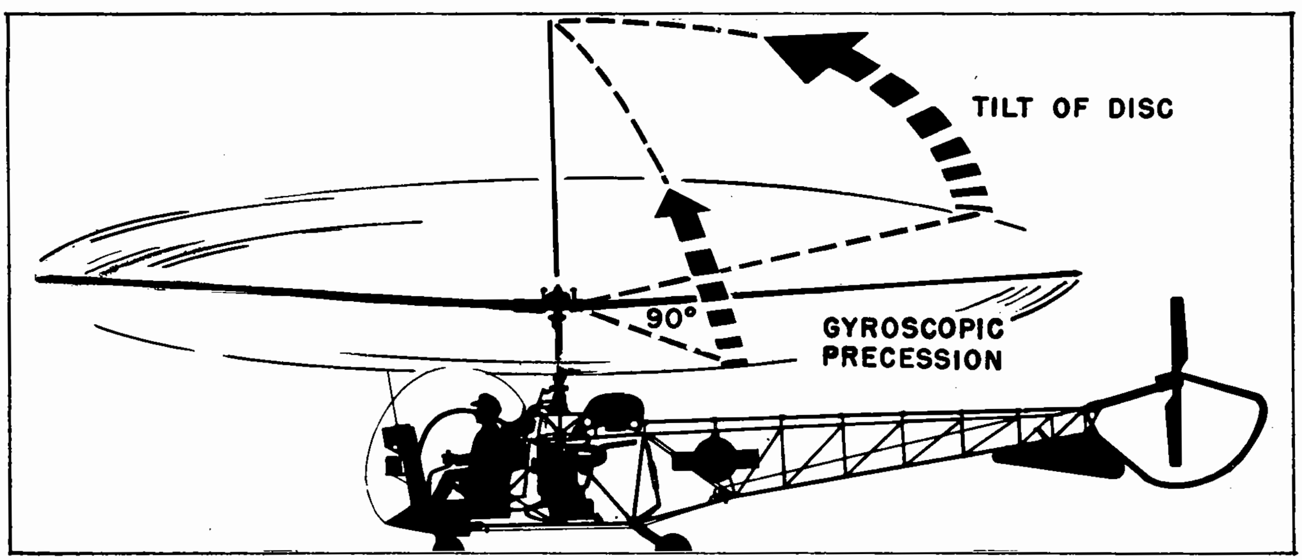


Figure 4-19

the tip-path-plane mechanically, the tilting action must be applied aerodynamically. To do this the angle of attack of one of the blades is increased with the result that a greater lifting force is applied at some point in the plane of rotation which tends to raise the blade. But because of gyroscopic precession, the blade rises at a point about ninety degrees later in the plane of rotation. Therefore, all control systems must take this effect into consideration.

TRANSLATIONAL CONTROL WITH FULLY ARTICULATED ROTOR HEAD

The means of achieving translational motion with a fully articulated rotor head will be discussed first. It has been shown that in a no wind hovering condition, the angle of attack of each blade will be the same. Therefore, the lift is the same on each blade.

If the angle of attack of each blade in the rotor is increased mechanically as the blade rotates past the midpoint in the retreating blade area, the lift in that area of the disc will be increased. This increase in lift will, due to gyroscopic precession, increase the coning angle of the rearward blade. An equivalent decrease in angle of attack and therefore lift in the advancing position of the blades will decrease the coning angle in the forward direction. (See Figure 4-20.)

The over-all effect of the change in coning angle is a tilting of the tip-path-plane with the high side to the rear of the helicopter. This results in a forward component of the lift of the

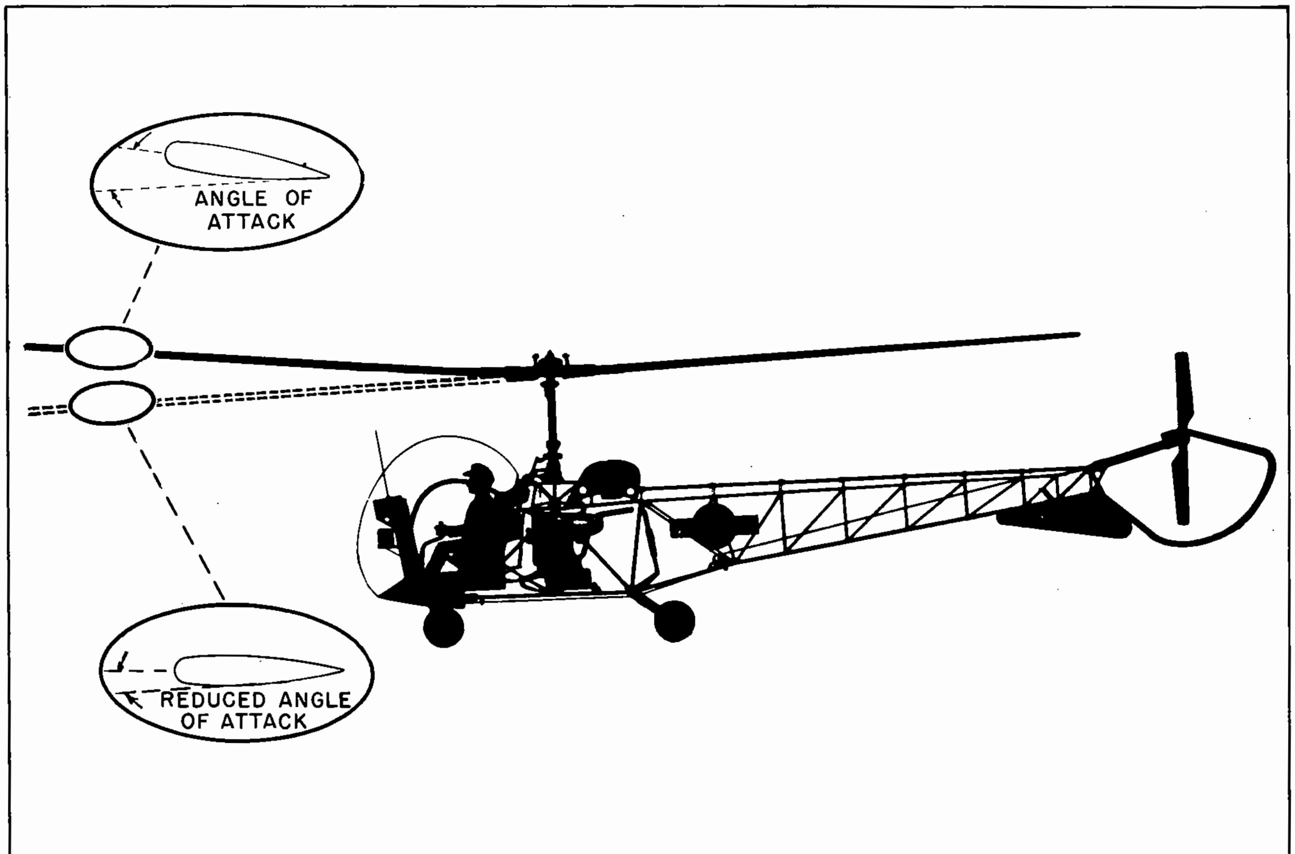


Figure 4-20

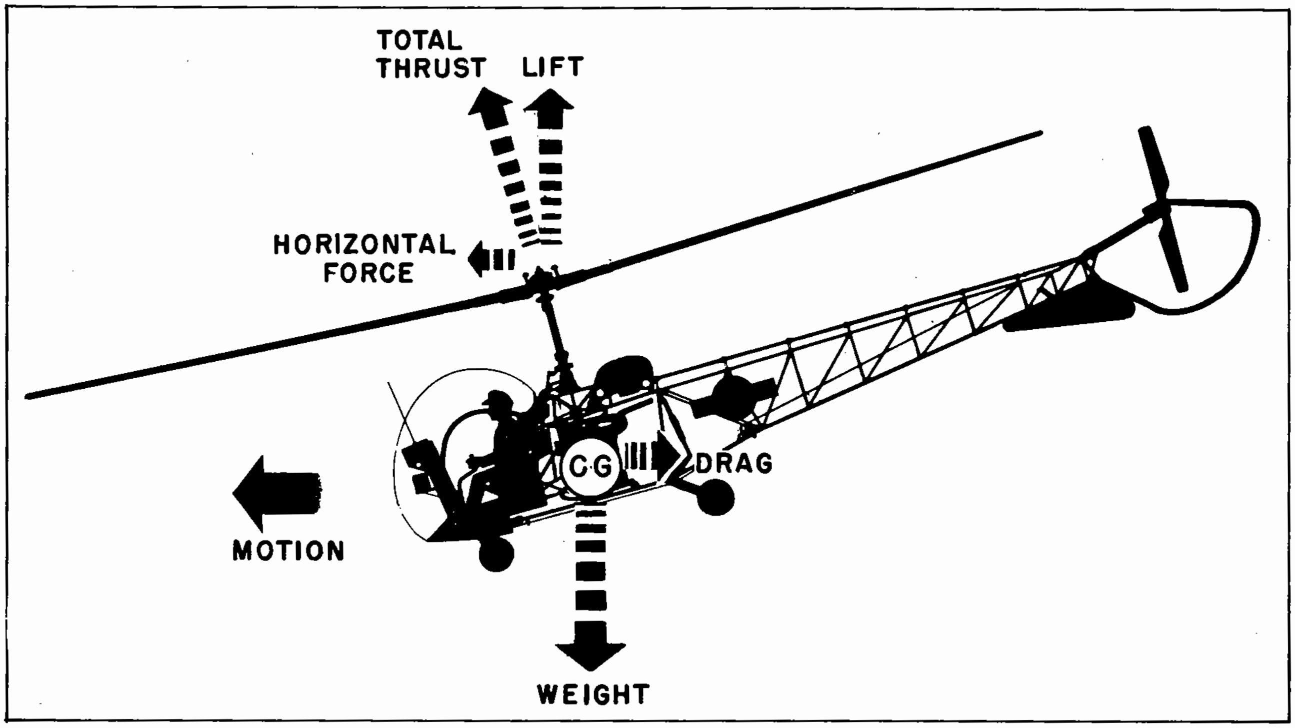


Figure 4-21

rotor system and the helicopter will move in the forward direction. (See Figure 4-21.)

As soon as the forward motion of the helicopter begins, the relative motion of the air will become a combination of the forward velocity of the helicopter, the rotational velocity of the blades and the velocity due to blade flapping. It has been demonstrated that aerodynamic forces which cause flapping action tend to even out the lift across the rotor disc. This leaves the continuing over-all condition of the rotor disc in a forward tilted position. The motion of the helicopter continues then in the forward direction.

Once the tip-path-plane is tilted, and translational motion is taking place, the angles of attack can be equalized and the lift on the advancing blade and the retreating blade becomes equal. This means that there is no force tending to change its position. Therefore, it will remain in a tilted position until some force is applied to it which tends to upset this new condition of equilibrium.

A mechanical increase in lift in the advancing position of the rotor blade would cause the disc to tilt up in front with a resultant thrust vector in the rearward direction. Conditions in rearward flight would then be identical to those in forward flight. (See Figure 4-22.)

TRANSLATIONAL CONTROL WITH A SEMI-RIGID ROTOR HEAD

While the result of moving the control stick of the semi-rigid rotor is the same as that of moving the cyclic pitch control stick of the fully articulated rotor, the mechanics of the action is different.

To get the required tilt in the tip-path-plane, the blades are feathered mechanically, that is, the rotor head is rotated on the feathering axis. This causes an increase in angle of attack on the retreating blade and an equal decrease in angle of attack on the advancing blade. The resultant increase of lift on the retreating blade, due to gyroscopic precession, causes the retreating blade to rise in the rearward position. The opposite effect on the advancing blade causes it to be forced downward in the forward position. The over-all effect, then, is a tip-path-plane with a forward tilt. (See Figures 4-23 and 4-24.) The forward tilt of the rotor disc causes a horizontal force in the forward direction.

The forward motion of the helicopter will change the relative wind and therefore the angles of attack of the advancing and retreating blades. This causes flapping action which tends to even out the lift on the two halves of the rotor disc.

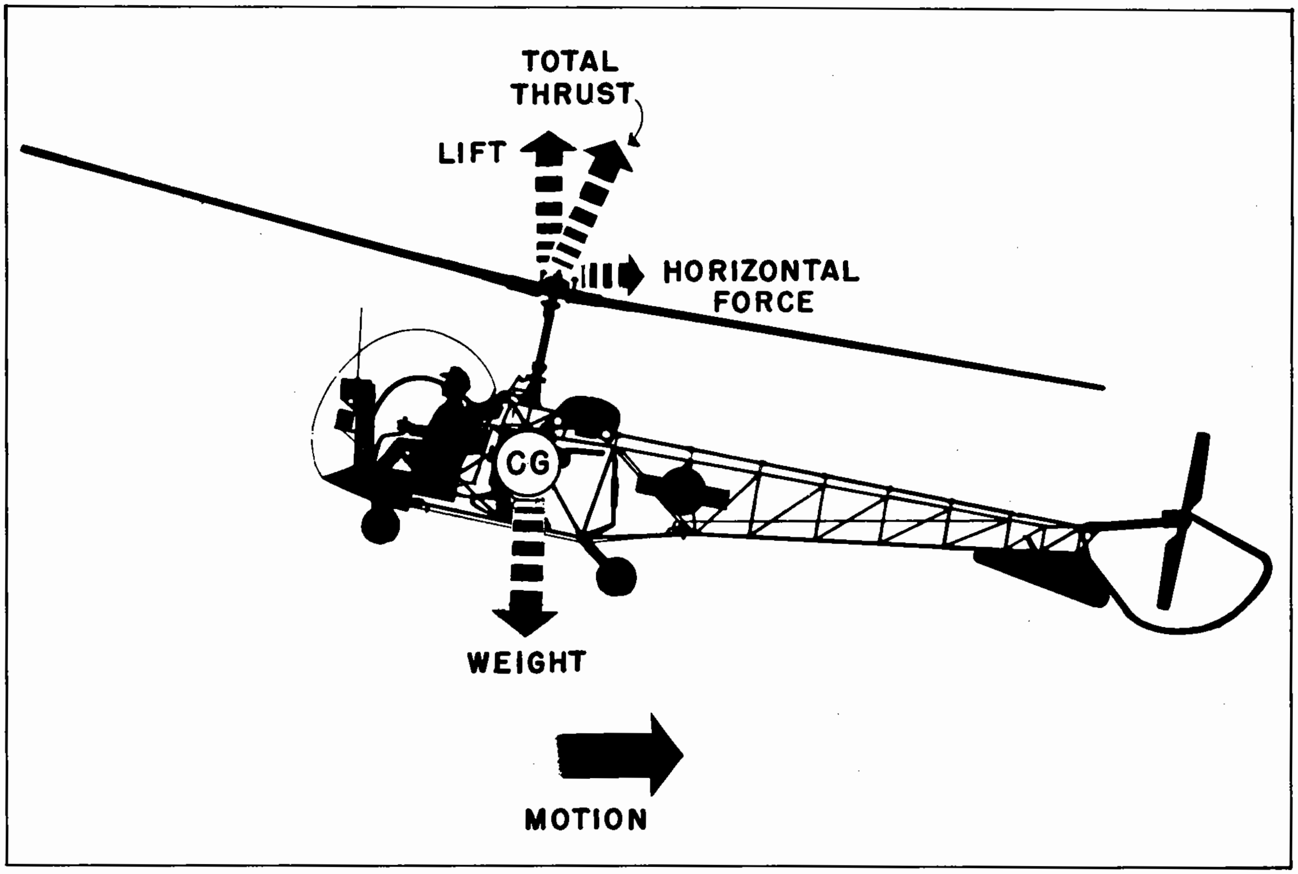


Figure 4-22

Once translational motion has started, the angle of attack and therefore the lift of the advancing and retreating blades can be equalized and the rotor disc will remain tilted until some outside force is applied which changes its position.

CONTROL SYSTEMS

There are several systems of helicopter control in use which meet helicopter flight requirements, that is, they make the helicopter rise vertically, move into translational flight in any direction, follow any desired flight pattern, and make vertical landings.

To point out specific differences, the control systems of a few makes are described briefly in the following paragraphs:

BELL: The control system in this helicopter depends on a pair of semi-rigid blades moving with a see-saw motion around a gimbal in the drive shaft. There are two rotor control actions: One, collective pitch control, which changes the pitch of both blades simultaneously, and is used to cause the helicopter to rise from the ground; and, two, cyclic control, which causes a tilt of the tip-path-plane by a mechanical feathering of the blades which in effect increases the pitch of one of the blades while it simultaneously decreases the pitch of the other blade. This latter change is cyclic so that the pitch

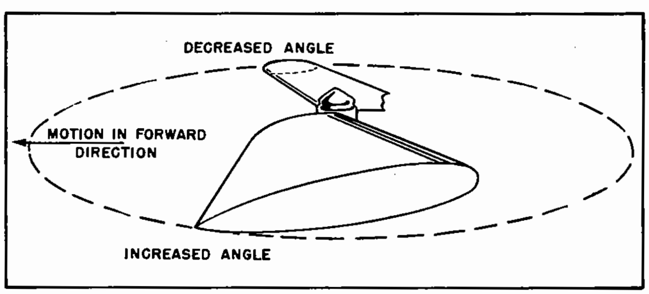


Figure 4-23

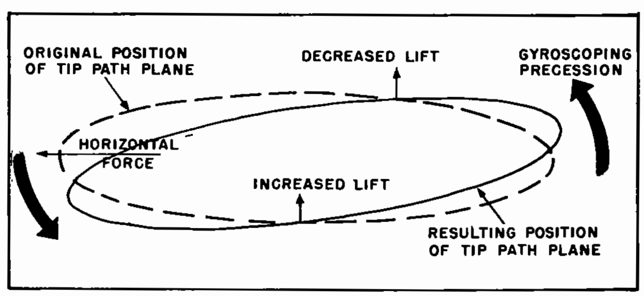


Figure 4-24

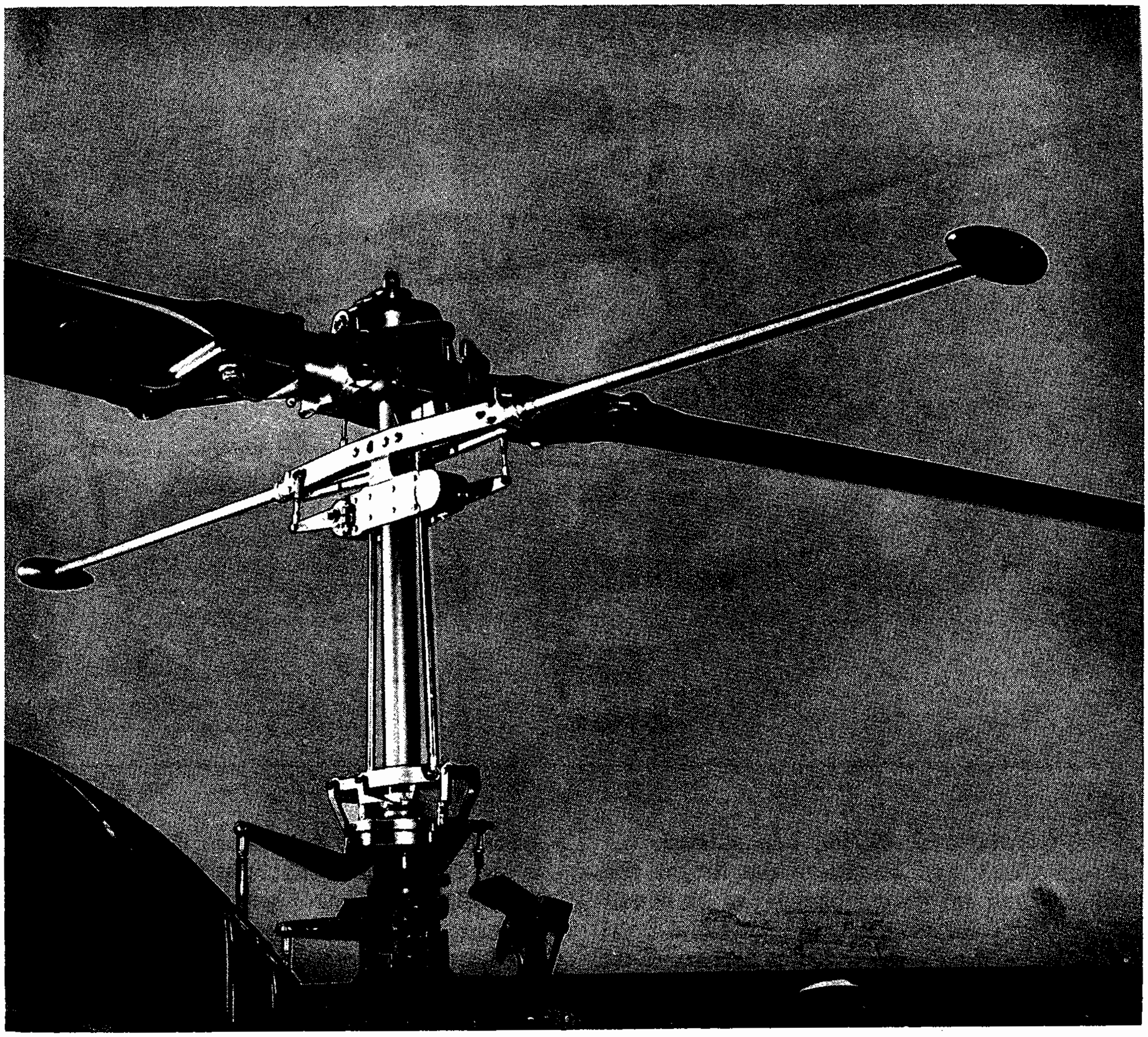


Figure 4-25

of a blade is higher or lower depending on the point in the cycle of rotation necessary to give motion in the desired direction.

A feature of the Bell control is a stabilizer bar. (See Picture 4-25.) This bar is positioned 90° from the rotor blades and rotates with the blades. The stabilizer is hinged to the rotor drive shaft so that it can work with a see-saw motion, transmitting its movements to the rotor blades. As the rotor turns, this bar always tends to assume a position at right angles to the mast, due to centrifugal force. At the same time, the bar and the cyclic control system linkage are designed to take advantage of the inertia of the bar. If while hovering, for example, in level attitude, the helicopter is tilted in any direction the stabilizer bar will for a short time retain its plane of rotation. The blades, through a mixing lever arrangement will function in a way to return the helicopter rotor to the plane of the stabilizer bar; that is, to a horizontal attitude. Due to the manner of attachment to the mast, the bar will lag in following the mast in its movements; the time of lag is regulated by the adjustment of hydraulic dampers which are part of the mechanism. The pilot, at all times, retains complete control.

HILLER: In the Hiller, HTE, two paddles, which are small airfoils, are controlled by the cyclic stick. These apply a force at about 90

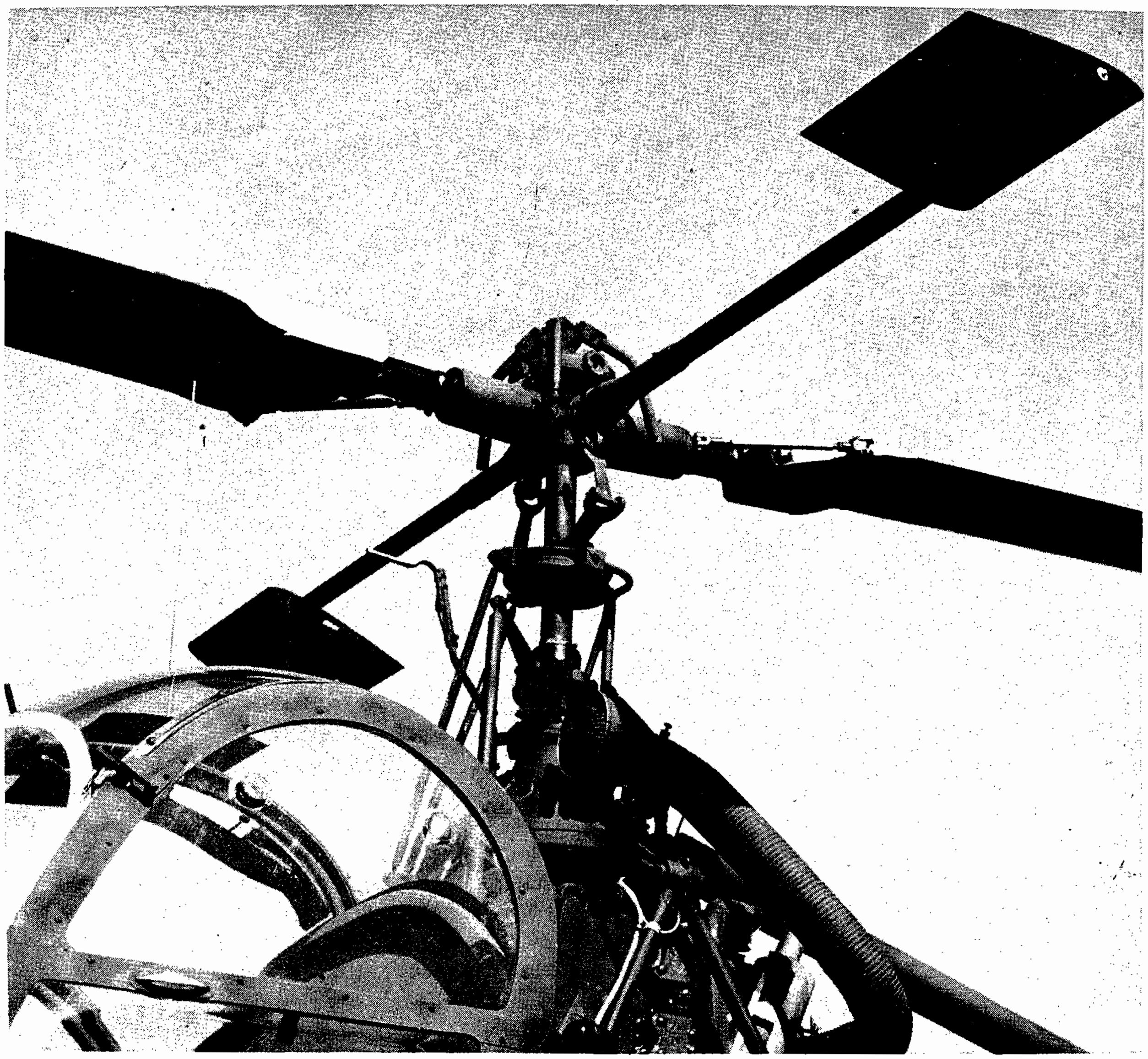


Figure 4-26

degrees from the main rotor and cause the rotor to tilt as required to cause motion in the desired direction. (See Figure 4-26.) This is known as a "Rotor-Matic" Control System. In this helicopter also, the blades are semi-rigid, so that when one blade is depressed the other rises. Like the Bell, the Hiller in its present models is limited to the use of a two-bladed rotor.

SIKORSKY: In the Sikorsky models, the blades are fully articulated so that they are free to move up and down with what is called a "Flapping" motion, or to move horizontally to take up the differences in forces applied through different parts of the cycle. In addition, each blade turns in a sleeve so that the pitch is controlled either collectively or cyclically as desired. The flapping of the rotor blades, which was the principle learned from de la Cierva's Autogyro, balances the lift forces so that they are equal on both sides of the rotor and have no upsetting effect on the structure. As in other types of helicopters, change of collective pitch controls the lift, while change of cyclic pitch controls the direction of flight.

PIASECKI: In the Piasecki helicopter, the blades are also fully articulated, operating in much the same manner as those of the Sikorsky. There is of course the difference that, as Piasecki uses two rotors, directional control is

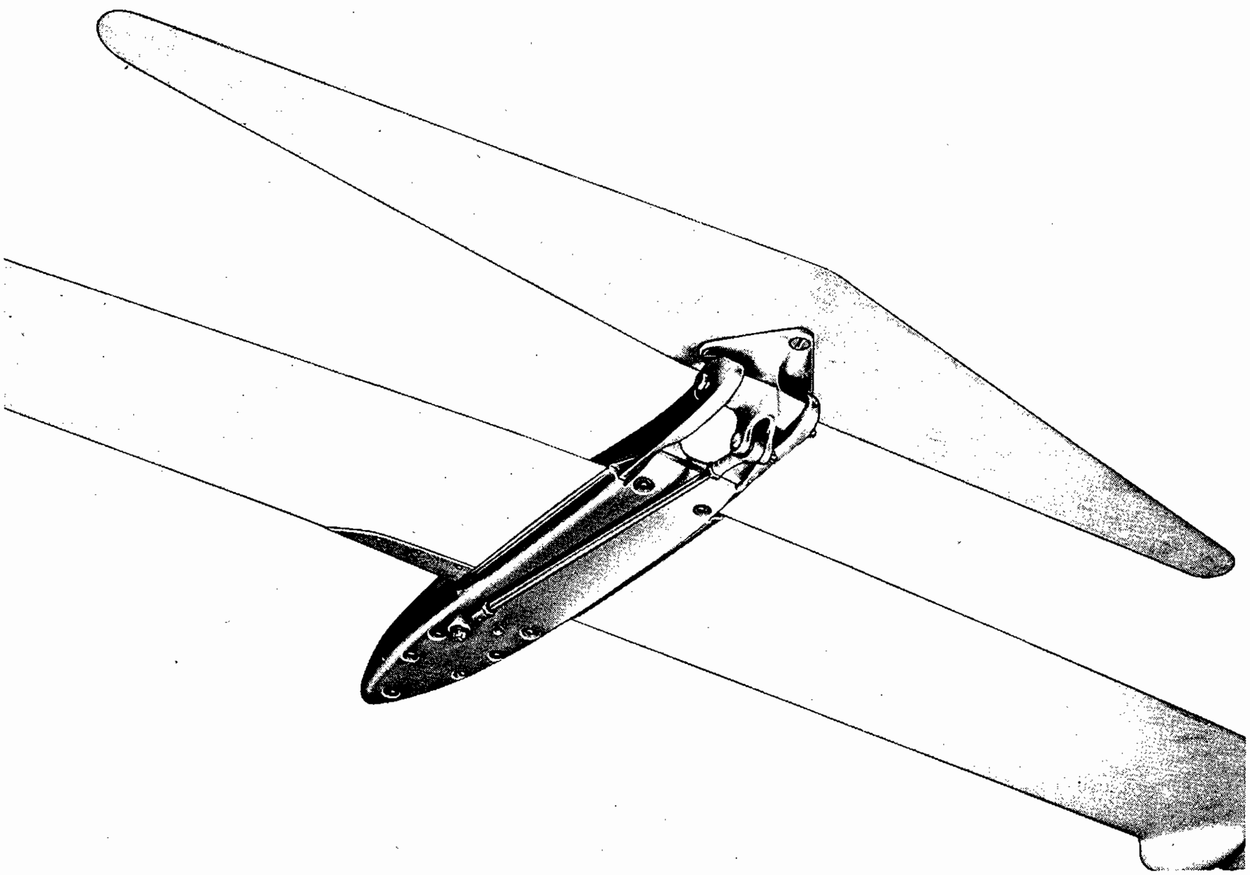


Figure 4-27

accomplished by a differential change in the cyclic pitch of the two rotors rather than by the use of a tail rotor with variable pitch.

Because the rotors do not operate in the same horizontal plane, the same amount of tilt of the two tip-path-planes in opposite directions would not cause pure rotation about the vertical axis. This requires that different amounts of tilt be introduced automatically by the rudder pedal action because it is the objective of good control designs to have a motion in one plane which does not require additional co-ordination of the other controls to achieve the desired pure motion. This is also true in the Piasecki when a direct sideward motion is desired. Equal tilt on both the front and rear rotors would not give pure sideward motion because of the differences in location of the rotors in relation to the C.G. of the helicopter.

KAMAN: Another method of control is that used in the Kaman helicopter. In this helicopter the blades have neither hinges nor pivots. The rotor blades are flexible, and each blade has a controllable tab or "servo" airfoil attached to its trailing edge. (See Figure 4-27.) These surfaces are moved by a linkage through the hub of the rotor. Movement of the tabs in one direction increases pitch; movement in the other direction decreases it. Both collective and cyclic pitch are controlled through the movement of these surfaces.

The Kaman helicopter, being a synchropter, is made to turn by tilting one tip-path-plane forward and the other backward by use of the rudder pedals. Lateral and longitudinal control result from tilting both rotors to one side or forward, respectively. Because of the symmetry of this design, differential tilting action of the two rotors is not a problem.

SPECIAL CONDITIONS APPLYING TO HELICOPTERS

There are certain conditions that apply to helicopter operations which are more important than with conventional aircraft or are not common to conventional aircraft. Among these are: Ground Effect, Ground Resonance, Pendulous Action, and Coriolis Effect.

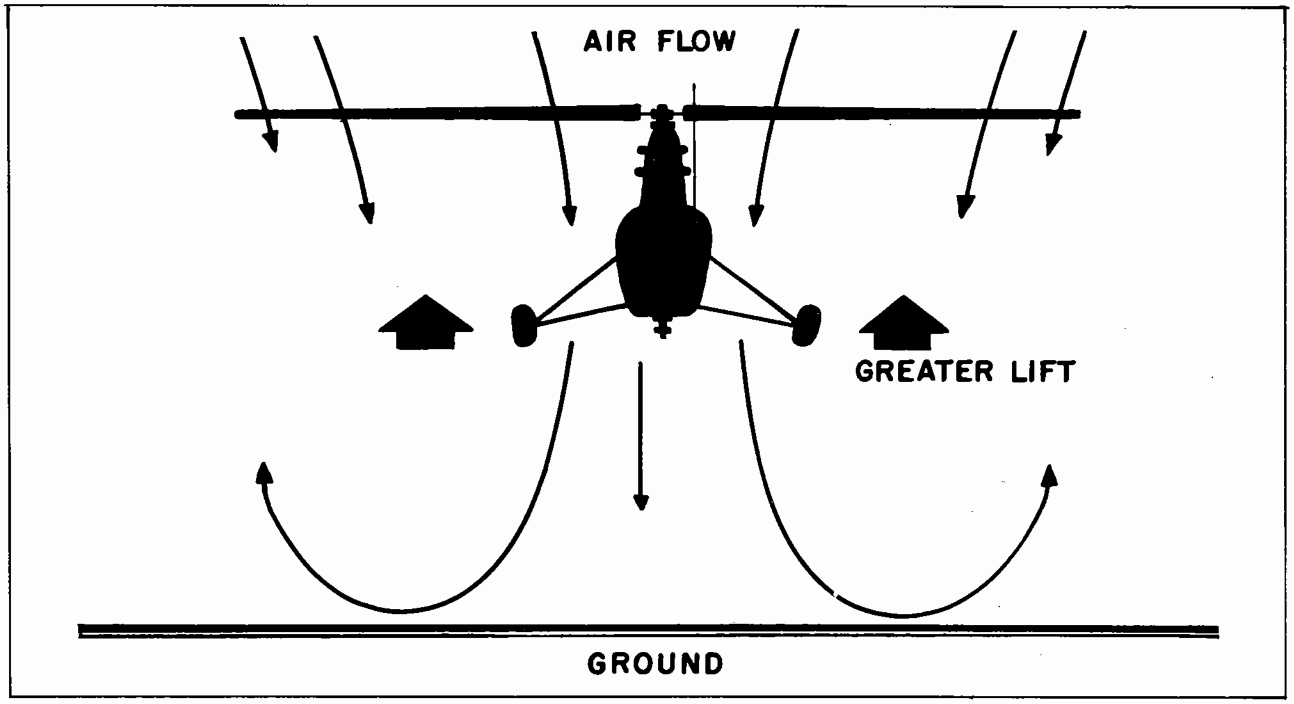


Figure 4-28

GROUND EFFECT OR GROUND CUSHION

When a helicopter hovers close to the ground, the downwash from the rotor builds up a cushion of denser air between the ground and the helicopter. (See Figure 4-28.) The increase in density results in a greater lift than would normally be expected. This column of air is called the ground cushion and extends upward for about one half the diameter of the rotor. Above this altitude, the air spreads out over too great an area and there is no effect. This effect holds up to relative speeds of about 5 to 7 miles per hour.

It is desirable to establish this ground cushion during both take-offs and landings. A heavily loaded helicopter may be able to take off and hover by use of the ground cushion. However, caution must be exercised because when the helicopter moves off the ground cushion in horizontal flight, it may descend again to the ground.

GROUND RESONANCE

The rotor blades of fully articulated rotor hubs are free to move back and forth in the plane of rotation. This is called dragging and the vertical hinge that makes this possible is the drag hinge. Because of this freedom of movement, it is possible for the angular spacing of the blades to become uneven. The 3 blades are normally 120 degrees apart. However, if anything changes this spacing when the rotor is in motion, a vibration may develop due to the unbalance. This vibration is known as ground resonance since it will only occur when the helicopter is in contact with the ground.

Ground resonance builds up very rapidly so that it must be checked immediately to prevent physical damage. There are two possible ways to stop ground resonance. One is to shut down the rotor immediately by closing the throttle and putting the blades in low pitch. Generally, an even better method is to take off immediately. In the air ground resonance generally disappears in two or three oscillations.

An example of what may cause ground resonance is an uneven landing. In this case, if one wheel strikes first, it may cause the blades straddling the shock point to be forced closer together. The spacing might then be 122°, 122°, and 116°. (See Figure 4-29.) When one of the other wheels strikes, the unbalance could be aggravated and become even greater. Ground resonance would then result in a severe wobbling or shaking.

Complete elimination of ground resonance by design improvements is difficult because the natural frequency of the helicopter changes as lift is applied to the rotor.

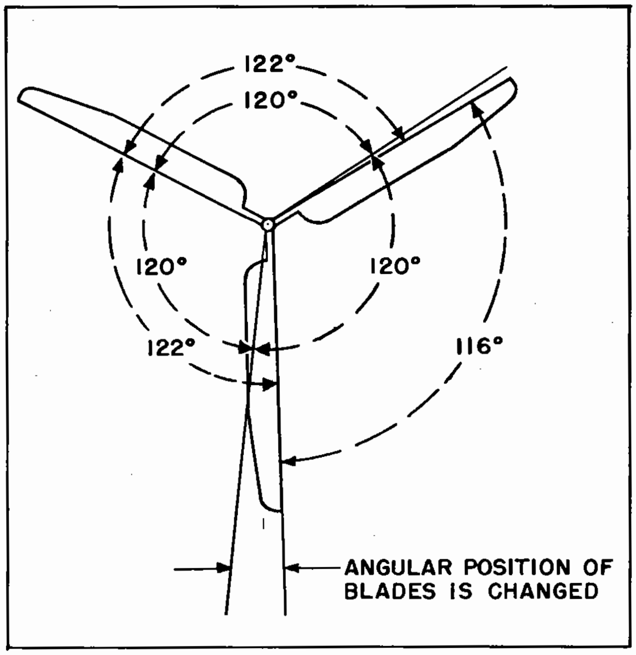


Figure 4-29

PENDULOUS ACTION

The single rotor helicopter has the characteristics of a pendulum. It is free to swing both longitudinally and laterally. Over-control of the helicopter will cause this action to become excessive. Controls should be used moderately to hold this action to a minimum. However, until the student pilot has had sufficient experience to prevent pendulous action, the helicopter should be hovered at least five feet off the ground. This will allow the helicopter to swing without danger.

In hovering flight, pendulous action is greater laterally than it is longitudinally. But in forward flight, the more pronounced swinging will be longitudinal, especially if the wind is gusty.

Pendulous action seems to be minimized as the helicopter pilot builds up flying time so that it appears to be associated more with pilot technique than with the characteristics of the helicopter.

CORIOLIS EFFECT

When a rotor blade flaps upward, the distance of the center of mass of the blade from the axis of rotation decreases. This distance times the rotational velocity must always remain the same for a given rotor rpm. If the distance becomes shorter when the blade flaps upward, the rotational velocity must increase for the product of the two to remain the same. Conversely, if the blade flaps down the blade must slow down. The change in blade velocity in the plane of rotation causes a hunting action about the vertical hinge. This hunting action is known as Coriolis Effect. The acceleration is absorbed by dampeners or the blade structure itself depending on design.

CHAPTER 5

COMPONENT PARTS OF THE HELICOPTER

PARTS FOUND IN MOST HELICOPTERS

In the automobile, while there is a considerable difference between the details of various models and makes, a number of elements such as wheels, engine, differential, clutch and other standard units are common to all. In the helicopter, similarly, there are elements which are common to a number of types. Certain requirements have become standard, and are met in much the same manner regardless of the make or model.

The following component parts are found in most helicopters:

(1) Engine
(2) Cooling fan
(3) Clutch
(4) Rotor brake
(5) Anticoning devices
(6) Transmission
(7) Freewheeling element
(8) Swash plate
(9) Rotor blades
(10) Controls

(1) ENGINE. Among the engines used in helicopters are the Pratt & Whitney air-cooled R-985-AN-5, the Franklin, six-cylinder opposed air-cooled engine, and the Continental R-975-42, nine-cylinder, air-cooled engine.

One of the main requirements of the helicopter engine, aside from reliability, is low weight per horsepower, so that there is sufficient horsepower available for lift to raise the helicopter vertically off the ground at a fair rate of climb, and to hover when and as required. Due to the weight of the engine, the general practice is to install it near the center of gravity of the helicopter. In the single rotor helicopter, the engine is most often mounted with its shaft vertical. (See Figure 5-1.) With the shaft of the engine in a vertical position, the front or nose section will be on top and the accessory section of the bottom. Accessories generally include magnetos, fuel pump, starting motor, engine tachometer and oil pump. (See Figure 5-2.) In some types of helicopters, the

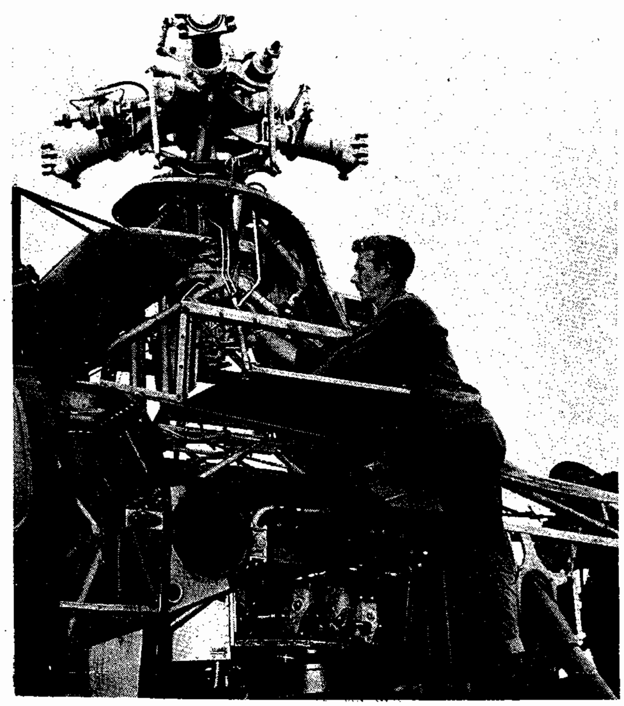


Figure 5-1

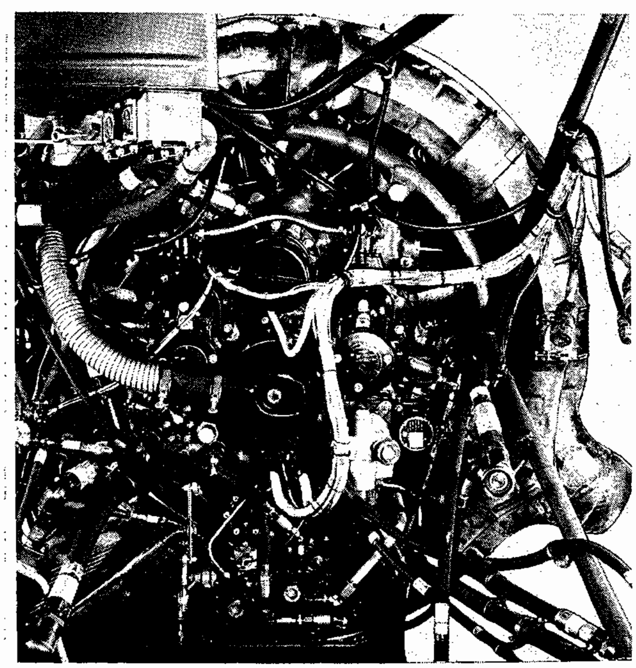


Figure 5-2

engine is bolted to a mounting ring which is in turn bolted to the fuselage. The weight of the engine is supported by vibration absorbing mounts that allow a slight freedom of movement when the engine is running.

Many dual rotor helicopters have the engine mounted with the shaft horizontal just as in conventional fixed wing aircraft. (See Figure 5-3.)

(2) COOLING FAN. In the conventional airplane in flight, there is a continuous stream of air flowing past the engine. This air flow keeps engine temperatures in the range that assures most efficient operation. Even though the airplane may be on the ground with engines idling, the propeller supplies sufficient air circulation for effective cooling.

But with the helicopter, the condition is entirely different. It is not practical due to balance factors to place the engine in the nose where it would be cooled to some extent when in flight. Also, the relative air speed may be zero, as in hovering, producing no air flow at all. For these reasons it is necessary to provide positive means of air circulation to remove heat from the engine. The usual method is to include in the engine design a fan which provides for air

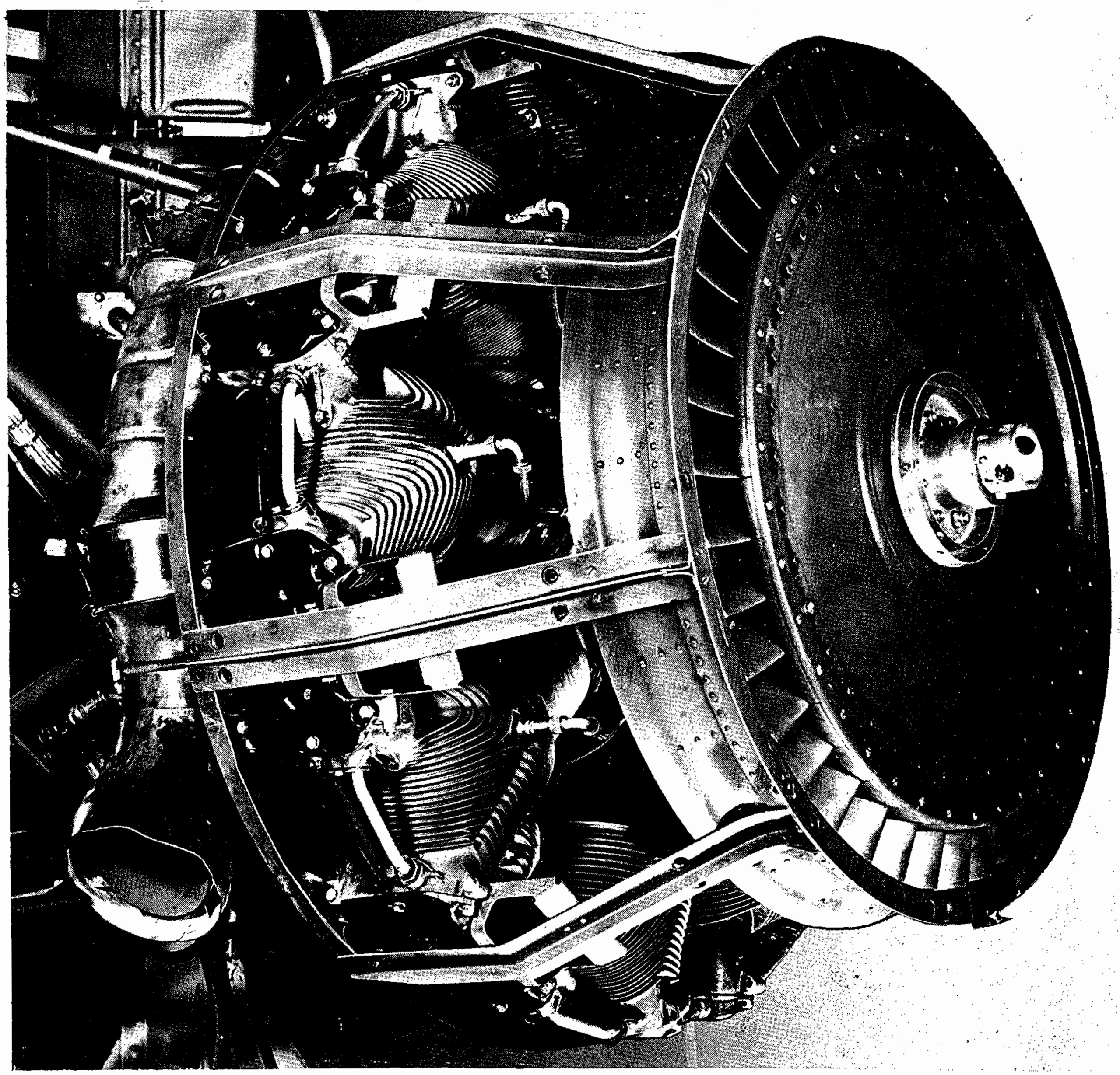


Figure 5-3

cooling whenever the engine is running. (See Figure 5-4.) With a vertical engine, air enters at the top or side and is pulled inside the engine cowling and forced around the engine by the fan. Besides cooling the engine, air is sometimes drawn off and supplied to the induction system.

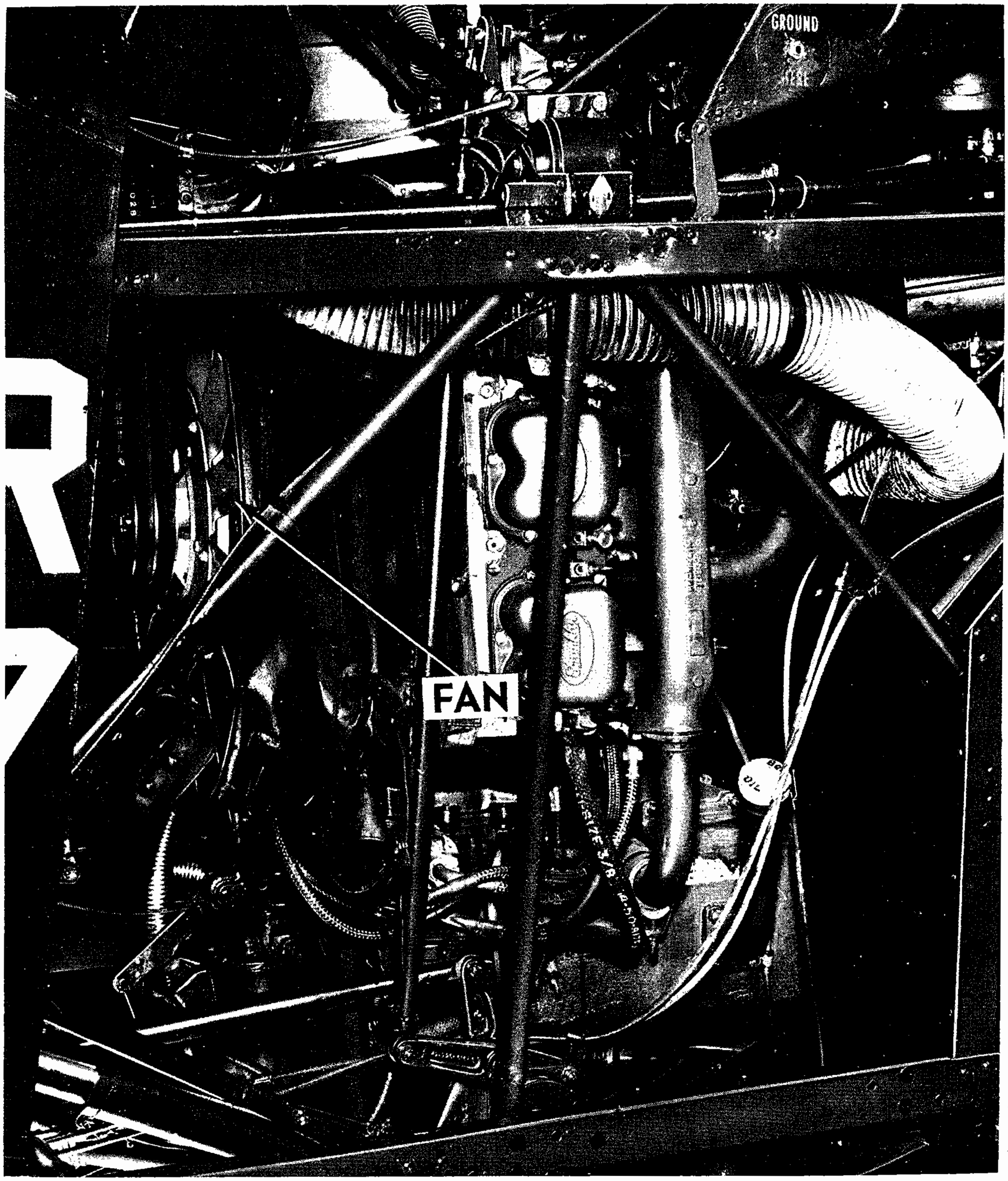


Figure 5-4

(3) CLUTCH. In the conventional airplane it is standard practice to have the engine and the propeller permanently connected. The propeller serves both as a flywheel and as a cooling fan, and there is no good reason why the propeller should be at a standstill when the engine is running. In the helicopter, there is a different relation between engine and rotor.

It is sometimes desirable to have the engine running while the rotor is stationary, such as during warm-up. Also, because of the much greater weight of a rotor in relation to the power of the engine than the weight of a propeller in relation to the power of an engine in a conventional aircraft, it is necessary to have the rotor disconnected from the engine to relieve the starter load. Because of this, it is necessary to have a clutch between the engine and rotor.

In the vertically mounted engine, the clutch is either just above or below the cooling fan, and operates automatically. Contact between the inner and outer parts of the clutch is made by a set of spring loaded clutch shoes. At low engine speeds the shoes are held out of contact by the springs, but as engine speed increases, they are thrown outward by centrifugal force, and motion is transmitted from the engine drive shaft to the input shaft of the transmission.

Another type of clutch is the manually engaged friction clutch. In this type a series of friction discs transmits the power. (See Figure 5-5.)

Because of this clutch, it is possible to start the engine and warm it up without bringing the rotor into action.

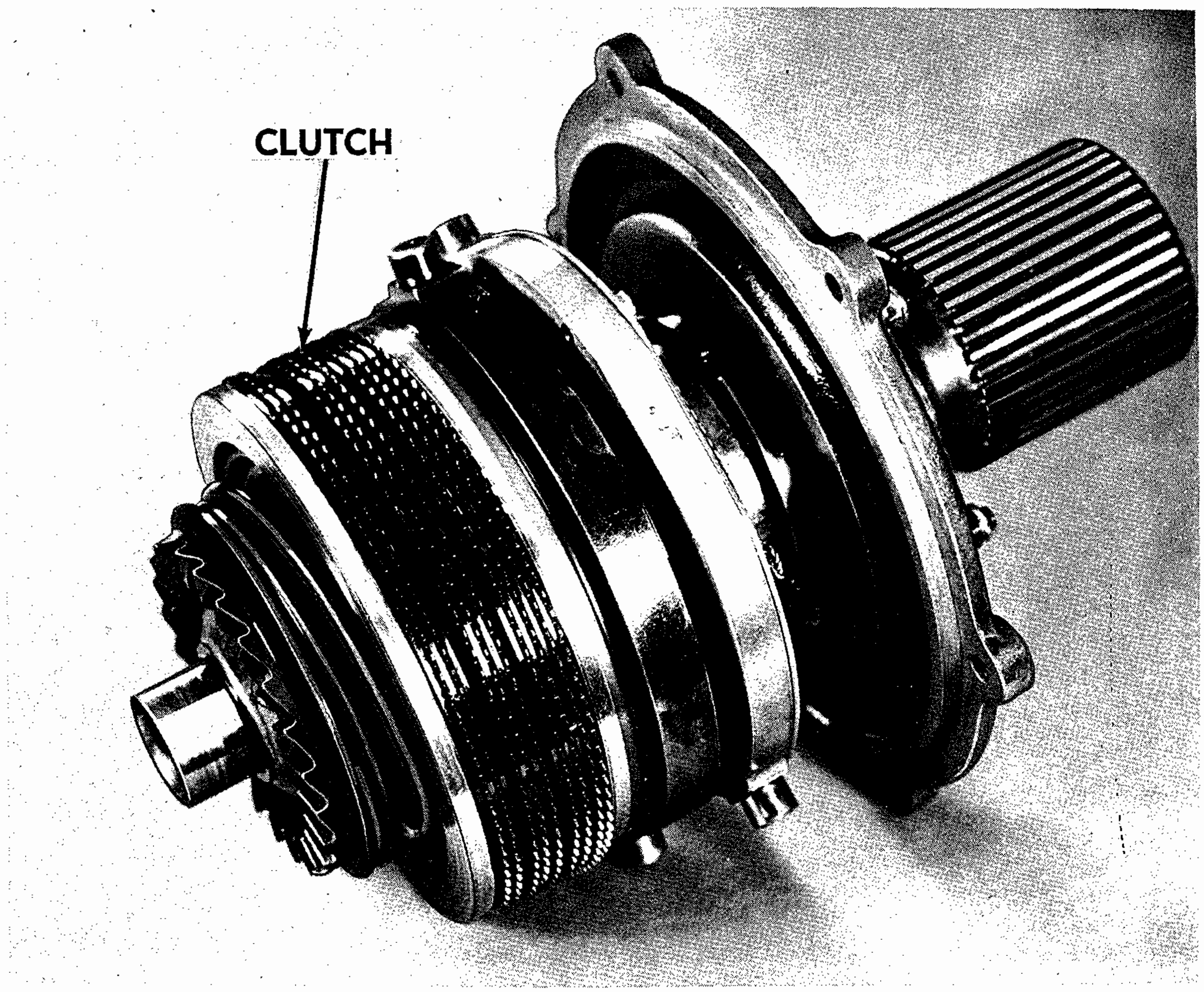


Figure 5-5

(4) ROTOR BRAKE. When landing the helicopter, it is desirable to bring the rotor blades to a stop as soon as practical. This reduces the possibility of coning if wind conditions are high across the blades. Also, stopping the main rotor stops the tail rotor so that the possibility of injury to personnel from either the main or tail rotor is reduced.

The braking action is applied by a band type brake. (See Figure 5-6.) In general, this brake should be operated only below a certain rotor speed because if used at high rotor speeds, the brake assembly will burn out There is also the possibility of damage to the blades themselves

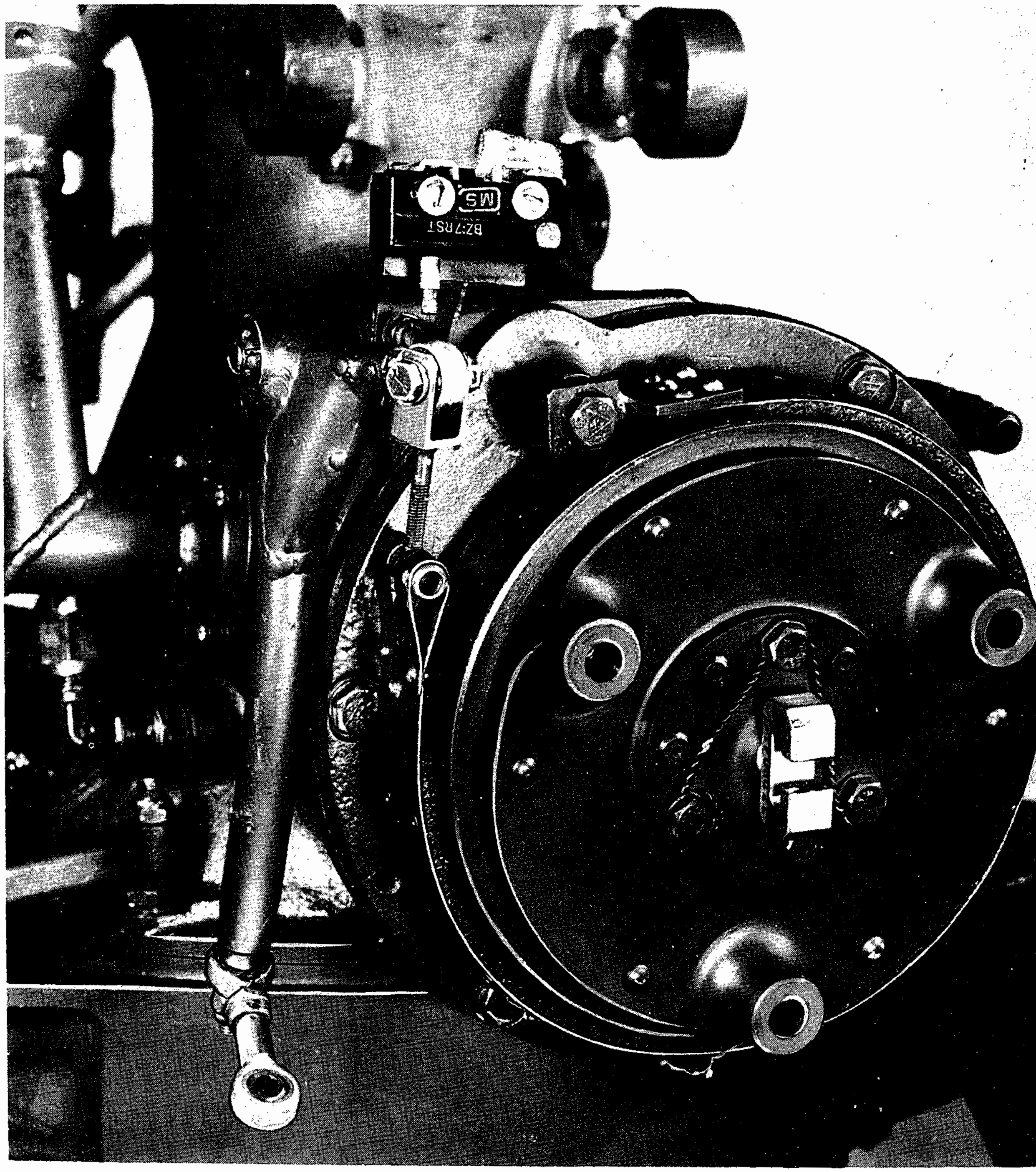


Figure 5-6

(5) ANTICONING DEVICES. Newer type helicopters with articulated rotor heads are coming equipped with anticoning devices. In one device, counterweights thrown outward by centrifugal force when the rotor is up to speed open a hydraulic valve. This releases pressure on blade stops, thus allowing complete flapping action of the blades. However, as the rotor rpm drops below a preselected speed, the counterweights close the hydraulic valve. This locks the blade stops and prevents the individual rotor blades from flapping upward. (See Figure 5-7.)

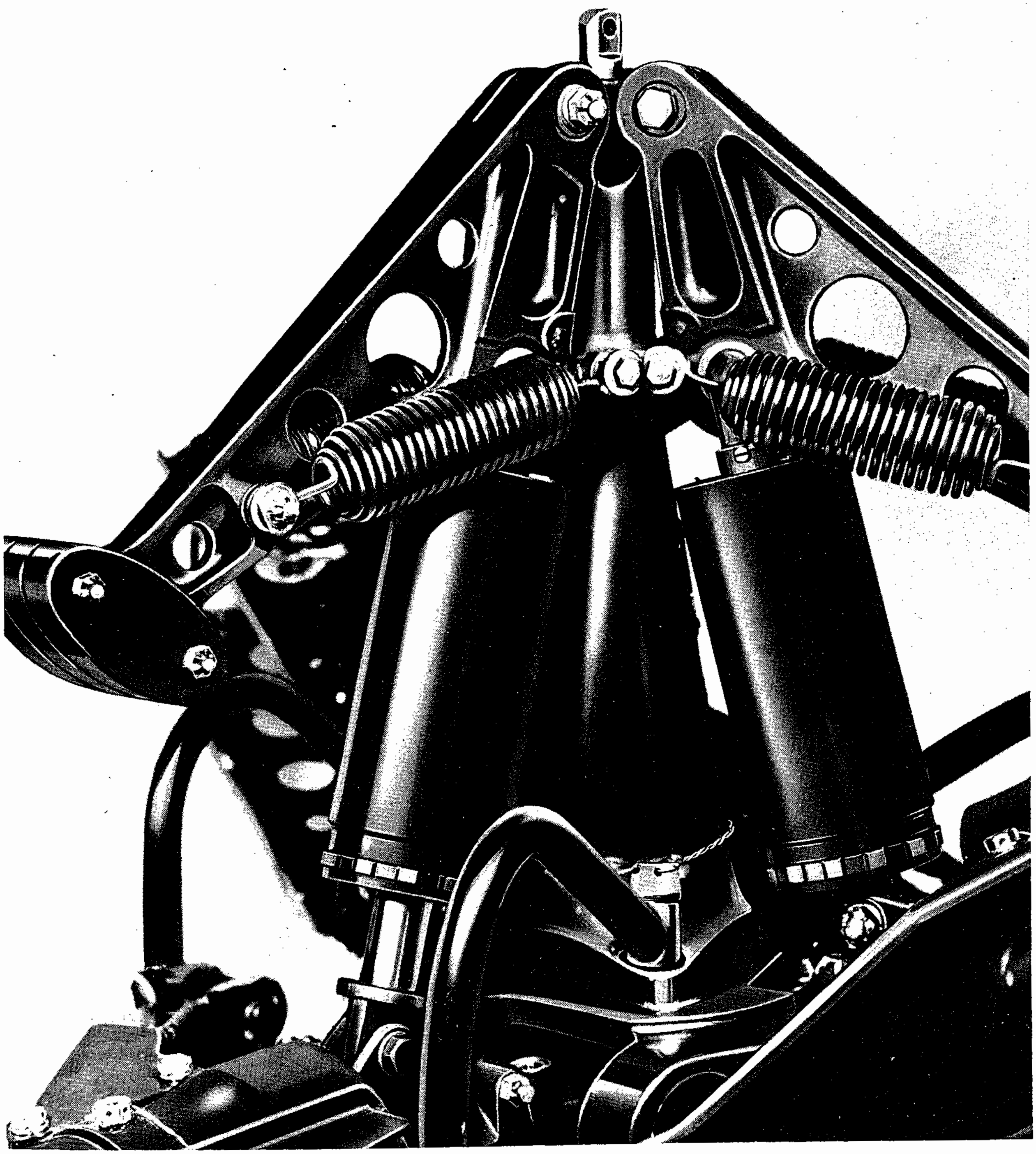


Figure 5-7

(6) TRANSMISSION. One of the principal engineering problems of the helicopter has been to deliver the maximum power from the engine to the rotor blades in such a way that the blades will be traveling at a speed and angle of attack to produce maximum lift for take-off. This means that the engine must run at high speed while the rotor turns at much lower speed. This speed reduction is accomplished by means of a transmission which changes the high speed, low torque input of the engine to a low speed high torque output for the rotor blades. Since the rotor speed and engine speed with a single speed reduction ratio is constant, the ultimate transmission reduction ratio must be a compromise between that for best high power operation and that for best cruise operation.

Speed reduction is usually obtained through a one or two stage planetary gear system. This type of transmission has the advantage of ruggedness, compactness, and simplicity. However, rather than compromise the reduction ratio between high power and cruise, a multiple speed transmission would be desirable in some cases and may be an eventual improvement of the helicopter.

In the design of the transmission to get maximum lift, one of the important considerations is the speed of the rotor tips. Tests have proved that rotor tip speed for greatest lift is between 350 and 420 feet per second. A rotor with blades twenty feet long, for example, turning at 175 rpm, will have a tip speed of slightly less than 366 feet per second, within the range of most efficient rotor operation and greatest rotor lift.

In multirotor helicopters, there may be more than one transmission. One transmission may be used at the engine and another at each of the rotors. These transmissions have another important function. They must keep the rotors synchronized so that the blades intermesh, so that there will be no possibility of blades striking one another. (See Figure 5-8)

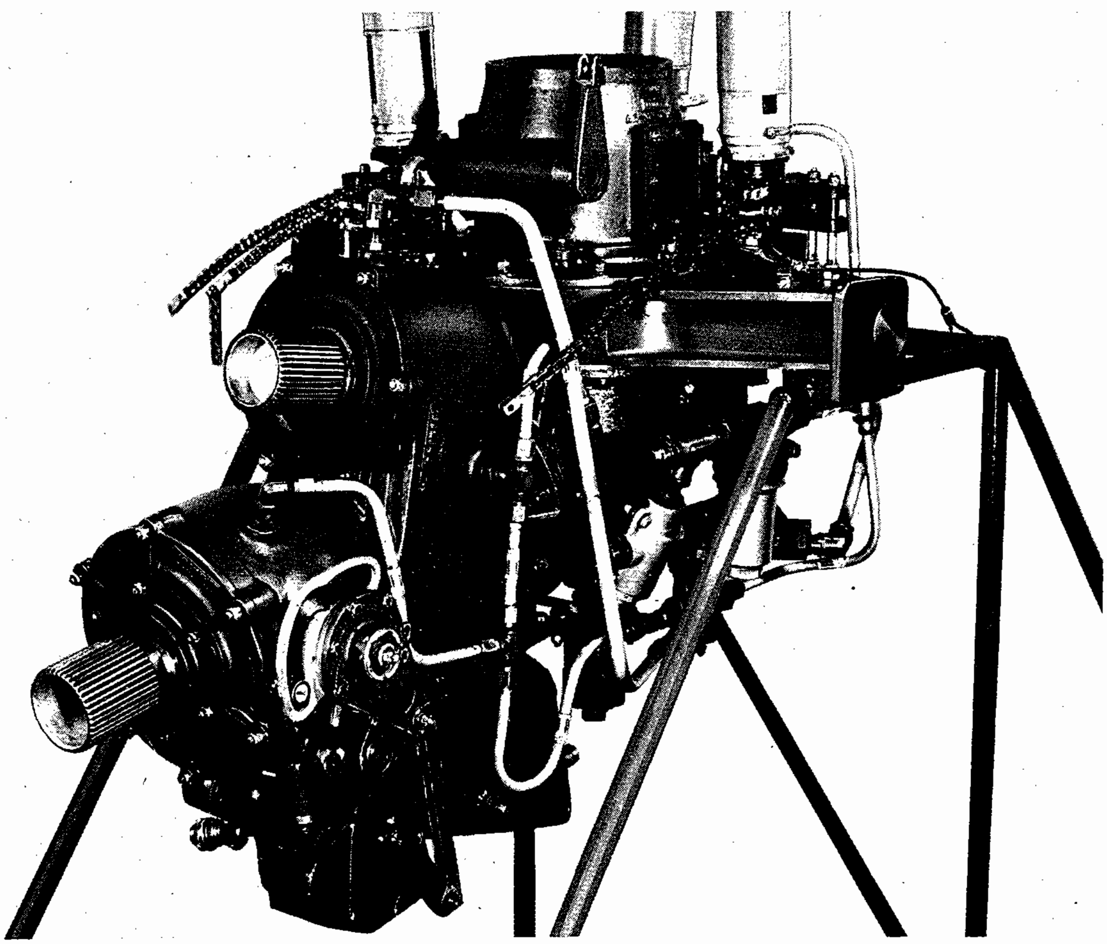


Figure 5-8

The drive shafts from one transmission to another must also be rigid enough so that this relation of the blades is maintained.

In multi-engined helicopters, the transmission and associated clutch is used to transmit the power of both engines to the rotor system so that in case one engine fails the rotor system will still be powered.

(7) FREEWHEELING ELEMENT. The clutch disengages automatically only when the clutch housing speed drops below the clutch engaging speed. If the throttle were retarded suddenly or the engine quit, the rotor would not disengage since the rotor during autorotation would continue to rotate the clutch housing, above the engaging speed. Therefore, the engine would be driven by the rotor causing a prohibitive drag. If the rotor were slowed sufficiently to disengage the engine from the centri fugal clutch, the rotor rpm would be so low that autorotative flight could not be maintained. To prevent this, a freewheeling clutch is installed. (See Figure 5-9.)

This device disengages the engine from the transmission whenever the speed of the transmission input shaft exceeds the speed of the engine drive shaft. Since the transmission is being driven by the rotor during autorotation, the tail rotor continues to operate.

Figure 5-9

(8) SWASH PLATE. Though in different form in different makes and models of helicopters, the swash plate, also called the "star plate," or "wobble plate," is a standard feature of this type of aircraft. It consists essentially of three parts: a tiltable ring encircling the mast and supported by gimbals for universal movement; a rotating ring moving at the same speed as the rotor; a nonrotating ring, and a ball bearing between the rotating and nonrotating rings. (See Figure 5-10.)

The universally mounted ring is controlled as to tilt by movements of the cyclic control stick, which corresponds to the control stick of the conventional airplane.

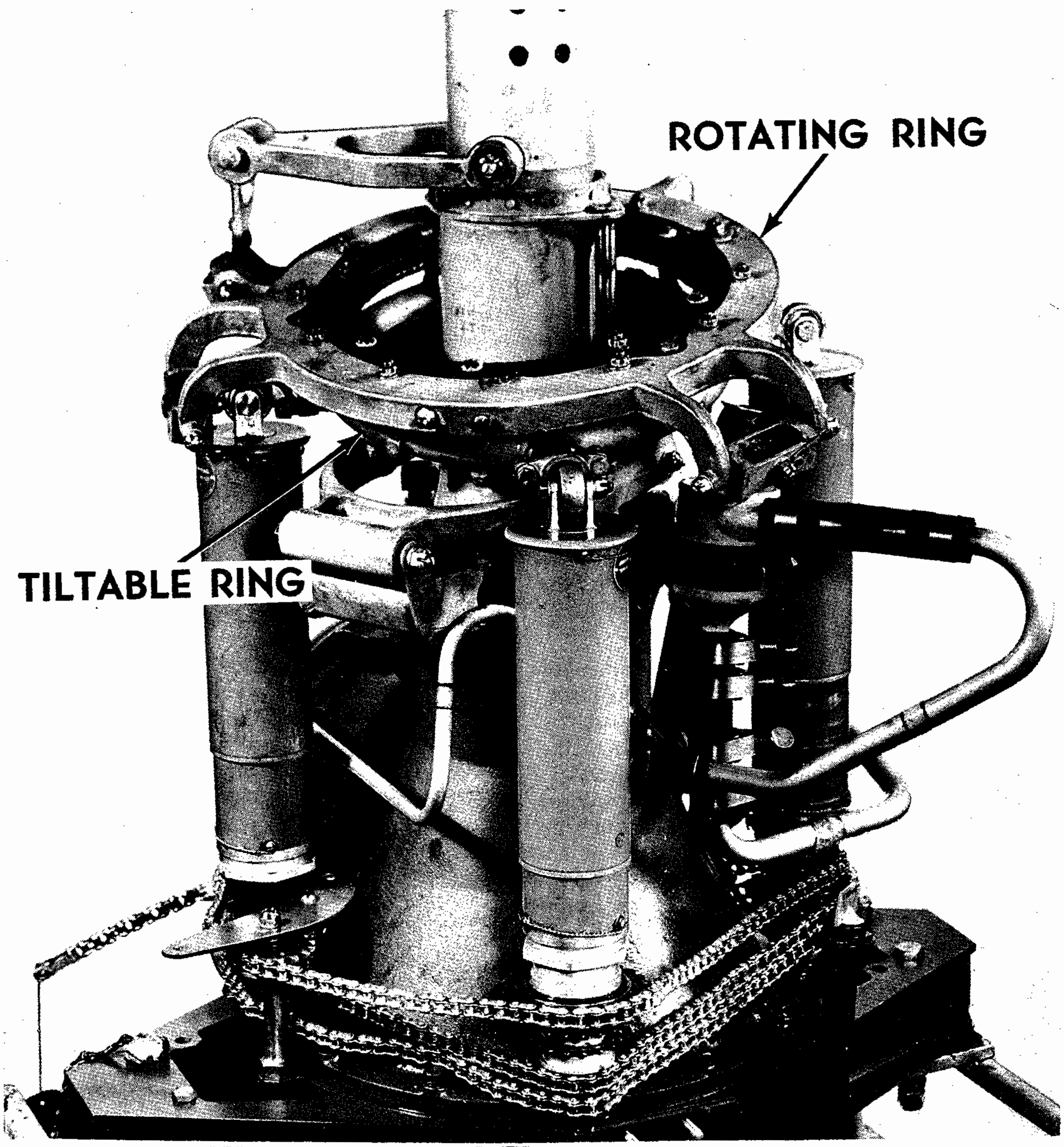


Figure 5-10

This tiltable ring which actuates the rotating ring is connected by bell cranks, chains, or other mechanism to the cyclic stick. Push-pull rods from the rotating plate connect with the rotor blades to change the pitch of the blades as they move around the rotor disc. Assume that the swash plate is in level position, as in hovering in a zero wind speed condition. Since the swash plate is not tilted, there is no change in the angle of attack of the rotor blades as they turn through each 360 degrees of travel; that is, there is no cyclic change of pitch. The only change of angle of attack under these conditions is effected by use of collective pitch control through a second control stick. Movement of this stick changes the angle of attack of all blades simultaneously and by equal amounts.

When the swash plate is tilted, an entirely different action takes place. If the cyclic pitch stick is pushed forward, the angle of attack increases as the blade passes through the retreating section of its travel and decreases as it passes through the advancing section. Therefore, there is a tendency of the blade to rise in the aft position and drop in the forward position, so that the tip-path-plane is tilted in the direction which gives the necessary forward drive to the helicopter.

Both the two-blade and three-blade rotors require the swash plate in some form for cyclic control, the principal difference being in the simpler mechanism required where the semirigid, two-blade rotor is used.

(9) ROTOR BLADES. While the propeller blades of a conventional airplane provide only the reaction that produces forward speed, the rotor blades of the helicopter are the wings, the propeller, the speed control and the directional control. The rotor takes the place, not only of wings, but of ailerons, elevators, flaps and trim tabs. The helicopter is essentially a set of rotating airfoils with the addition of the necessary power, controls, instruments and weight carrying structure.

The principal difference between the rotary airfoils and the blades of the conventional propeller is in the shape of the cross section. As mentioned elsewhere in this text, rotary airfoils are designed with a symmetrical cross section for better performance in autorotation, and so that the center of pressure remains the same even though the angle of attack of the blade is changed.

In order to overcome the dissymmetry of lift and to permit control in directional flight, it is necessary to have some degree of flexibility between the rotor blades and the hub. This flexibility may be obtained in any of three ways:

(1) With semirigid blades
(2) With fully articulated blades
(3) With flexible blades

In the rotor with semirigid blades, the blades are attached to the mast by a gimbal which permits either seesaw motion of the blades or motion around the longitudinal axis of the blade to change the angle of attack. For change in collective pitch, the angle of attack of all blades is changed simultaneously and by the same amount; while for changes in cyclic pitch, any increase in the angle of attack of one blade causes an equal and opposite decrease in angle of attack of the opposite blade. As the blades are free to take the angle demanded by the cyclic pitch change, the tip-path-plane is always under control of the pilot.

In the fully articulated rotor blade, a somewhat different construction is required. In this design, there are three movements possible in each blade independent of those in other blades. That is: The blades may move in flapping action; they may move to change the angle of attack; and they may move fore and aft in the plane of rotation.

In the Kaman helicopter a still different method is used of changing blade pitch. In this helicopter the blades are quite flexible, and the angle of attack is changed by warping or twisting the blades. The warping action is accomplished by changing the angle of control tabs or servos placed on the trailing edge of the blade. The tabs are controlled by movements of the pilot's control stick.

(10) CONTROLS. The following controls are common to helicopters in general:

(1) Cyclic pitch control
(2) Collective pitch control
(3) Throttle control
(4) Tail rotor control (In single rotor designs)

A principal difference between the controls of the conventional airplane and those of the helicopter is that while the conventional airplane may be flown hands off under certain conditions, the helicopter not only needs constant control, but must have all controls operating at once. Concentrated attention must be given to all four controls during take-off, hovering, and landing. The cyclic pitch control (See Figure 5-11) is directly in front of the pilot, and moving on a universal joint, it produces horizontal flight in the direction of its movement. The collective pitch control (See Figure 5-12) is at the left of the pilot and increases the angle of attack of the blades equally and simultaneously when it is raised, and causes a decrease of pitch when it is lowered. While throttle control is linked to this control stick, further regulation is provided by a motorcycle type throttle control in the handle. The pilot's foot pedals act to change the pitch of the tail rotor blades and provide steering control in the case of single rotor helicopters.

As in the conventional airplane, right pedal swings the nose to the right, and left pedal swings the nose to the left. Control of this rotor, too, demands constant attention to keep the helicopter headed in the desired direction.

In the case of multirotor helicopters, the rudder pedals generally operate through the cyclic pitch and collective pitch control mechanisms to give differential action on the rotors which gives control in azimuth.

JET HELICOPTER COMPONENTS

If instead of using reciprocating engines to drive the rotor, jet reaction type engines are used, many of the mechanical components described in this chapter are unnecessary. For example, the cooling fan, clutch, transmission, freewheeling element and tail rotor controls are not needed. When ram jet or pulse jet engines are used, the only mechanical requirement is delivery of the fuel supply through the rotor head to the rotor blades.

Another system of jet operated rotor blades is under development. A conventional turboprop engine in the fuselage supplies compressed air from its compressor through the rotor head to the rotor blades. Fuel also is pumped into the rotor blades. The compressed air and fuel are then mixed and ignited in combustion chambers at the tips of the blades. With this type power plant there is no drag from the combustion air, should the engine fail and autorotation become necessary. The flow of air through pulse jet or ram jet engines when they are not burning, causes excessive drag at the tips of the rotors.

RIGGING THE HELICOPTER

Rigging the helicopter has many things in common with rigging a fixed wing aircraft but is far more complex. Just as there are the wing, tail and controls to rig in the conventional aircraft, there are the main rotor, tail rotor, and controls to rig in the helicopter. A check of the rigging will be required whenever a major component has been changed or a change has been made that affects the weight distribution.

In order to do a thorough job, the helicopter must be level and must remain stationary throughout the operation. This will present difficulties when operating aboard ship or outdoors in moderate winds. Some helicopters have jack points and level lugs to simplify rigging.

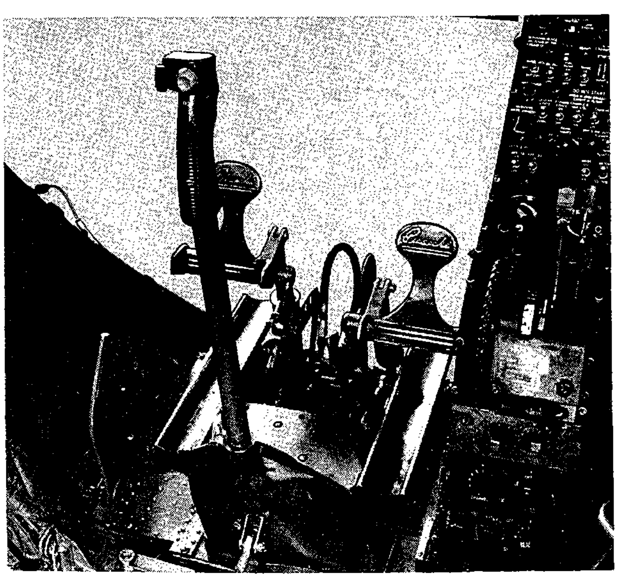


Figure 5-11

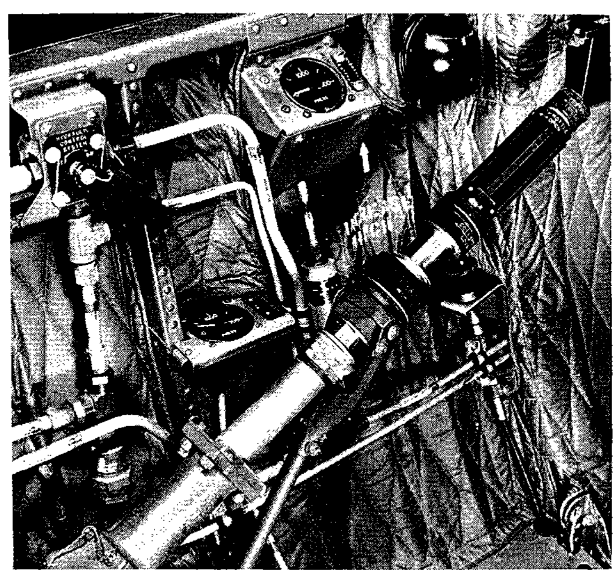


Figure 5-12

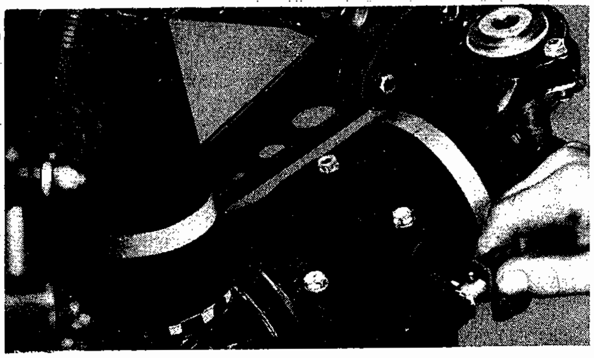


Figure 5-13

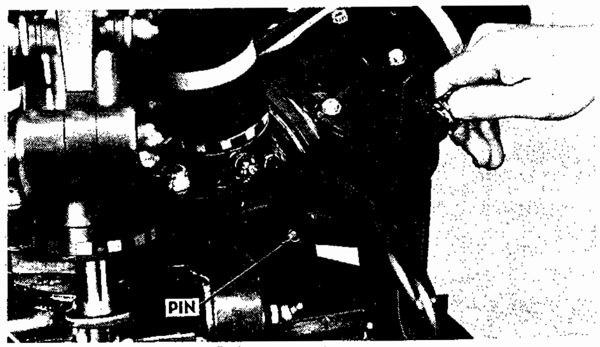


Figure 5-14

To assist in rigging helicopters aboard ship, locating pins on each blade make it possible to lock the blade in the zero position while cables and controls are being adjusted. (See Figure 13 and Figure 14.)

RIGGING THE MAIN ROTOR

The main rotor must be checked for blade spacing, angular change in collective and cyclic pitch, and track.

Drag links (See Figure 5-15) are provided to adjust the angular spacing of the blades of two-blade rotors. Two-blade rotors must have the blades exactly 180 degrees apart. Three-blade rotors automatically space themselves 120 degrees apart. Dampers are used to help control this spacing in flight. Improper spacing will cause ground resonance and other objectionable vibrations.

With the blades correctly spaced, the next check is for blade angle settings. With the collective pitch lever bottomed, the minimum blade angle is set. A difference of one degree may cause as much as ten to twelve rpm difference in autorotative speed. Therefore, this low angle

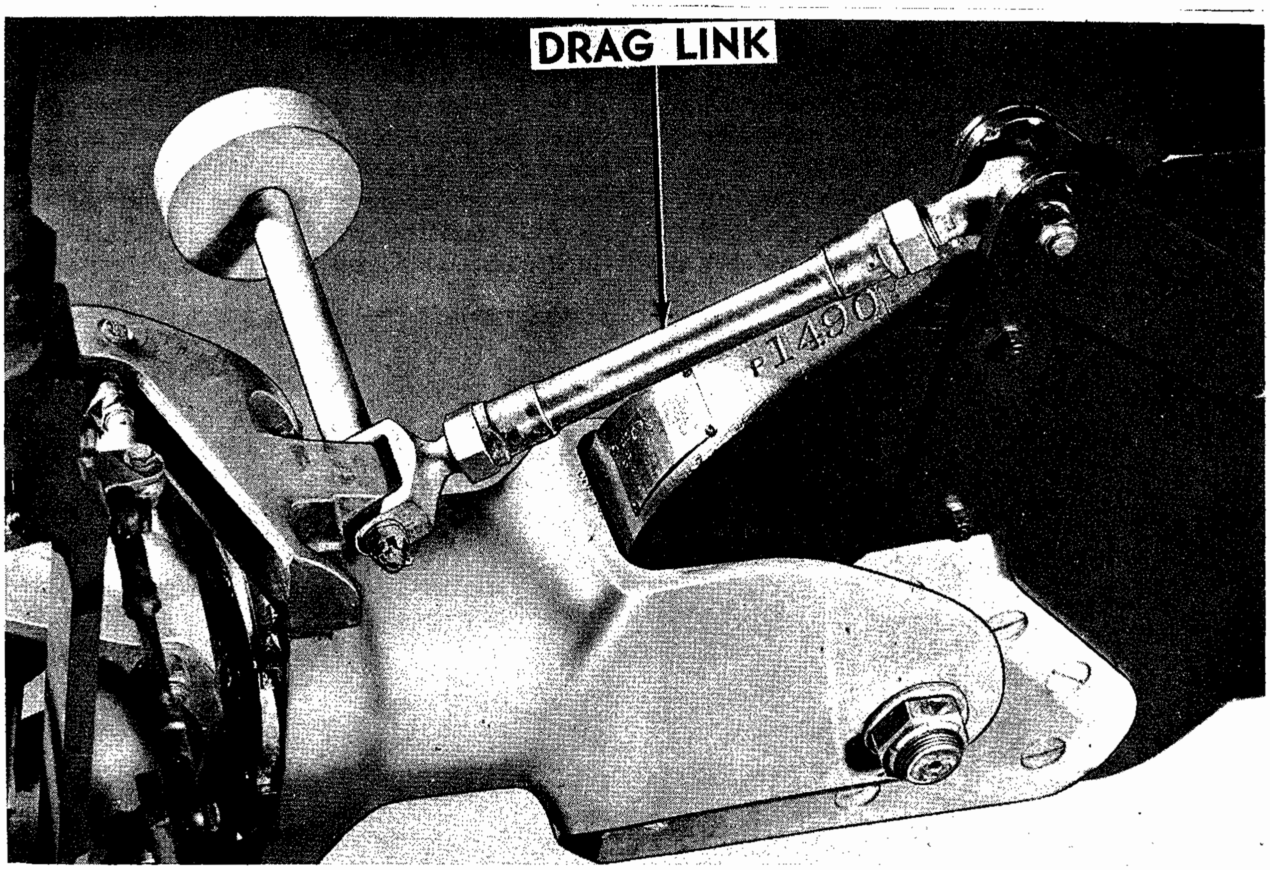


Figure 5-15

setting must be right on and not just "about right." (See Figure 5-16) When the low angle is right, the maximum angle can be checked. This is usually determined by stops in the system which can be adjusted.

When the collective pitch settings are correct, the cyclic pitch settings can be checked. It is important to understand at what position in the plane of rotation changes in pitch should occur in relation to the position of the cyclic stick. This is explained in Chapter 4 "Forces on the Helicopter." Maximum angles will occur approximately ninety degrees ahead of the direction in which translational flight is desired.

Tracking of the main rotor is similar to tracking a propeller on a conventional aircraft, but must be done with the rotor turning. (See Figure 5-17.) Fixed trim tabs on the trailing

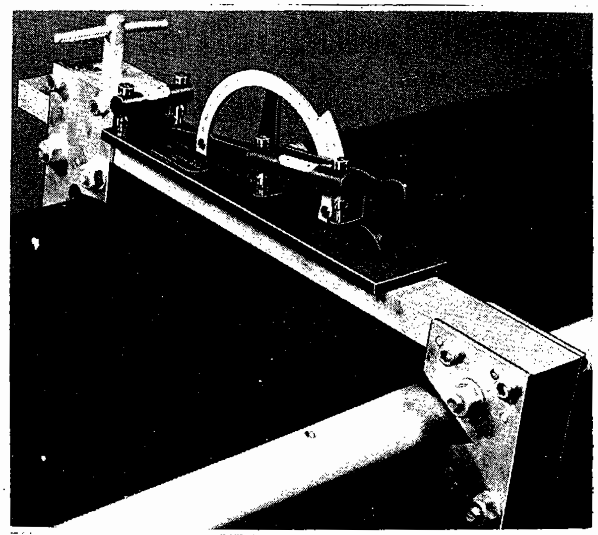


Figure 5-16

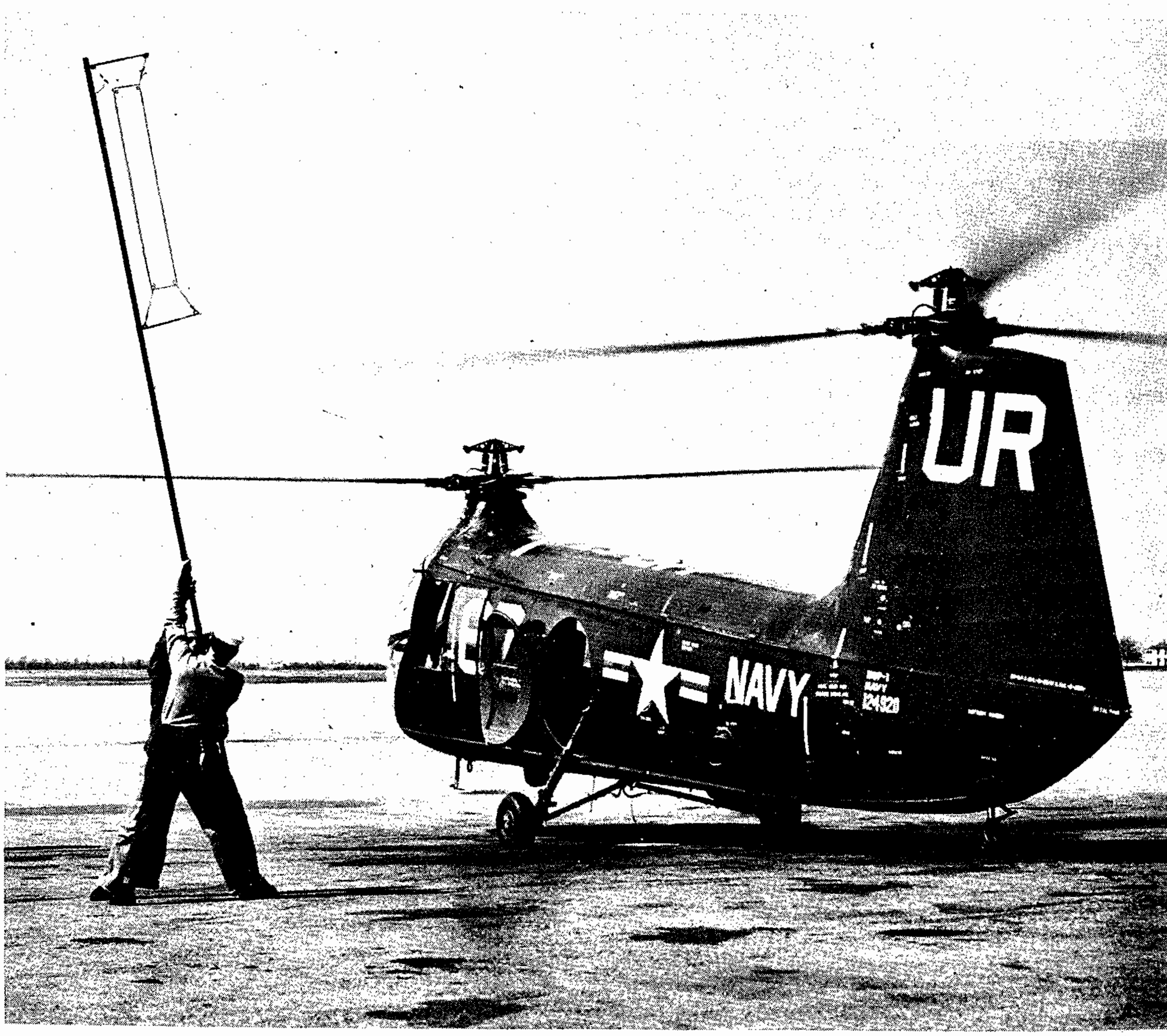


Figure 5-17

edge of the blades of semirigid rotors are provided to change the track of an individual blade. Articulated rotor head types have an adjustment of the angle of attack of the individual blades which will change the track. This adjustment is made through push-pull rods in the head mechanism.

RIGGING THE TAIL ROTOR

For this operation, the helicopter needs to be level laterally only. The first check is to see that the shaft from the gear box is perpendicular to the main rotor mast. Then, the individual blades are placed in the down position and checked to be sure that they return to straight down position when they are pulled outboard. This will prove that the bearings are in good condition. Then, with the rudder pedals clamped in neutral position, the angle of each blade is checked. The highest blade is used as the starting point and the other blades are brought to the same angle by means of adjustment in the pitch changing links. (See Figure 5-18.) With the rudder pedals unclamped, the maximum and minimum blade settings are checked. These settings are controlled by stops in the control box which may be adjusted if required.

The last check of the tail rotor is the amount of flapping action available. This is controlled by rubber stops in the hub. Too much flapping action will allow the blades to strike the fuselage and too little will put excessive stresses on the blade shanks. Too little flapping action of the tail rotor also results in a medium frequency vibration of the rudder pedals which is undesirable.

RIGGING THE CONTROLS

Rigging the controls is generally an operation that takes place while the rotors are being adjusted. The position of the collective pitch lever and the cyclic pitch stick must be checked at the same time that neutral and maximum and minimum pitch settings of the rotor are determined. The control cables in the system must be checked for tension the same as in a fixed wing aircraft control system. (See Figure 5-19.) In some control systems bicycle-type chains are used. These also must be checked for tension. If the tension cannot be corrected by the turn-buckles in the cables attached to the chains, short links can be used in the chain to make the cable adjustment come into range.

The rudder pedal travel must coincide with the maximum and minimum travel of the tail rotor stops in the tail rotor controls box. Cable adjustment makes this possible. Neutral position is also determined by changing the length of the cables to align the pedals and tail rotor blades at the same time. In multirotor helicopters, rudder pedal adjustments must be checked against the required motion of the main rotor heads.

CHECKING THE RIGGING

Because practically all helicopters, even of the same model seem to fly and feel different, it is important that suggested rigging changes be made only at the direction of an experienced helicopter check pilot. There are certain tests which will pretty well determine the proper operation of the helicopter as it is put through its basic maneuvers such as the amount of skid developed by full right rudder in autorotation. However, the most desirable operating condition for various types is enough different that standard rules cannot be set up for all makes and models.

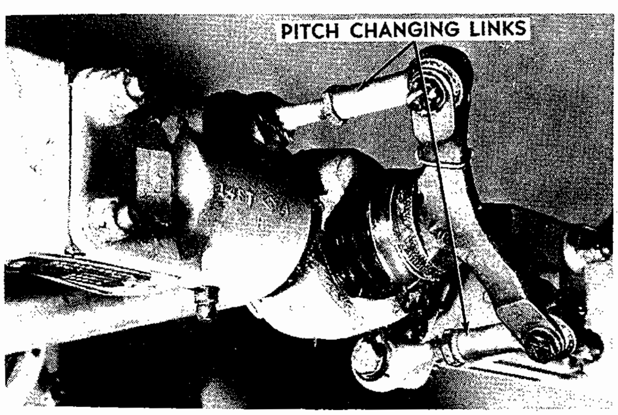


Figure 5-18

Figure 5-19

TROUBLE SHOOTING

The helicopter is subject to most of the troubles of other aircraft as they pertain to the engine, hydraulic system, fuel system, landing gear or other conventional aircraft parts. The symptoms and the means of correcting these difficulties will be the same as they would be in the conventional aircraft. But there are certain difficulties which are peculiar to helicopter operation. Every pilot and mechanic must be aware of the symptoms since the earlier the trouble can be determined, the less the eventual damage may be. For example, if a brinelled bearing is detected soon enough, the required repair may only be bearing replacement while if the trouble persists the resulting repair may necessitate replacement of the entire rotor head.

Generally speaking, troubles peculiar to the helicopter show up as unusual stick forces or vibrations.

UNUSUAL STICK FORCES

Excessive stick forces due to stiffness usually are the result of defects in the controls at the rotor head. Cables that are too tight, defective bearings, lack of lubrication, or grit or burrs that may cause tightness are the usual causes of stiffness in the control system. Looseness in the control system is generally just the opposite in its causes. This includes a stick that's loose in the socket, loose cables or chains, or worn parts, either bearings or ball and socket assemblies.

There is a natural tendency of the main rotor to cause a stick force to the left. This is generally neutralized by means of a bungee spring (See Figure 5-20) in the system which puts a right stick force on the system at all times to counterbalance the natural left stick force. This can only be neutral in some definite flight speed range. Above or below normal operating range of the helicopter, lateral stick forces to the left are normal. However, if there is excessive left stick force in the normal speed range, the bungee spring is weak and must be tightened or replaced. If the stick forces are excessive to the right, the bungee spring is too strong and must be eased off.

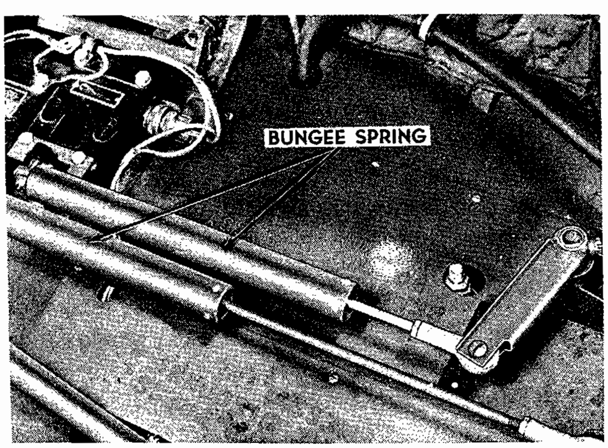


Figure 5-20

If there should be a fore and aft vibration of the stick, the flapping links may have stiff or brinelled bearings. The rotor head must be replaced.

If there is a sharp kick in the stick forces in a fore and aft direction at high forward speed, high altitude or at low rotor speed, it is probably a stalled blade condition and can be corrected by changing the flight condition to a lower forward speed, lower altitude or higher rotor rpm.

VIBRATIONS

Abnormal vibrations in the helicopter will fall into three ranges:

(1) Low frequency—100 to 400 cycles per minute

(2) Medium frequency—1000 to 2000 cpm

(3) High frequency—2000 cpm or higher

(1) LOW FREQUENCY. Abnormal vibrations in this category are always associated with the main rotor. The vibration will be some frequency related to the rotor rpm and the number of blades of the rotor such as two, four, six or three, six, nine, cycles per second. (See Figure 5-21.)

Figure 5-21

The frequency and the strength of the vibration will cause the pilot or passengers to bounce or shake noticeably. If the vibration is felt through the stick, it will have the same definite kick at the same point in the cycle. These low frequency vibrations may be felt only in the fuselage or only in the stick or they may be evident in both at the same time. To some extent this will determine the cause.

If the vibration is felt definitely in both the stick and fuselage, the cause is generally in the rotor or the rotor support. The rotor should be inspected for visible defects such as damaged fabric. The rotor track should be checked if there is no visible evidence of damage. A failure of the pylon support at the fuselage is also a possible cause. Helicopters with dampers in the drag hinge may also be subject to low frequency vibrations if the dampers have uneven rates, if there is air in the dampers or if there is binding in the bearings which gives a false damper rate.

If there is a low frequency vibration felt predominately through the fuselage, it is generally the result of a brinelled main link bearing or cocked needle bearings.

If the low frequency vibration in the fuselage occurs only during translational flight or a climb at forty to fifty knots the vibration may be a result of the blades striking the blade rest stops. This can be eliminated by avoiding the flight condition that causes it.

For low frequency vibrations felt predominately through the stick, the most likely place to look for trouble is in the control system linkage from the stick to the rotor head. This may be bad bearings either at guides or at tube ends.

(2) MEDIUM FREQUENCY. Medium frequency vibrations are a result of trouble with

Figure 5-22

the tail rotor. (See Figure 5-21.) Improper rigging, unbalance, defective blades or bad bearings in the tail rotor are all sources of these vibrations. The trouble must be isolated and then the rotor properly rigged or the defective part replaced. If the vibration occurs only during turns, the trouble may be caused by insufficient flapping action. This can be corrected by increasing the action allowed by the stops.

Figure 5-23

(3) HIGH FREQUENCY. High frequency vibrations are associated with the engine only. (See Figure 5-23.) A defective clutch or missing or bent fan blades will cause vibrations which should be corrected. Any bearings in the engine or in the transmission or the tail rotor drive shaft that go bad will result in vibrations with frequencies directly related to the speed of the engine. Replacement or alignment of the bearings will be the usual remedy. Proper lubrication will do much to prevent the damage that results in these disturbing vibrations.

Experience in detecting and isolating the three different classes of vibrations when they first develop makes it possible to correct the vibrations long before they become serious. Every pilot should develop this skill so that he can report to the plane captain immediately. It must be remembered, however, that there are certain inherent vibrations in some helicopters that are not dangerous and the pilot must learn to recognize them. Also, certain vibrations may not be cause for stopping operations immediately. For example, if a blade is out of track, it would not be necessary to declare an emergency unless the vibration increased excessively during the day's operations. These exceptions noted here are what make trouble shooting a difficult but important pilot skill.

PART III

OPERATION

Helicopters in use at present by the Navy are well suited for general utility and rescue work from land and sea bases, for plane guard, for transfer of personnel, mail pickup and delivery and many other tasks. They are limited to short-range missions and should be used only where flights can be conducted under contact conditions. They cannot be trimmed to fly "hands off"; they demand the pilot's attention at all times. Vibration is still excessive, and induces pilot fatigue in relatively short time, another factor that limits length of flight. However, some helicopters now carry automatic pilots which make "hands off" flying possible thereby reducing pilot fatigue. With this equipment, it will also be possible to conduct flights under instrument flight conditions.

CHAPTER 6

HELICOPTER OPERATION

GENERAL

At the present time there are many types of helicopters in operational service in the U.S. Navy. (See Figure 6-1.) These vary in size from the Bell HTL, (See Figure 6-2) a two place

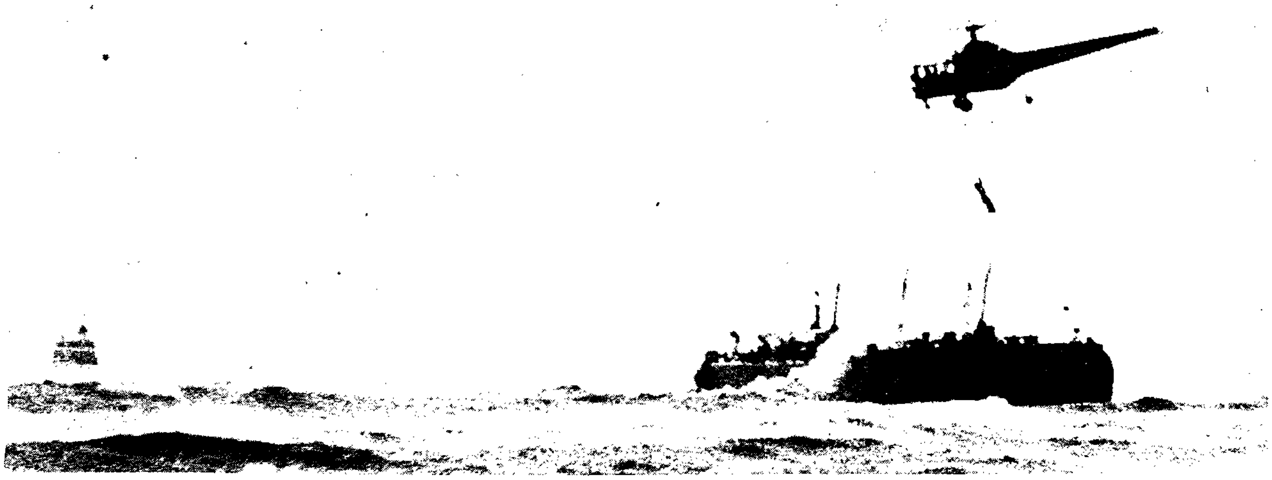


Figure 6-1. A telephoto picture of an actual rescue by a Sikorsky helicopter of a man from a disabled vessel in stormy weather.

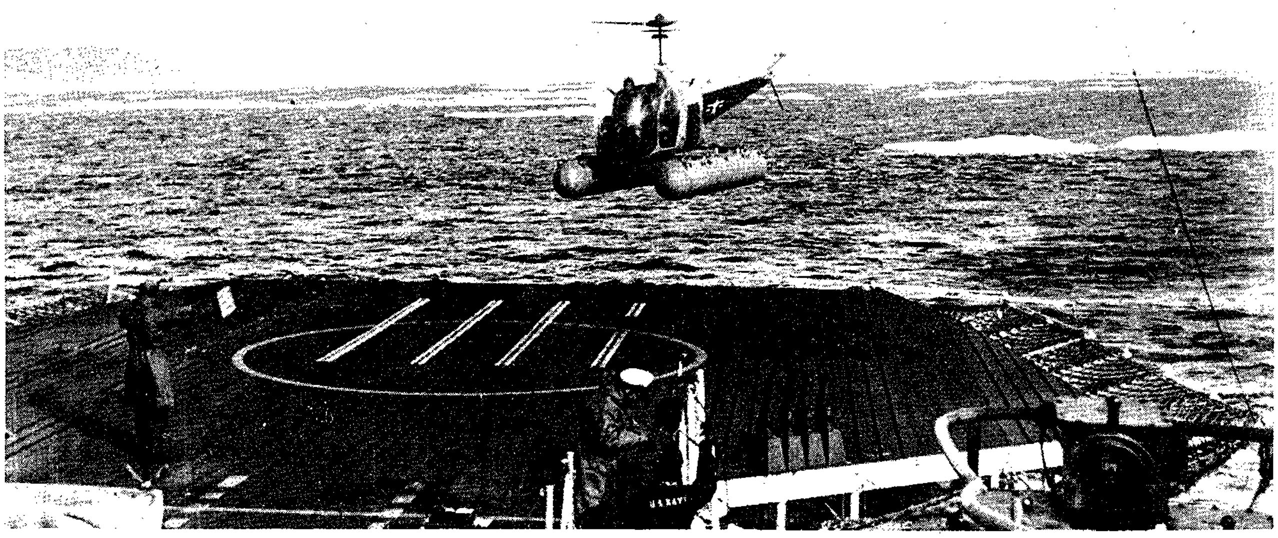


Figure 6-2

helicopter used on icebreakers and for air evacuation, to the HRP, (See Figure 6-3) a dual tandem rotor helicopter capable of carrying eight men in addition to the pilot and copilot and used for assault landings.

LOADING LIMITATIONS

In the transfer of mail, material and personnel, the loading limitations of the helicopter must be kept constantly in mind, as it is the pilot's responsibility to determine the quantity and placement of cargo to be loaded. When landing aboard is not practical, mail and other material up to a weight of 30 pounds may be picked up or delivered by means of a weighted hand line with a bag attached. Where personnel, or an object of over 30 pounds, must be raised, the hydraulic hoist is used. Personnel are transferred by means of a rescue sling. Heavy objects should be placed in a canvas bag. Where any single hoist load exceeds 50 pounds the pilot should be informed by means of a placard and his approval should be obtained before attaching the load to the hoist line.

DECK HANDLING

The HO3S-1, one of the helicopters used aboard ship for rescue operations, is a comparatively light aircraft, and can normally be handled for respotting operations by a five-man crew. (See Figure 6-4.) The nose wheel is full

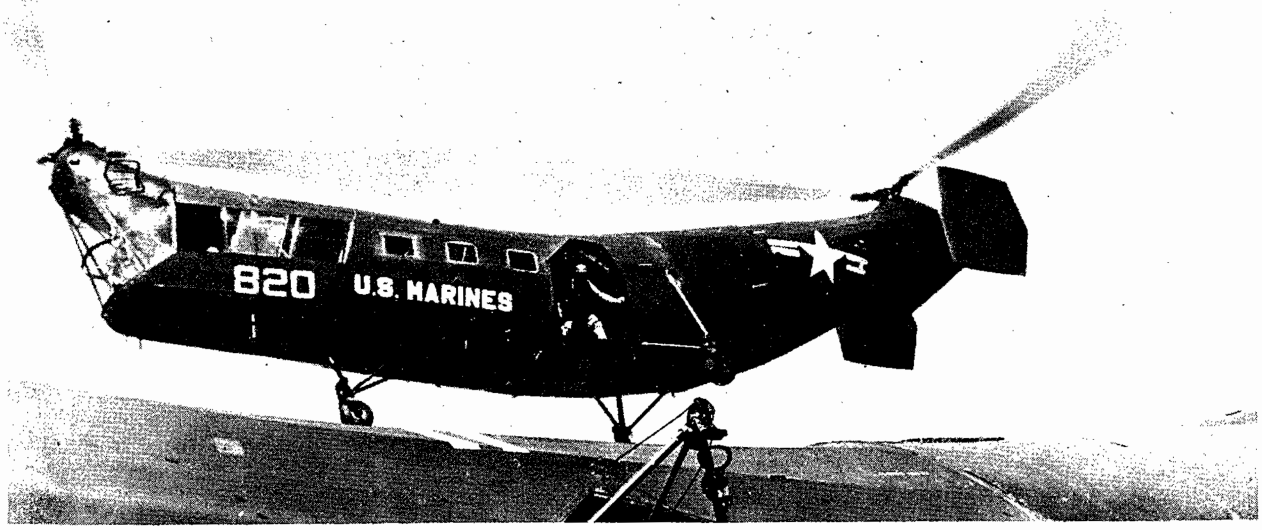


Figure 6-3

Figure 6-4

swiveling, permitting good maneuverability. Brakes on this helicopter are for parking only and cannot be used for steering; also they are not fully effective in stopping any tendency for the helicopter to move as a result of the ship's roll. A high center of gravity gives it a tendency to overturn rather easily. As it has a tendency to slide on a rolling deck, chocks must be used at all times, and tie-downs are often necessary. Deck handling and storage should always be supervised by a helicopter pilot or a plane captain.

The HUP, now commonly used for plane guard service, has most of the same handling characteristics as listed above for the HO3S. The main exception is that the HUP has a tail wheel rather than a nose wheel. It is also full swiveling and maneuvering is easy.

With rotor blades extended, the HO3S can be handled on any elevator of a CV or CVB. With blades extended, clearance is also sufficient on the elevators of CVL-48 and CVL-49. On elevators of all other CVL's and CVE's the rotor blades must be folded. The HUP can be handled on any elevator of a CV, CVB, CVL or CVE with the rotor blades extended or folded. (See Figure 6-5.) Spotting is expedited and is more accurate if marks are painted on elevators and decks to show the proper position of wheels.

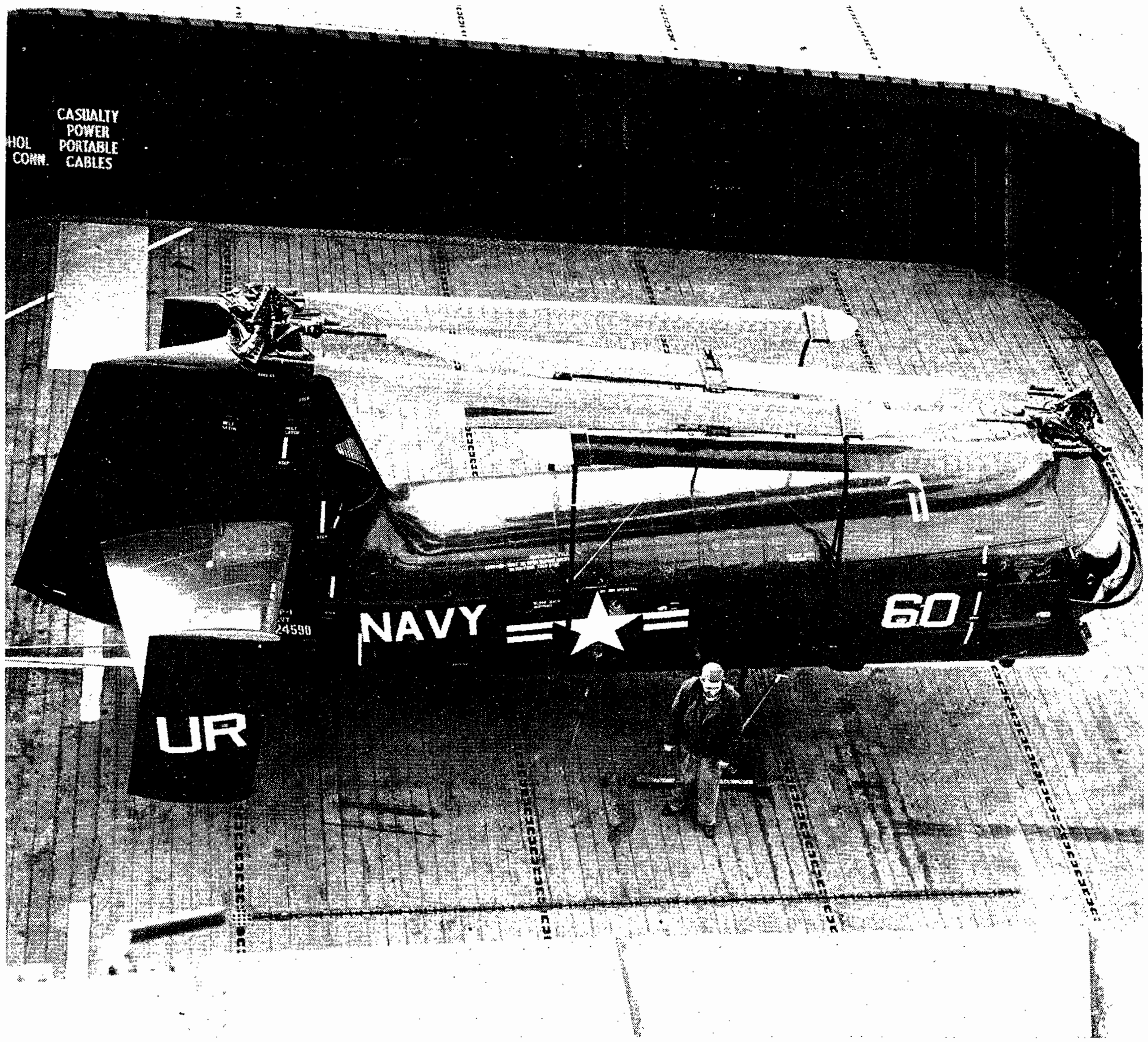


Figure 6-5

Figure 6-6

Rotor blades of the HO3S-1, for example, can be folded in about five to ten minutes by an experienced crew. On the flight deck of a CV or CVB this is easily done by spotting the plane on the elevator and lowering the elevator about six feet. (See Figure 6-6.) This brings the rotor blades down where they can be reached without the use of work stands. Folding the blades is hazardous in winds of more than twelve knots, and whenever possible they should be folded and spread on the hangar deck or in a protected area.

PREFLIGHT CHECK

A preflight check must be made every day before the first flight and again before each flight. The five-man crew ordinarily supplied is sufficient to perform all functions of launching, recovery and maintenance.

As a general rule, the helicopter should be manned and ready with the engine warmed up, ten minutes before the scheduled launch. The sounding of flight quarters for the helicopter may be based on this time, depending on the location and status of the plane. The senior helicopter pilot should be informed of any unscheduled flights as far in advance as possible. This will enable him to plan fuel loadings and to assemble any special gear that may be required.

PRESTART PROCEDURE

As soon as the rotor blades have been spread, canvas boots should be put on and the blades tied down. On CV's and CVB's this should be done on the hangar deck if possible. The plane is raised to the flight deck and spotted in the take-off position. It is headed into the relative wind or direction of anticipated take-off. It should be securely chocked and tied down. All obstructions, such as antennae, cranes, flagstaffs and life lines, should be lowered, trained clear or unrigged prior to helicopter operations. Normal safety precautions should be observed.

STARTING THE HELICOPTER ROTOR

The pilot starts the engine on direction by proper authority. The blade boots should be made ready for casting loose on signal from the pilot. As soon as engine oil pressure permits, the rotors should be engaged. Experience has shown that there is considerable possibility of a blade coning when the wind velocity exceeds 30 knots, and that the possibility increases sharply as the speed of wind increases. Therefore, unless in an emergency, rotors should not be started or stopped when wind velocity exceeds 30 knots. Even with less wind there is some danger due to turbulence, roll of the ship, position in which the aircraft is spotted and various other factors.

It should be kept in mind by all personnel concerned with helicopter operations that starting or stopping the rotor under marginal conditions of safety presents an extreme hazard to the pilot, the aircraft, and the personnel in the immediate vicinity. Whenever doubt exists of the possibility of a safe start or stop, decision must be made on the safe side, except in cases of extreme urgency where a calculated risk may be justified. Whenever the tactical situation permits, reduction of relative wind to 20 knots is desirable.

Before rotors are started, a launching officer with red and green flags is stationed in front of the helicopter. Also, for safety reasons, it is imperative that a guard be stationed at the tail rotor or the rear rotor to warn anyone in the area. During warm-up, a red flag is displayed by the launching officer, who maintains a close watch to keep spectators clear of the danger zone.

LAUNCHING

On completion of the warm-up, the pilot notifies the launching officer that he is ready for take-off, and the launching officer relays this information to the proper authority. When he receives instructions to launch the helicopter, the launching officer checks the take-off area to make certain that it is clear of obstructions, and that personnel stand clear. The launching officer directs that the chocks be removed, if advisable, and gives orders to remove tie-downs. Display of the red flag is continued. During warm-up, and until the green flag is displayed, the pilot holds collective pitch in the down (low pitch) position. Under adverse conditions, the take-off should be made with the chocks still in place.

RECOVERY

When the ship is ready to recover the helicopter, the order to land aboard may be given by any standard signal: flaghoist, blinker, or radio. The landing officer is stationed in the landing area, equipped with red and green flags. He displays a red flag if the helicopter is not clear to land. A green flag indicates that the landing area is clear and that the helicopter pilot should complete his approach and land. (See Figure 6-7.) Immediately after the helicopter has landed aboard, and upon signal from the pilot, standard shipboard procedure is followed.

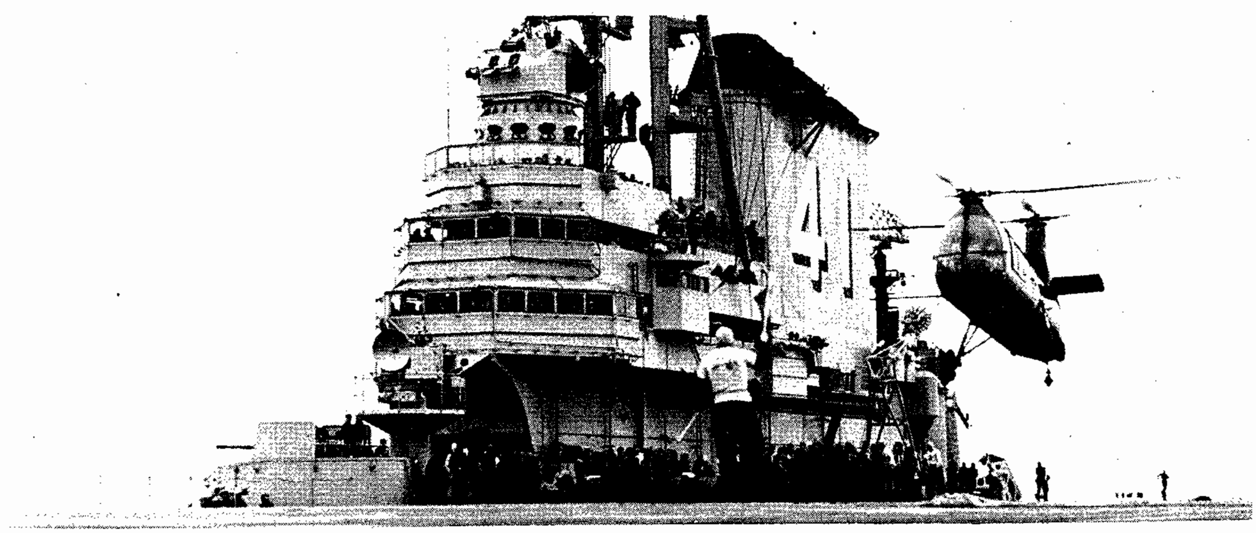


Figure 6-7

SECURING THE HELICOPTER ON SHIPBOARD

It should be kept in mind that all rotary wing aircraft have a much higher center of gravity than conventional airplanes. Due to this fact, tie-downs should be used, to prevent any possibility of overturning. In rough sea operation where the ship has a short period of roll, the landing gear should be secured to the deck immediately after the helicopter is landed on board. Otherwise, skidding and damage may occur. Chocks alone will not provide adequate security. (See Figure 6-8.) If possible, all helicopters should be stowed below decks.

SAFETY PRECAUTIONS ON SHIPBOARD

Every pilot should be familiar with the sources of danger to personnel and property when conducting shipboard helicopter operations. The greatest personnel hazard is the tail rotor which revolves in a vertical plane and is

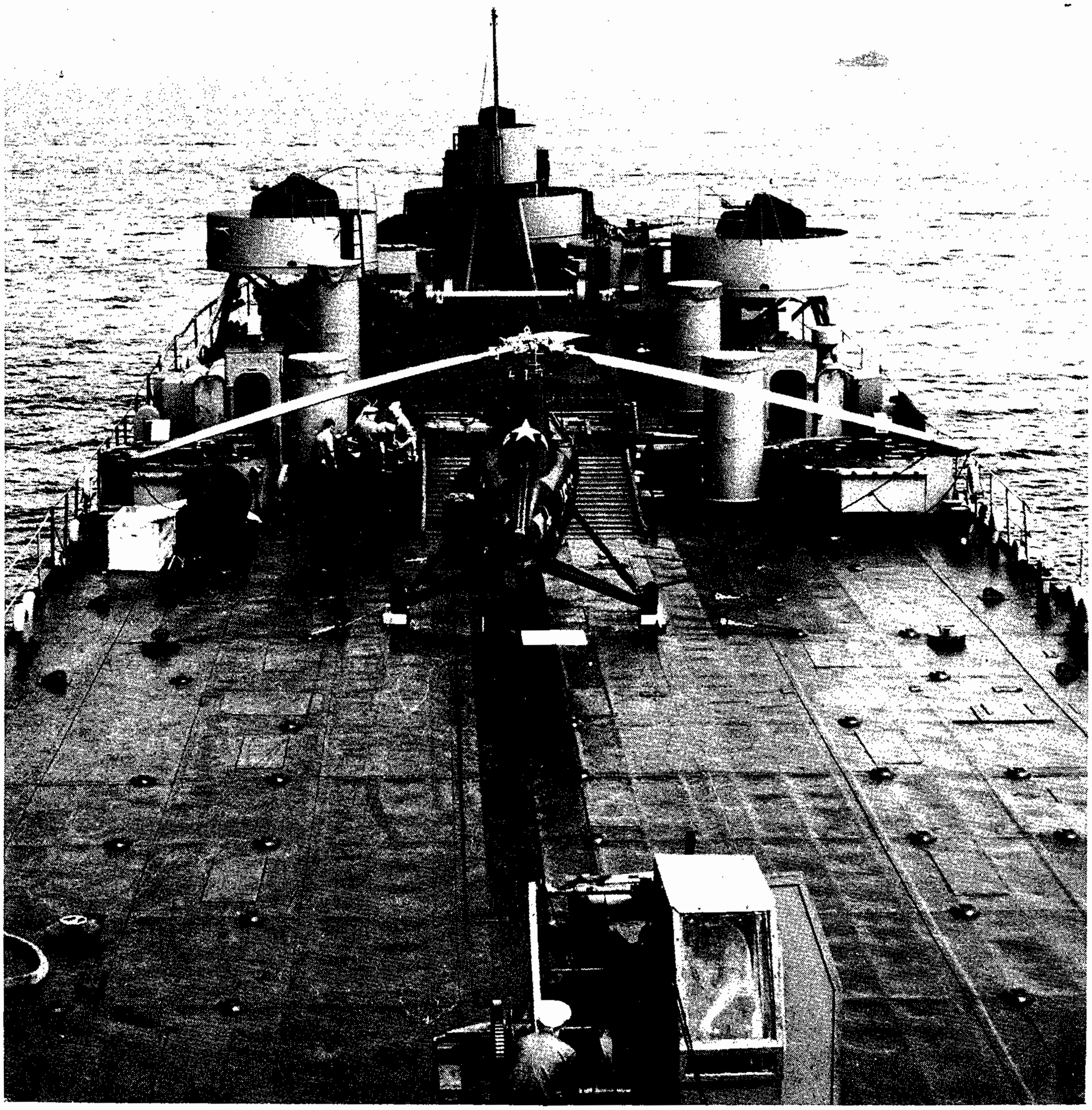


Figure 6-8

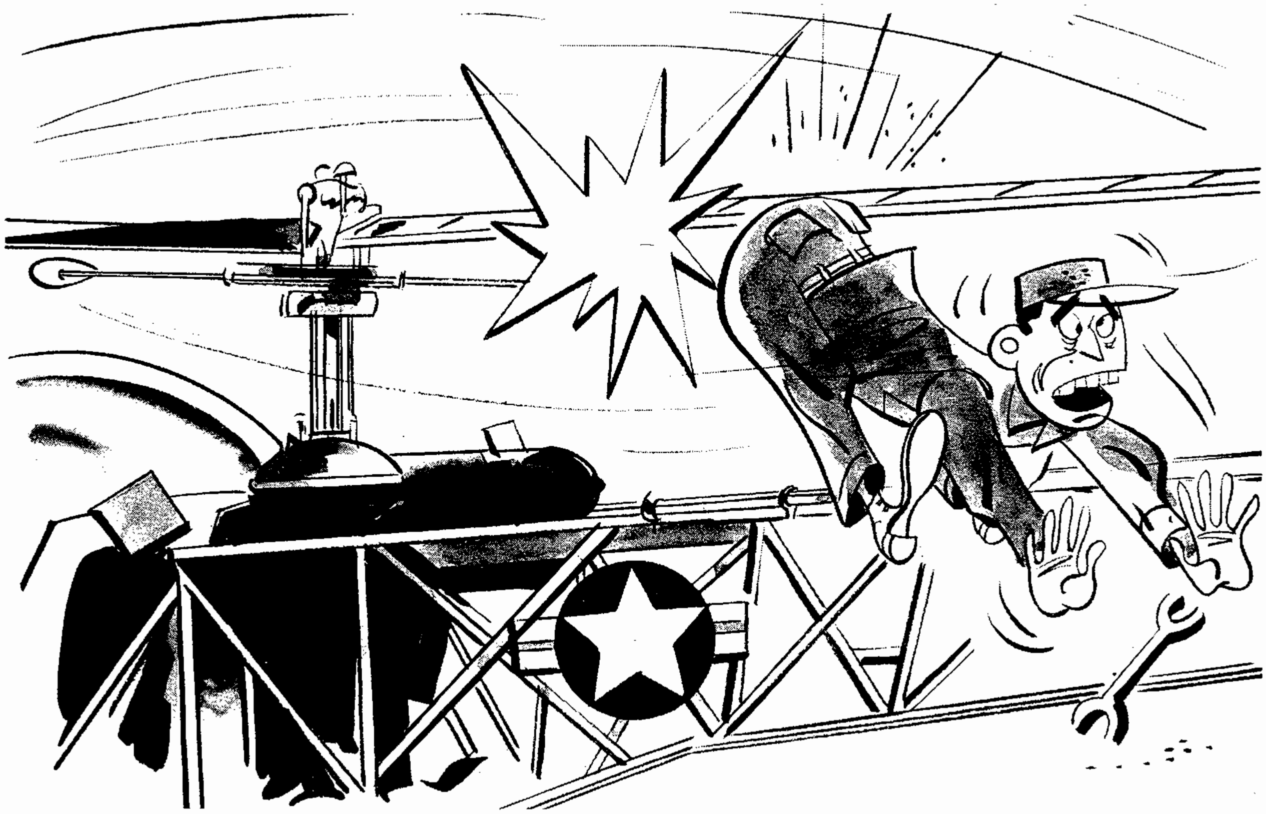


Figure 6-9

low enough to strike anyone passing within range of its blades. The main rotor also is dangerous, because it revolves in a horizontal plane, in some models only about 5 feet above the deck. Even in the HUP the tips of the forward rotor are at a dangerous height where they may cause serious injury. In the HO3S, while the track of the main rotor is well above deck level, it is possible for the blades to flap down into a position that endangers personnel. All rotors should be regarded as *highly dangerous.* (See Figure 6-9.)

If the main rotor blades should cone or strike the tail section, all personnel will be endangered by flying debris.

In addition to personnel safety, the safety of the helicopter itself must be considered. As downwash is very strong during take-off and landing, all rags, hats and loose gear should be kept clear of the area. Extensive damage may result from any small object blown into the fragile rotor blades.

Rotor blades for some helicopters are installed as matched sets, and damage to one blade may require replacement of a complete set at a cost of approximately $7000. A carelessly pitched handball, for example, may cause damage sufficient to require replacement of an entire set of blades. In some of the newer helicopters such as the HO5S and HRS, matched blades are not required. To avoid damage, the blades must be well clear of muzzle blasts if the ship's guns are fired.

Wind damage is another possibility that should be guarded against. The main rotor blades are flexible, and will bend when exposed to strong or gusty winds. Canvas boots fitted over the blade tips and secured by the line to the landing gear limit the flapping action, and should be secured at all times when the main rotor is not in motion.

The helicopter should never be placed so that any part of a blade extends over the side of the ship, even with the blade boot attached. Violent updrafts and downdrafts may cause damage. Tail rotor blades are rigid and need only be guarded by wedges placed to prevent flapping in the vertical plane. When working with a crew unfamiliar with the operation of the helicopter, the pilot should make certain that the personnel are advised of the things that must be done and of others that must be avoided in the interests of safety.

SHIPBOARD RESCUE PROCEDURES

Sea rescue operations (See Figure 6-10) are one of the most important functions in the special field of the helicopter. On plane guard station, during daylight launching and recovery operations, the helicopter is normally airborne. On being launched for plane guard duty, the pilot should orbit in a clear area near the carrier, until the ship begins to turn into the wind. Normally, the plane guard station during the launching of aircraft is close aboard the starboard side of the carrier abreast the bridge or landing area of the flight deck at an altitude of about 100 to 200 feet. (See Figure 6-11.)

During the recovery of aircraft, the normal plane guard station is about one point on the starboard quarter of the carrier, abreast the cross wind leg of the landing approach at an altitude of 100 to 300 feet. When more than one carrier conducts flight operations, the plane guard station should be in a central position relative to the landing circles, far enough aft to insure clearance with landing patterns, and with enough altitude, 200 to 400 feet, to maintain sight contact with all aircraft in the traffic patterns.

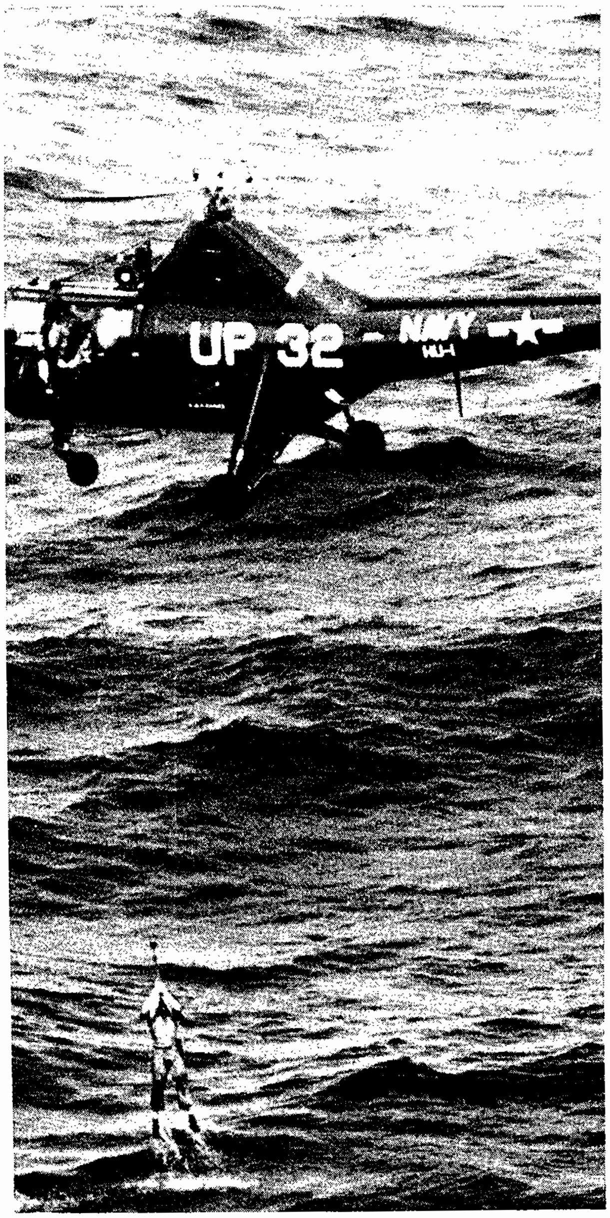


Figure 6-10

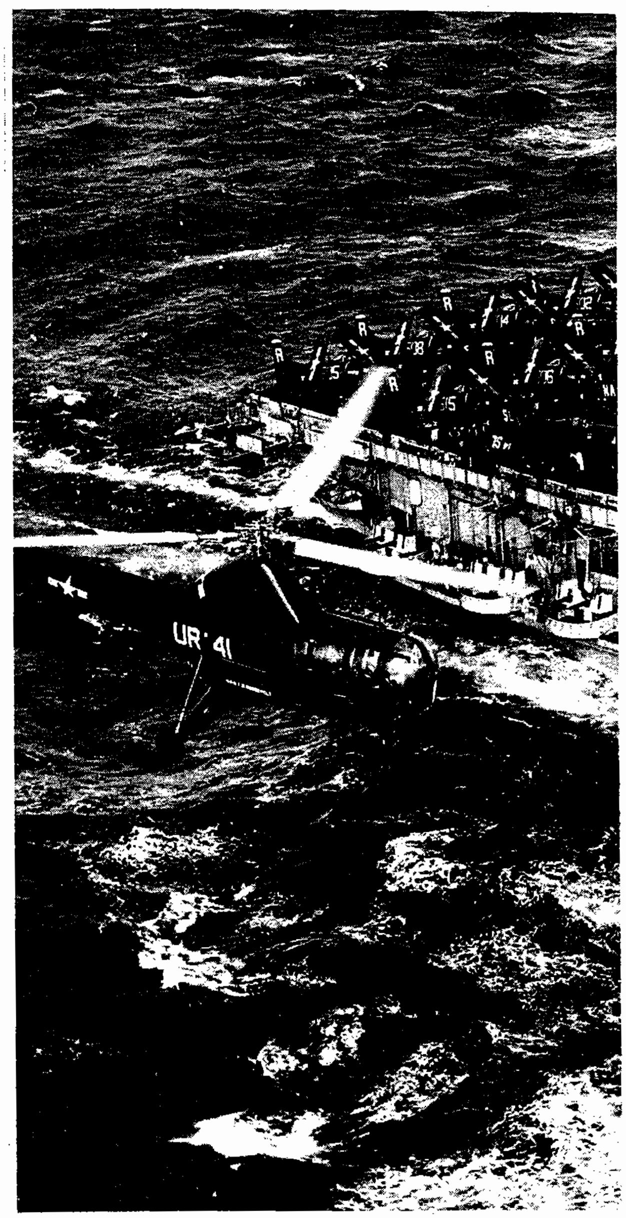


Figure 6-11

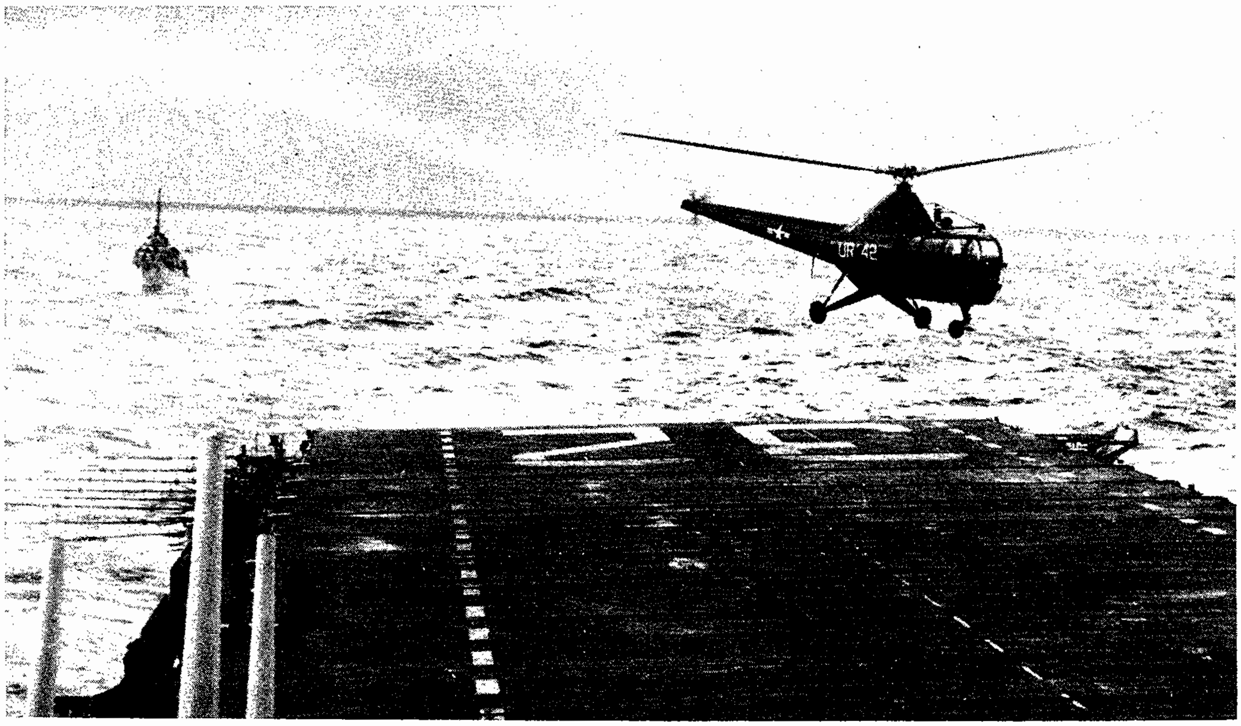


Figure 6-12

CO-ORDINATION BETWEEN SURFACE SHIPS AND HELICOPTER DURING RESCUE OPERATIONS

In making rescues of personnel from the water, the responsibility rests equally with the plane guard destroyer and the plane guard helicopter, and each is required to take the most effective and expeditious action. (See Figure 6-12.) Both the helicopter and the destroyer are to proceed immediately to the position of the emergency, and the destroyer prepares a boat for lowering.

If the helicopter arrives first or seems to be in a position to effect the rescue most rapidly, the pilot is the officer conducting rescue. The pilot proceeds with the rescue, keeping the plane guard vessel informed of his progress. The plane guard vessel then remains clear of the hovering area and proceeds to a standby position, prepared to assist as may be directed by the helicopter pilot. The standby position of the destroyer should be such that the helicopter is a short distance upwind on the destroyer's bow.

If the plane guard vessel arrives at the scene first, the commanding officer is the officer conducting rescue. The helicopter then proceeds as directed by him. Should the helicopter arrive first at the scene and find that the personnel in the water are incapable of assisting themselves, or that conditions are unfavorable for helicopter rescue, he will inform the plane guard vessel and will hover over the position until the vessel arrives. Command of the operation will then be turned over to the commanding officer of the surface vessel.

In the transfer of mail or personnel from ship to helicopter, it is the responsibility of the ship's personnel on deck to see that the hand line or the hoisting cable hook does not foul with any part of the ship.

Where contact cannot be established with the ship during the approach, the ship is alerted for pickup and delivery by a low pass across the forecastle followed by orbiting on the bow until the green flag is displayed. If the ship is not ready for the transfer, or if the landing area or hovering area is not clear, this condition is indicated by displaying a red flag. When the ship is ready to proceed with the transfer, a green flag is displayed. A minimum of 10 knots relative wind must be maintained for hovering, particularly if the weather is warm. Increased velocity of relative wind will always improve helicopter hovering performance.

CONTROL OF RELATIVE WIND

Relative wind conditions should always be taken into account in shipboard operations. In any case, the true wind and the relative wind should be within 90 degrees of each other. Then if a wave-off is necessary, a minimum turn will put the pilot into the true wind. Battleships, cruisers, icebreakers, and other ships with considerable superstructure forward of the launching area should maneuver as necessary to obtain a relative wind from between two points on the bow to broad on the quarter, in order to avoid turbulent winds in the launching area. (See Figure 6-13) When landing or taking off on CV's from a spot forward of the island, it is advisable to avoid relative winds from broad on the starboard beam to dead astern. When the helicopter is spotted aft of the island, relative winds from dead ahead to broad on the starboard beam are to be avoided.

Where high relative winds are present the ship should be maneuvered to reduce the winds to within safe operating limits. On account of their flexibility the main rotor blades may be bent upward to a considerable extent without damage. If strong winds or gusts are present, the blades may cone to a vertical position and be seriously damaged. There is also danger to the helicopter and to personnel. Coning can occur only at low rotor speeds (65 rpm or less), or when the blades are static. The higher the velocity of the wind the greater the danger of coning, whether the rotor is turning or not. Coning, however, is improbable if gusts do not exceed 30 knots. Therefore, the relative wind velocity should be below this figure when either engaging or disengaging the rotor. Also, the relative wind should be forward of the helicopter beam when starting or stopping the main rotor, to prevent any possibility of the blades striking the tail boom.

For the safety of the pilot and the helicopter, commanding officers of ships from which helicopter operations are being conducted are requested to make every effort to obtain satisfactory relative winds for launching, recovery and hovering operations. To minimize gusts and turbulence, all ships, particularly plane guard destroyers, are cautioned to remain clear of the area immediately upwind from a helicopter engaged in hovering to effect the rescue of personnel from the water. Due to the extreme pilot concentration necessary for this maneuver, every precaution should be taken by the plane guard destroyer to avoid approaching too closely and particularly to avoid creating a disturbance of the source of lift by lying-to upwind of the helicopter.

EQUIPMENT FOR SEA RESCUE MISSIONS

When used as a plane guard, the helicopter should carry:

Rescue hoist
Sling
Dye markers
Smoke floats
Extra life jackets
Small life raft
Fifty feet of 21-thread manila line
Blanket or extra clothing
Boltcutters

RESCUE HOIST

The hoist is one of the outstanding features of the helicopter. It permits a hovering pickup to be made and provides a means of getting a survivor into the cabin of the helicopter in a very short space of time. The usual position of the hoist is directly over the rescue hatch in the cargo compartment. A hook, chair, or litter can be attached to the cable. In the Piasecki HUP the hoist is designed to lift 400 pounds and is provided with a 100 foot cable. (See Figure 6-14.) The hoist is driven by a hydraulic pump on the engine, and the pump operates continuously all the time the engine is running. Between pump and motor is a 4-way valve which starts and stops the hoist. The valve is controlled by solenoids operated either by the pilot or by a crew member. The valve can be operated manually, if desired, overriding the solenoid control. A switch on the cyclic stick is provided so that the pilot can control the up and down motion of the hoist without moving his hand from the control stick.

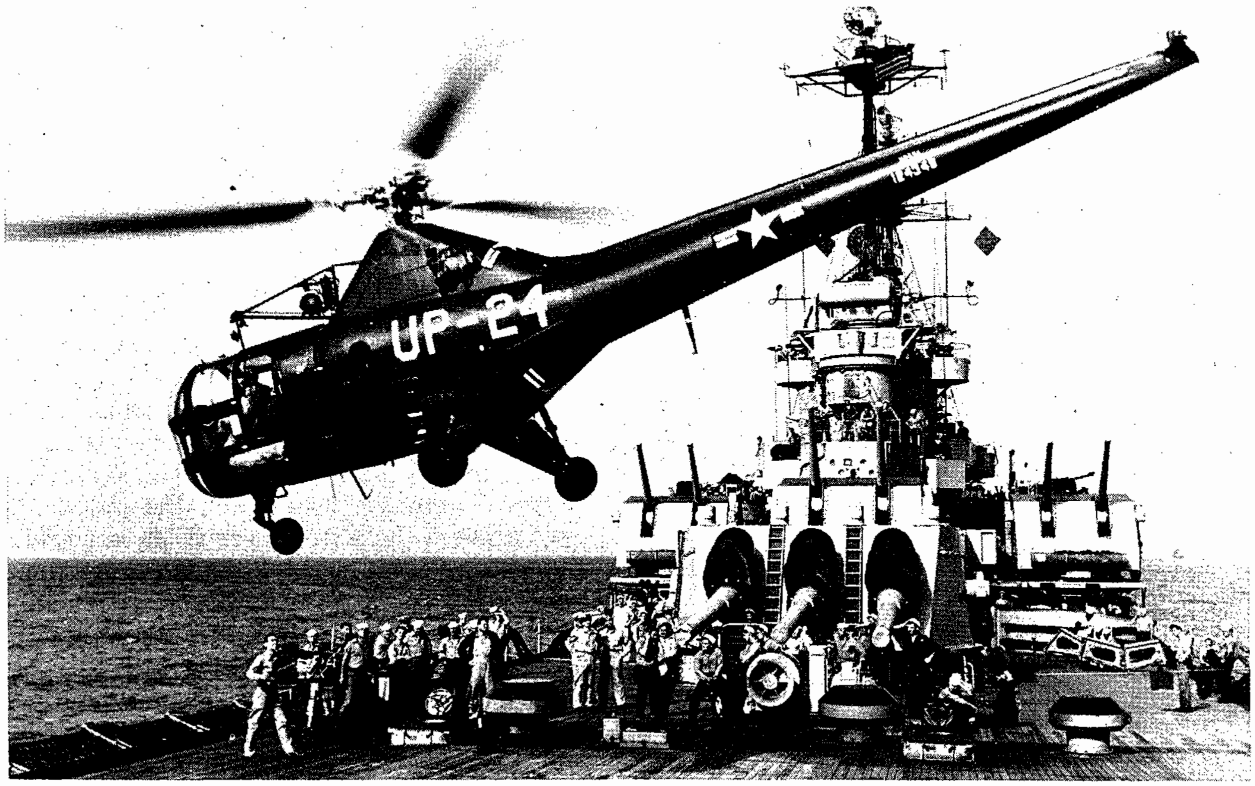


Figure 6-13. Take-off from USS Helena. Note location of wind shown by Fox flags.

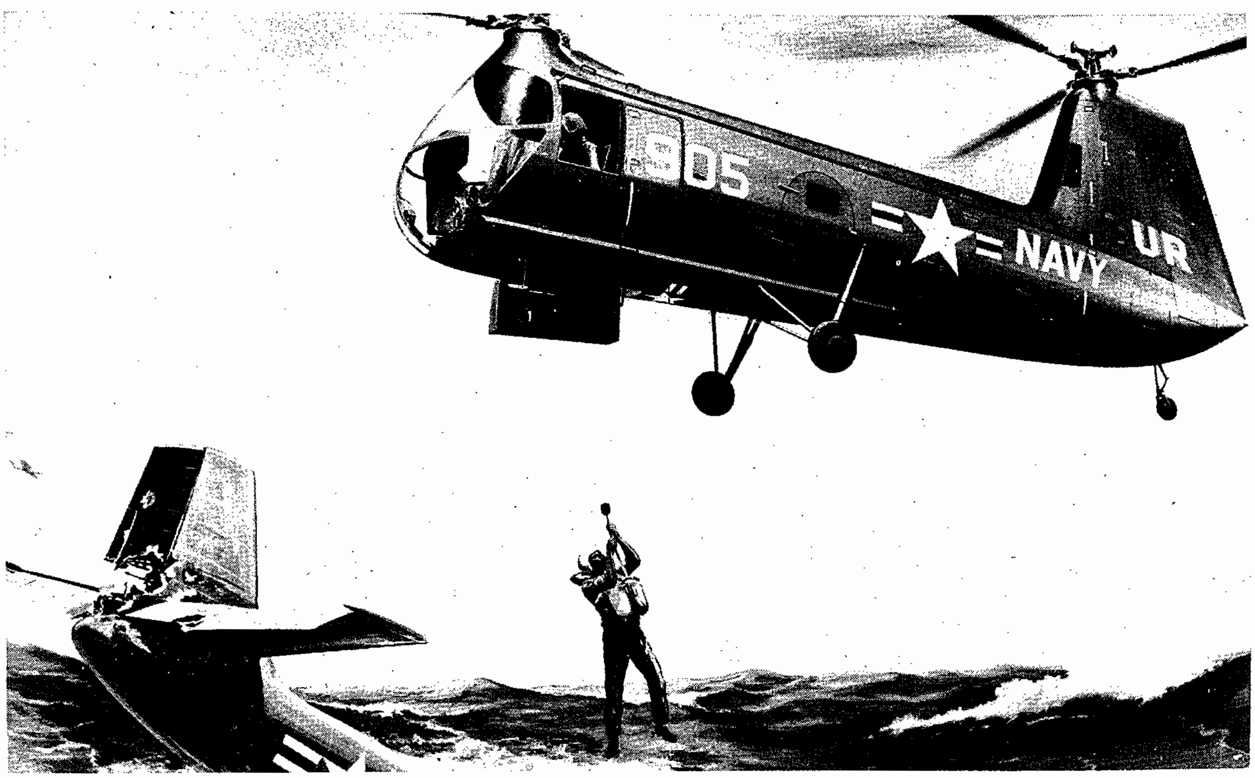


Figure 6-14

RESCUE SLING

Attached to the pickup end of the hoist line is a device known as a sling. Originally, this sling was simply a closed belt, approximately three feet in circumference. It was attached to the end of the hoist cable by a "D" ring and was lowered to the survivor, who slipped it over his head and under his arms. (See Figure 6-15.) Its principal advantage was simplicity, making it possible for the survivor to get into it quickly and easily. Its disadvantage was that, if the survivor should lose consciousness after putting it on, he was likely to slip out while being hoisted.

A newer type of sling has been devised which is still easy to put on, and will not come off while the survivor is being hoisted, even though he may lose consciousness in the meantime. This sling is filled with kapok and is rigid enough to exert pressure against the survivor's body so that he cannot slip through. The kapok sling floats, and is more comfortable to wear than the former belt.

Carrying a small life raft is recommended, so that it may be thrown to survivors if rescue procedures cannot be carried out as planned. As many carrier aircraft are multi-place, the helicopter rescue crew may find more survivors than one helicopter can accommodate. Even though survival gear may have been included in the downed airplane, its use may have been impossible due to the short space of time prior to the sinking of the aircraft. A raft, dropped from the helicopter, will serve as a common buoy, helping to keep the group intact.

OTHER SEA RESCUE EQUIPMENT

Dye markers and smoke floats should be carried to mark the spot where the pilot is down, in the event that the helicopter cannot make an immediate pickup. The extra life jackets may be necessary if the helicopter itself is forced into the water, and the manila line may prove to be a life saver in an emergency. Blankets or extra clothing for the protection of a downed pilot taken from the water should be carried whenever possible. If a line ever fouls, it should be cut immediately with the bolt-cutters. In case of failure of the helicopter hoist, a sling may be bent on the end of the rescue line, and the survivor should be picked up and dangled until it is possible to land him ashore or on the deck of a vessel.

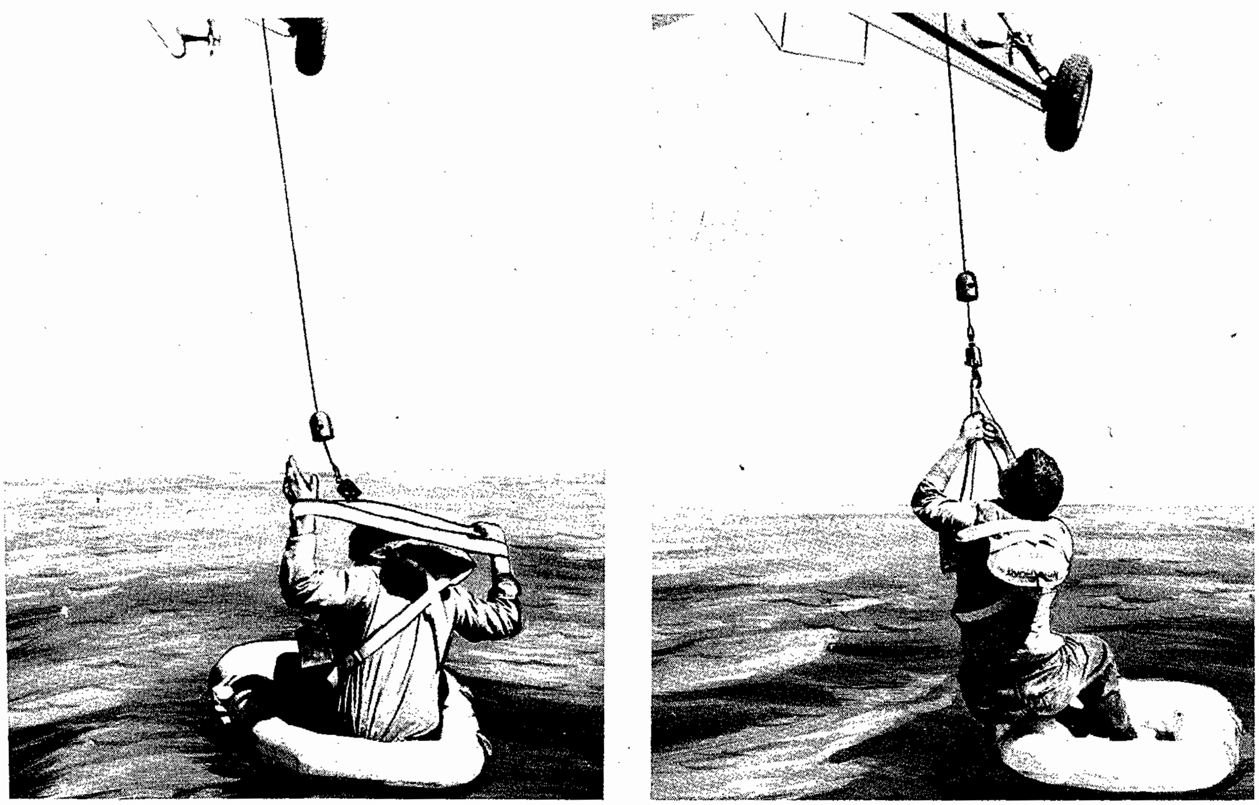


Figure 6-15

Figure 6-16

SEA RESCUE PRECAUTIONS

Approach to the water should always be made from a downwind position. Altitude should be sufficient so that the subject is kept in sight at all times. Hovering altitude should assure clearance of swells. (See Figure 6-16.) It is essential that ships in the vicinity avoid crossing or lying-to close upwind from a hovering helicopter. Otherwise, turbulence or blanketing of the wind may present a real danger.

In practically all cases the rescue mission is begun with the belief that the survivor will be able to help himself. If he is not able to help himself, the helicopter crew must consider sending the helicopter crewman into the water to make the rescue.

The absence of an extra crewman in the helicopter handicaps the pilot. The pilot is able to control the hoist but also has the problem of bringing the injured man into the cabin without the help of the crewman. An answer to the problem of not having an extra crewman is an ingenious friction hook that has been developed. (See Figure 6-17.) This hook can be quickly attached to the hoisting cable at any point, and permits the pilot to raise the crewman into the cabin before hoisting of the survivor is begun. This permits the rescue to be completed in the normal manner, with full cooperation of the crewman.

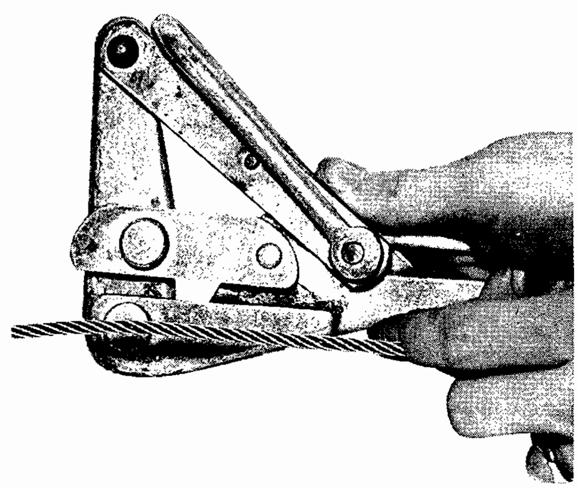


Figure 6-17

Figure 6-18

If a survivor in the water appears to be conscious and not severely injured, and the water is fairly calm, he may be rescued by the weighted web rescue sling. If the water is rough, it may be advisable to use the kapok-filled buoyant sling. This is like a large egg-shaped life ring, has good floating characteristics, and can be readily seen by a man in rough water. (See Figure 6-18.) The sling should be placed as near to the survivor as possible. To prevent possible ignition of fuel on the water from a crash due to static discharge of the sling cable, the sling should touch the water first in an area away from the crash. If the survivor is unconscious or injured to such an extent that he is unable to attach himself to the rescue device, an immobile rescue should be attempted, following this procedure:

(1) The crewman should be sent to the victim's assistance at the moment it becomes apparent that the man is immobile.

(2) The crewman must be attached to the hoist cable all the time he is out of the helicopter.

(3) The crewman is returned to the helicopter *before* hoisting the immobile man.

The special crewman's harness should be worn by the crewman at all times when airborne and when the possibility of performing a rescue exists. This harness is worn over the flight gear but under the life jacket. (See Figure 6-19.)

Figure 6-19

As the helicopter approaches the man to be rescued, the hoist sling may be partially lowered to expedite the rescue in the event the man is mobile. If he should prove to be immobile, the crewman fastens himself to the hoist cable by means of the cable grip and his harness, and is lowered by the pilot for assistance to the man in the water. The pilot should maintain a position slightly downwind of the man, and *as low as possible.* He then reels out cable equal to about three times his altitude. The crewman inflates the injured man's life jacket, releases dye marker, and puts the man in the rescue sling. He then threads about 30 feet of cable through the grip (the 30-foot point may be marked on the cable with yellow paint) and signals his readiness to the pilot who returns him to the helicopter with the hoist. The crewman then detaches the cable grip and completes the rescue.

It is important to see that the cable passes straight through the grip jaws. The pilot should make it a point to hover as low as possible; five feet is not too low for this type of rescue. The pilot should also exercise care to prevent reeling out the entire cable length, which might result in rewinding the cable in the opposite direction. It is suggested that the last 20 feet of the cable be painted solid yellow.

PLANNING A SEA SEARCH

On receipt of a distress report, personnel concerned with rescue operations are required to obtain all information available for planning the course of action to be taken. If a search is planned, the following points are among those which should be taken into consideration:

(1) Probable position of accident

(2) Is estimated position within range of helicopter operation?

(3) Did personnel parachute, or was craft ditched?

(4) How much time elapsed since accident?

(5) Are personnel in life raft?

(6) Strength and position of wind

(7) Weather conditions

For fuller detail than can be given here, consult publications dealing with the effect of wind and current on those adrift at sea. H.O. 235, "Methods for Locating Survivors Adrift at Sea on Rubber Rafts," contains specific information useful to Search and Rescue helicopter crews.

SEARCH ALTITUDES

Search altitudes are based on the limit of practical visibility and sighting distance of survivors and their equipment.

Life rafts are not visible from high altitudes, but dye markers and smoke are visible from greater distances and at higher altitudes. A survivor swimming and not using dye marker will be visible for not more than one-quarter mile, but if he is in a raft and using signaling equipment he may be seen for more than five miles.

Depending upon information concerning equipment being used by a survivor, the following search altitudes are recommended (See Figure 6-20):

(1) Below 500 ft. if survivors are without raft or dye marker.

(2) 500 to 1000 ft. if survivors are in a raft but without dye marker or signaling equipment.

(3) 1000 to 2000 ft. if survivors have dye marker.

(4) 2500 to 5000 ft. if survivors have signaling equipment.

These figures must always be limited to the range of effective surface visibility. The limit of visibility for an airplane searching at an altitude of 500 ft. should be assumed to be not more than one mile unless there is some likelihood that the survivor may be using either dye marker or signaling devices.

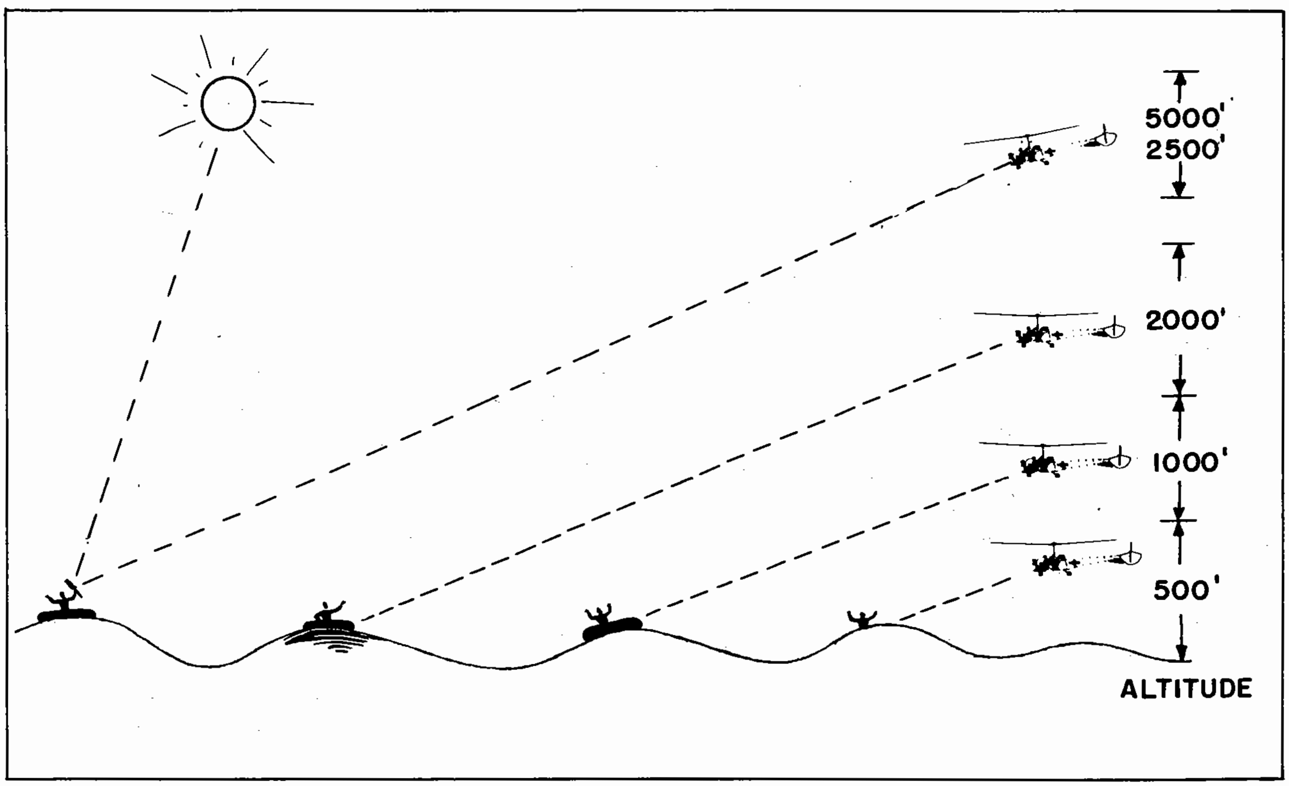


Figure 6-20

SEARCH PATTERNS

The search pattern is a methodical and logical means of making a thorough search over a definite area. Patterns most applicable to helicopter search are:

(1) Expanding square search
(2) Creeping line search

(1) The expanding square search, (See Figure 6-21) begins at a point near which the survivor is assumed to be and proceeds in a square pattern widening in proportion to distance of visibility. The square search should start either upwind or downwind. Considerable care must be used in navigation of this pattern, especially if only one helicopter is available for the search.

(2) The creeping line search, (See Figure 6-22) is more effective than the expanding square search when survivors are reported as being somewhere between two known points. This search pattern is particularly adapted to use in combination with a ship's search. The ship proceeds on the track where the crash is presumed to have occurred. The helicopter then searches on either side of the track with a speed of advance equal to that of the ship. Do not overestimate range of visibility.

COMMUNICATIONS IN SEA SEARCH

Adequate communications facilities are of the utmost importance in making a sea search. From the original call of distress to the completion of the rescue, the entire success of the operation will depend on information correctly and quickly passed along. Standard frequencies are maintained and guarded by rescue agencies, and serve as a common link between rescue craft and the rescue center.

SEARCH AND RESCUE ASHORE

Another important use of the helicopter is for search and rescue work in enemy territory. Where helicopter units are based ashore and are called upon for search and rescue flights, it is suggested that they make it a standard practice to carry adequate rescue gear. The following equipment is suggested if space is available:

(1) Stokes litter
(2) Hand-held walkie-talking transceiver
(3) Panel signal gauge
(4) Hoisting sling
(5) First-aid kit and check-off list
(6) Two blankets
(7) Crash kit (boltcutters, hack saw, axe, etc.)
(8) Rescue kit (area, aerial and road maps)

This equipment totals approximately 100 pounds.

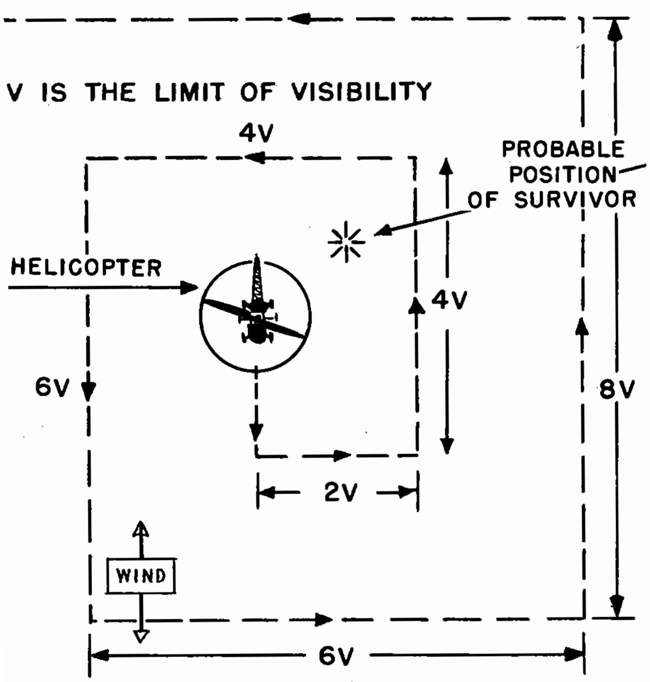


Figure 6-21

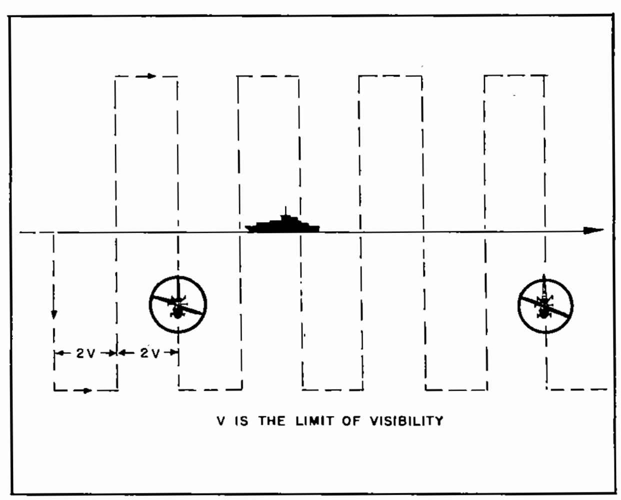


Figure 6-22

LAND RESCUE PROCEDURE

Search and rescue work with the helicopter begins when positive information has been provided by RESCAP that the downed pilot is alive, that he has been positively identified, and that his precise location is known. It may be necessary to signal the downed pilot to a more suitable spot for rescue, indicating the direction in which he is to proceed.

The helicopter making a rescue over enemy territory should have at least two VF's for escort. As high winds in mountainous terrain may result in low ground speeds, the flight may be more than ordinarily hazardous. For this reason the VF's should follow a rolling orbit around the helicopter. They must be alert for ground fire at all times and available at the helicopter pilot's call when he spots ground fire. It is the responsibility of the escorting planes to navigate the helicopter to the downed pilot.

Under no circumstances should the helicopter be used for searching. The RESCAP must find the pilot and ascertain his position, relaying this information to the helicopter pilot.

When the helicopter is approximately a quarter mile from the pilot's position, the RESCAP indicates the position of the downed pilot by diving at him, broadcasting a "Mark" when directly over him, and then pulling up. The dive is made into the surface wind to indicate its direction to the helicopter pilot.

On sighting the helicopter the downed pilot should use his smoke signal to indicate his exact position and wind direction in the area.

The most critical phases of the rescue are the helicopter's approach, landing and take-off. At these times the helicopter is especially vulnerable to enemy action. The enemy is familiar with rescue procedures, and has been known to lay traps for rescue helicopters.

During the pick-up phase of the rescue, the VF escort and RESCAP are responsible for making rapid and repeated passes at the area around the pilot and helicopter. At any sign of enemy activity, and, if requested by the helicopter pilot, they should strafe this area. The attacks should continue until the helicopter is safely out of the area.

In all the cases the helicopter pilot should come down as quickly as possible and make the pickup with a minimum delay. If the pilot to be rescued is unwounded, the recommended procedure is to hover above him, lower a weighted line and pull him up with a winch, getting back as quickly as possible. If seriously injured or unconscious, it will be necessary to put the helicopter down and get the man aboard with a minimum of delay. (See Figure 6-23.) In this work it is not always possible to find a clear and level spot for landing. The best available location may be a hillside or a rocky hilltop.

Figure 6-23

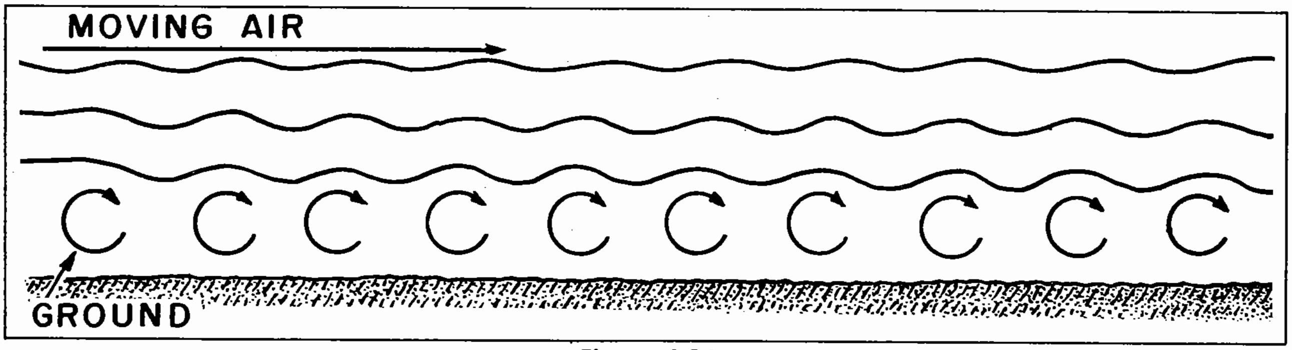


Figure 6-24

AIR CURRENTS IN LAND OPERATION

Due to the fact that he is operating a craft which is likely to be flying at low speeds and operating rather close to the ground, the helicopter pilot should have a basic knowledge of the behavior of airflow over level ground, and around hills, buildings, and other obstructions. The main source of air turbulence is friction between the earth and the moving current of air. There is always a degree of roughness present, and this roughness produces eddies or whirls of air which are forced up to higher levels. The turbulence consists of a succession of gusts and lulls of irregular periods, lasting only a few seconds each. The strength of the gusts is roughly porportional to the irregularity of the ground surface and the velocity of the wind; the effect increases as the stability of the air decreases.

Turbulence caused by friction along a rough surface is known as "mechanical turbulence." This disturbance is generally limited to a layer of air about 3000 feet thick.

A common source of turbulence is the irregular distribution of heat due to varying character of the heat absorbing surface of the earth. Warmer masses of air will rise and colder masses will sink, producing irregular and unpredictable air movements. This condition is called "thermal turbulence."

TURBULENCE FROM OBSTACLES

Figure 6-24 shows the character of turbulence that results from friction of moving air over level ground. And as long as the ground is level with no obstructions, the pattern continues to be much the same as shown.

But when such an air current meets an obstacle, the condition is greatly changed. The resulting turbulence depends on the dimensions and shape of the obstacle, the speed of the air current, and the stability of the air. Figure 6-25 shows the type of eddies formed when an air current passes an obstacle of rectangular cross section. Note that there is a stationary eddy on the windward side. On the flat top of the obstacle there is a development of small irregular traveling eddies that re-form continuously along the windward edge. On the lee side, eddies develop and travel downwind. The lee eddy is usually stationary during development, but when it has attained a certain intensity it leaves the obstacle and travels downwind, gradually dissipating.

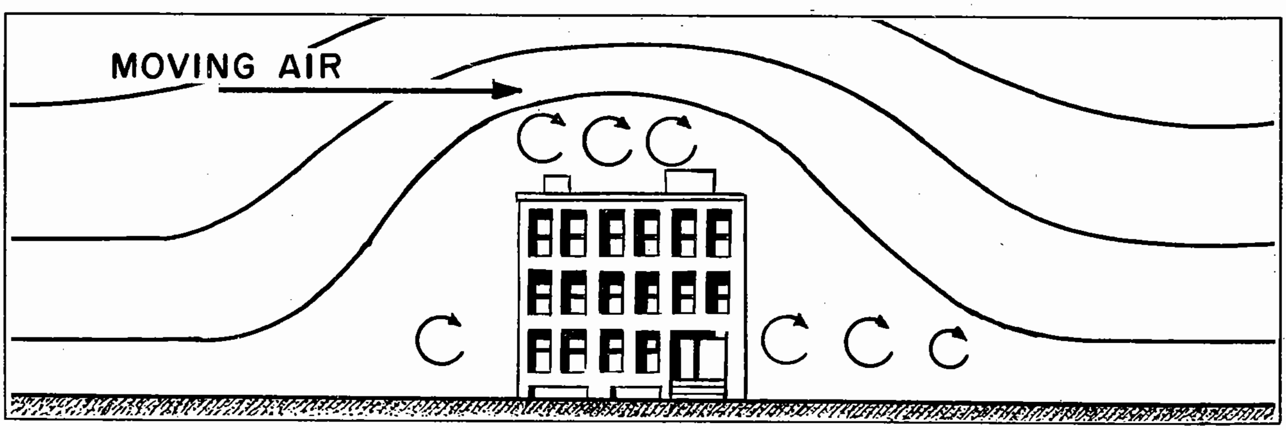


Figure 6-25

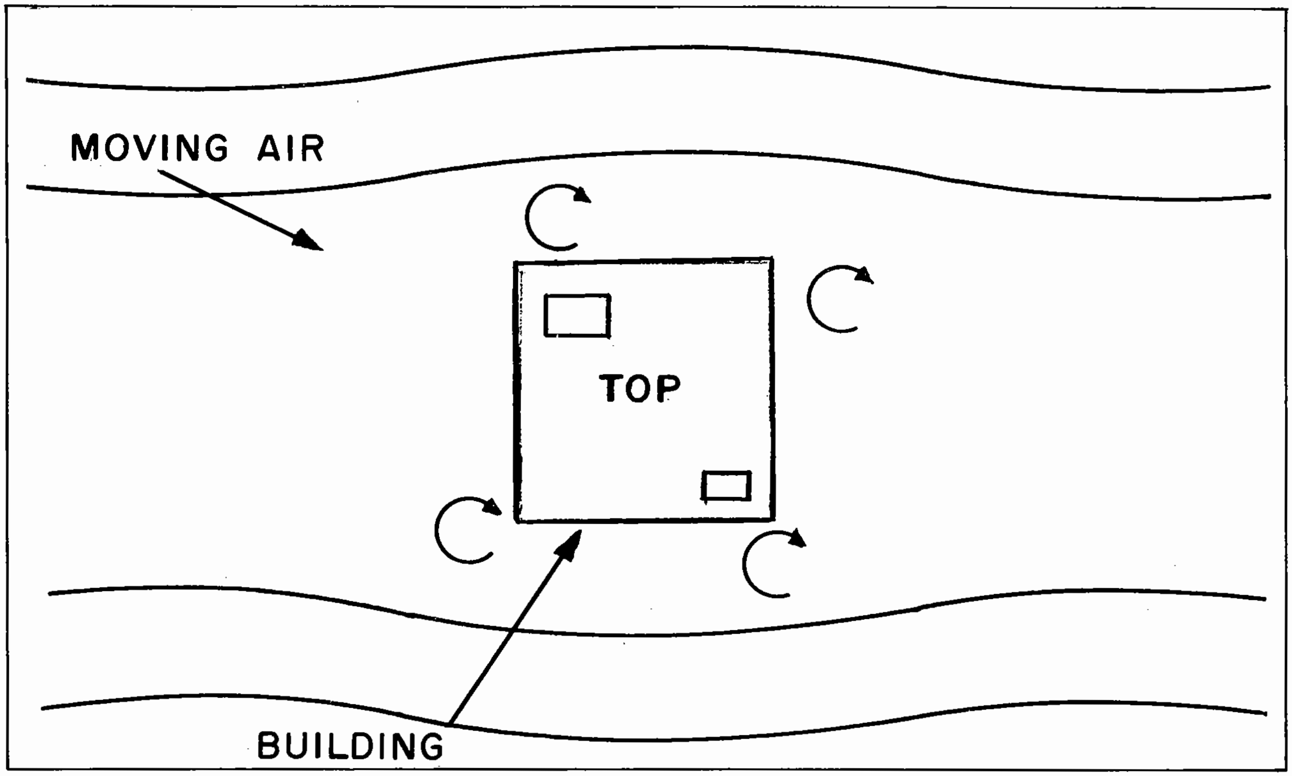


Figure 6-26

If the horizontal dimensions of the obstacle are small, the air current has a tendency to stream around it, and eddies with vertical axes form at the edges as shown in Figure 6-26.

Whether the air will stream around the obstacle or across it depends mainly on the length of the obstacle and the stability of the air. Turbulence caused by large buildings, such as factory and office buildings, hangars and the like is usually a combination of horizontal and vertical eddies.

Figure 6-27 shows the eddies that develop when a current of air passes over a small ridge. If the windward side is sloping and not too steep, the stationary eddy disappears and the only eddies present are those caused by the roughness of the surface. On the lee side, as shown, there are usually larger and stronger eddies that form on the slope and travel downwind. If the wind is strong and the air unstable, it may be dangerous to attempt a landing on the lee side close to the ridge.

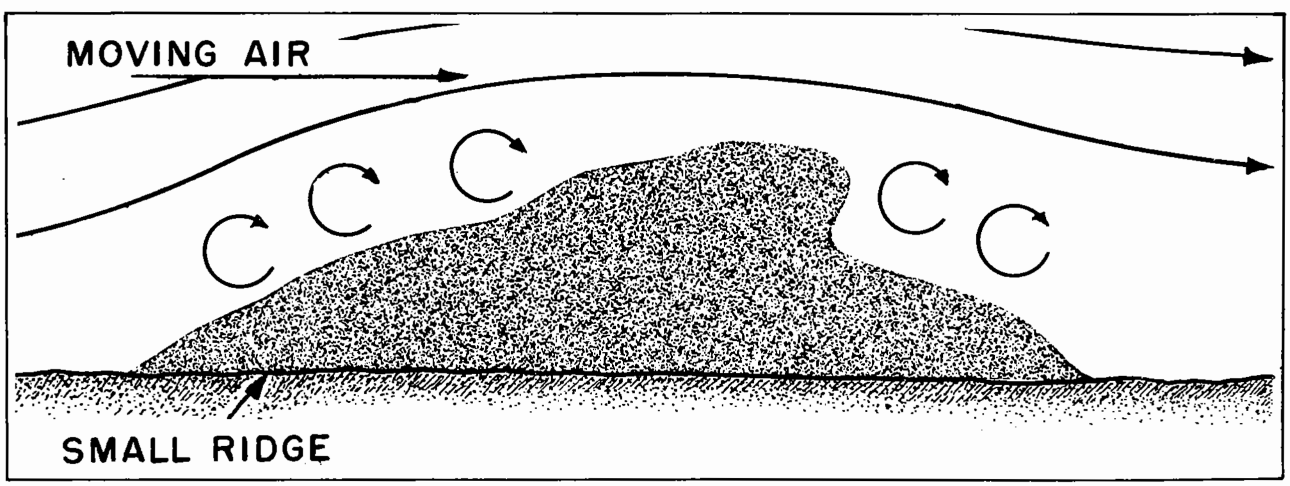


Figure 6-27

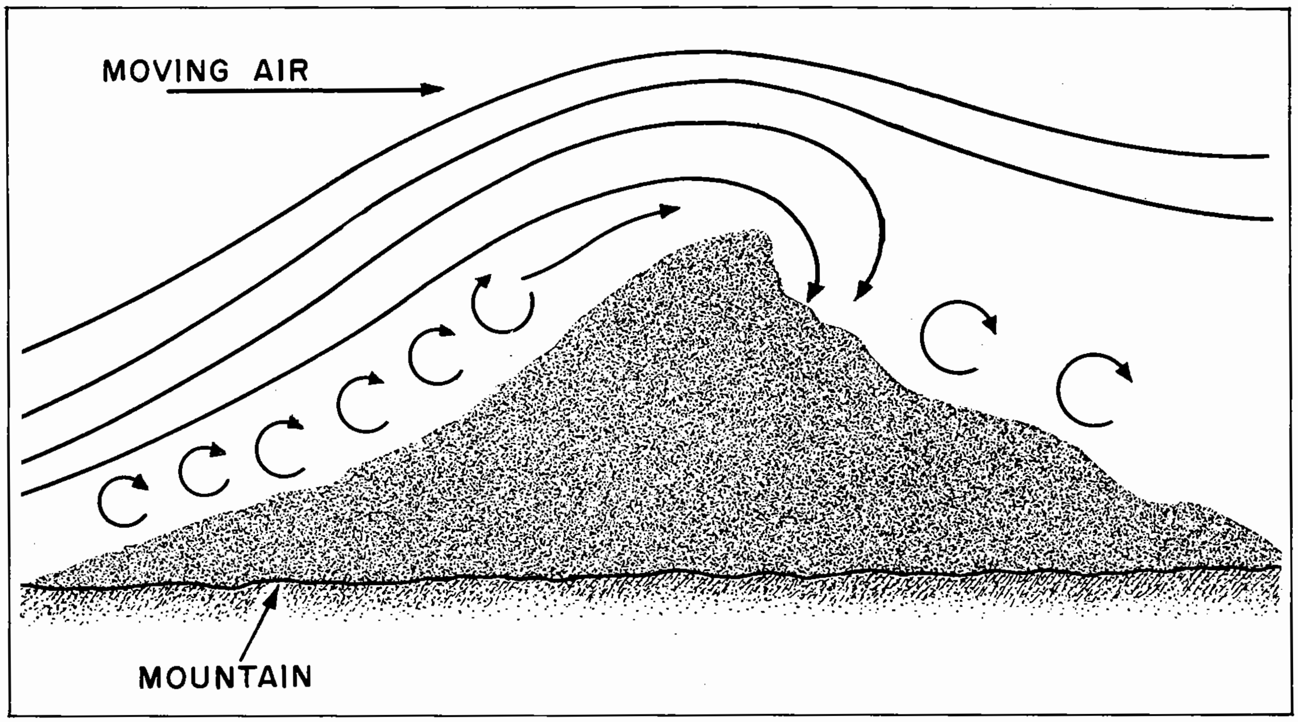


Figure 6-28

TURBULENCE FROM MOUNTAINS

As a general thing the influence of mountain ranges on air currents is the same as that already discussed. But due to the increased altitude and the greater roughness the turbulence is much more serious.

Figure 6-28 shows a cross section through a mountain range. Note especially the well-developed eddy on the lee side.

On the windward side the eddies may be either stationary or progressive, according to the slope and character of the incline.

While the eddies on the windward side are disturbing, the real danger is in those to leeward. If a pilot is flying against the wind it is necessary to keep sufficient altitude to prevent losing control of the helicopter and being forced down into the mountainside.

A pilot flying across the range with the wind will generally gain altitude as he approaches, but if there are cliffs or steep portions, there may be strong enough stationary eddies to cause trouble. The helicopter pilot must consider carefully the effect of ascending and descending air currents when carrying a heavy load and making turns or banks.

As the eddies around mountain ranges reach up to a considerable altitude, there is an intense mixing of air, which with the right distribution of humidity and temperature will cause the formation of clouds around and above the mountain range. A general layer of stratus clouds will be lower on the mountainsides than in free air, and often it appears only on the mountainside.

At a considerable altitude above the mountain range the currents are horizontal, and move at an accelerated speed. The general flow has an upward component on the windward side, and a downward component on the leeward side. This large scale influence on the main current is noticeable at great distances.

OPERATING IN ROUGH TERRAIN

In conducting operations in rough terrain, eternal watchfulness is necessary. (See Figure 6-29.) The pilot must be sure that the landing area he selects is large enough to make a landing without danger of hitting a tree, rock or other object with either the main rotor or the tail rotor. Before attempting the landing he should make certain that WHEEL BRAKES are firmly set. The nose wheel should also be locked if the helicopter has a tricycle landing gear and is equipped with a nose-wheel lock.

If the landing is made on a slope, the locked nose wheel will prevent the nose from swinging to the low side. If the slope is steep the landing

Figure 6-29

should be made with the nose uphill regardless of the direction of the wind. In a correct landing the nose wheel will make contact with the ground first and the rear wheels will follow as rotor blade pitch is decreased. The nose is held in position on the hillside by forward cyclic stick pressure. Collective pitch is then decreased.

Where the slope is too steep for a normal landing, and the wind is such that it is impossible to land with the nose wheel held on the slope, the pilot should try to find a more suitable landing area.

CAUTION

NEVER TRY TO LAND A *SINGLE ROTOR* HELICOPTER WITH NOSE DOWNHILL ON A STEEP SLOPE, AS THE TAIL ROTOR WOULD BE THE FIRST PART TO MAKE CONTACT WITH THE GROUND AND WOULD BE DAMAGED OR DESTROYED.

Tandem rotor helicopters may be landed with one side toward the hill instead of head on, if desirable, to prevent striking the ground with the forward rotor.

A helicopter pilot attempting a passenger pickup in rough terrain, may find it impossible to make a complete three or four wheel landing. Where a landing cannot be made and it is impractical to move to another spot the helicopter can be hovered with one or two wheels on the ground long enough for the passenger to get in. Due to the critical position of the helicopter during such an operation, the pilot should be sure about weight and balance before the pickup is attempted.

In a combat area it is to the advantage of all concerned to get into the landing spot, such as a front-line aid station, as quickly as possible and to get out with a minimum of delay. Crew members should be briefed before take-off so that operations are expedited as much as possible. (See Figure 6-30.)

Figure 6-30

PILOT MAY NEED TO DOUBLE AS MECHANIC

In the days when road shows used to travel from town to town and advertise their productions by a big parade, it was common for show owners to advertise for actors who could "double in brass," meaning tnat they had to play an instrument in the band in addition to taking a part in the stage performance. In the same way it is often necessary for a pilot in a combat area to "double" as a mechanic and service his own helicopter for perhaps a couple of days, or at least until he gets out of trouble.

Because of this it is essential that the pilot should know how to check not only the amount of fuel and lubricant, but condition of bearings, efficiency of ignition, condition and operation of rotor blades, functioning of controls and whatever else may be necessary. He should also know to what extent Jeep fuel is usable, whether it is safe for him to fly if he has less than the normal amount of oil, and just how far he can, with reasonable safety, depart from what is set down as standard practice.

Another point that should become second nature to the helicopter pilot is to gauge his fuel supply by hours. That is, he should know approximately the time in hours and minutes that he can expect to fly with the amount of fuel in the tank. With the helicopter, knowledge of the time in hours means a great deal more than the distance in miles. The greatest fuel consumption occurs in hovering when airspeed is down to zero.

A thorough review of the Ground Force chain of command is important to the helicopter pilot from a standpoint of safety. With sound knowledge of military organization he will be able to locate without delay the command post at which he is instructed to report.

Also, a review of map reading is important on behalf of his own security. He should be particularly familiar with large scale maps 1 to 50,000 scale. The helicopter pilot should be able to fly a distance of 40 miles or more over unfamiliar territory and land on exactly the spot indicated by his large scale map.

WHAT THE DOWNED PILOT SHOULD DO

The downed pilot waiting for rescue by helicopter should first seek a position in an uninhabited area, preferably on high ground at some distance from the downed airplane. It should be a spot where he can show himself to the RESCAP and provide positive identification. Use of a signaling device is not enough.

Having selected his rescue spot he should remain there so that RESCAP can know his exact location and direct SAR aircraft directly to his position. He should be alert for air drop of survival equipment from RESCAP in case rescue has to be delayed until the following morning. Smoke or tracer signals should not be used until the rescue plane is in sight and is prepared to make the pickup.

In picking an area for cover, the pilot should attempt to be near a clearing at least 100 feet square. The helicopter coming to make the pickup may not be equipped with cable lifts, in which case it must be able to land and take off. Any marked degree of turbulence in the area covered by the rotor disc is a definite hazard to flight . . . particularly as the forward airspeed of the helicopter approaches zero.

GUNFIRE SPOTTING

The use of the helicopter as an observation platform for the control of Navy or artillery gunfire is of growing importance. (See Figure 6-31.) The superiority of the helicopter over the conventional airplane for this type of work makes gunfire spotting an important part of the training of the helicopter pilot.

It is not intended that the pilot should be a fully qualified spotter. But he should be acquainted with the terms and procedure used if he should be called upon to spot gunfire, or should find himself in a situation to request gunfire support on a target confronting him.

The following paragraphs cover the procedure for conduct of shore bombardment of air-controlled artillery fire, and give the most generally used reports and commands:

GUNFIRE SPOTTING PROCEDURE

General procedure for conduct of shore bombardment.

(1) A uniform sequence shall be used for the transmission of the observer's "Initial Fire Request" and the subsequent spotting corrections and appropriate reports between ship or battery and observer. Each element of fire command remains in effect until cancelled.

(2) Any air observer who is familiar with the basic principles of bombardment, and who has communication and co-ordination with the

landing force and ship, may request Naval or artillery fire on a target confronting him.

INITIAL GUNFIRE REQUEST

After communication identification request, air observers for Naval gunfire will normally include the following information in the sequence indicated.

(1) Warning order
(2) Location of target
(3) Nature of target
(4) Classification of fire
(5) Type of adjustment
(6) Ammunition
(7) Fuze
(8) Control

A description of each step follows:

(1) The warning order is given to alert ship that a request for fire on a target will follow.

(2) Location of target may be given in any manner clearly understandable to observer and ship.

a. By giving the ordinates of the target area, using world grid, referring to pertinent map, photomap or photograph.

b. By indicating a prominent or known geographical point or position, and giving the corrections from the reference point, as Right (Left) so many yards in direction. Up (Down) so many yards in altitude and Add (Drop) so many yards in range.

(3) Nature of Target consists of a description of the enemy installation, personnel, equipment or observed activity. Should be brief but informative enough to permit evaluation of the target by the firing ship.

(4) Classification of Fire indicates proximity of the target to friendly troops.

a. Close (within 600 yards)

b. Deep (over 600 yards)

(5) Type of Adjustment. Adjustment means to fire one or more guns to center main point of impact on target. The observer requests the number of guns to be used for adjustment.

(6) Ammunition. The observer will designate any type of ammunition to be fired at the target—High Capacity, Smoke, Armor-Piercing, Illuminating, or other type desired. Unless otherwise indicated, the ship will use antiaircraft projectiles with full charge for 6″ and above.

(7) Fuze. Unless otherwise specified, ships will use the point detonating fuze set on "super quick," or in 5″ batteries, the mechanical time fuze is set on "safe."

a. "Fuze Quick" indicates that detonation without penetration is desired.

b. "Fuze Delay" indicates that some penetration before detonation is desired. If maximum penetration is wanted, substitution of armor-piercing, common or high-capacity projectiles with steel nose plugs should be required.

c. "Fuze VT" indicates that air bursts are desired.

d. "Fuze Time" indicates that air bursts

Figure 6-31

mum penetration is wanted, substitution of armor-piercing, common or high-capacity projectiles with steel nose plugs should be required.

c. "Fuze VT" indicates that air bursts are desired.

d. "Fuze Time" indicates that air bursts are desired using mechanical time fuzes.

(8) Control will include one or more of the following:

a. "Will adjust." Indicates spotting is necessary and when the observer can and will spot after each salvo. Ship commences fire when ready.

b. "At my command—will adjust." Indicates spotting will be difficult or intermittent. The observer transmits fire after receipt of "Ready" from firing ship when he is in a position to observe.

c. "At my command" may be inserted in subsequent commands when observation becomes difficult or intermittent during the adjustment.

d. "Fire for Effect" is started when the mean point of impact is on the target or when the observer is positive that effective fire will result after the last correction is made.

e. "Cannot Observe" indicates that the observer will be unable to spot the fire; that he believes the target exists and is of sufficient importance to fire without adjustments.

REPORTS TO SPOTTING OBSERVER

(1) Ready. Ship is ready to fire.

(2) Time of flight is always transmitted to the observer by ship before first "On The Way" of each mission.

(3) On The Way. Ship has fired.

(4) Splash. 5 seconds prior to impact.

a. Subsequent Correction. Transmitted in following order:

1. Deflection spot (in yards).
2. Altitude (impact burst) spot or height of burst spot (in yards).
3. Range spot (in yards).

b. When no spots or corrections are necessary, the observer will transmit "No Change" signifying:

1. His observation.
2. End of transmission.
3. For ship to keep firing, using same setup.

c. When the observer sends an erroneous spot, he rectifies the error by sending complete and correct data preceded by "Correction."

MISCELLANEOUS COMMANDS—USED WHEN APPROPRIATE

(1) Lost. If rounds were not seen or observer was not in position to observe.

(2) Check Fire. Used to stop all firing on target.

(3) Cease Firing. Used to stop all firing on target.

(4) Commence Firing. To resume firing.

(5) End of Mission. To indicate termination of fire mission.

If the ship does not give gun target line and maximum ordinate, the air observer should request this information. Gun target line is an imaginary line from gun to target, and it must be known before a correct right or left spot correction can be given.

Maximum Ordinate is the altitude a projectile will reach during its travel from the gun to the point of impact. This altitude may have a direct effect on the flight pattern used in directing the gunfire.

When possible, the fire should be directed parallel to friendly lines. It is easily possible to have a large range dispersion, while the deflection dispersion is usually small.

MISCELLANEOUS USES OF THE HELICOPTER

The characteristics of the helicopter make it, in many cases, an excellent photographic plane. (See Figure 6-32.) It is particularly adapted to taking moving pictures. There are, however, certain limits. As it is impossible for the pilot to maintain accurate headings, air speeds, and altitudes, it is not satisfactory for mosaic mapping. Because of the inherent vibration of the helicopter, shutter speeds of less than 1/150 second are not practical.

Generally speaking, all helicopters are good radar reflectors and are satisfactory for radar calibration exercises. Since hovering becomes increasingly difficult as altitude increases, hovering flight at altitude should not be attempted.

Other miscellaneous uses include wire laying, use as flying cranes, liaison work, and assault landings and transport work.

As a matter of fact, experience in Korea has transferred the use of helicopters in assault

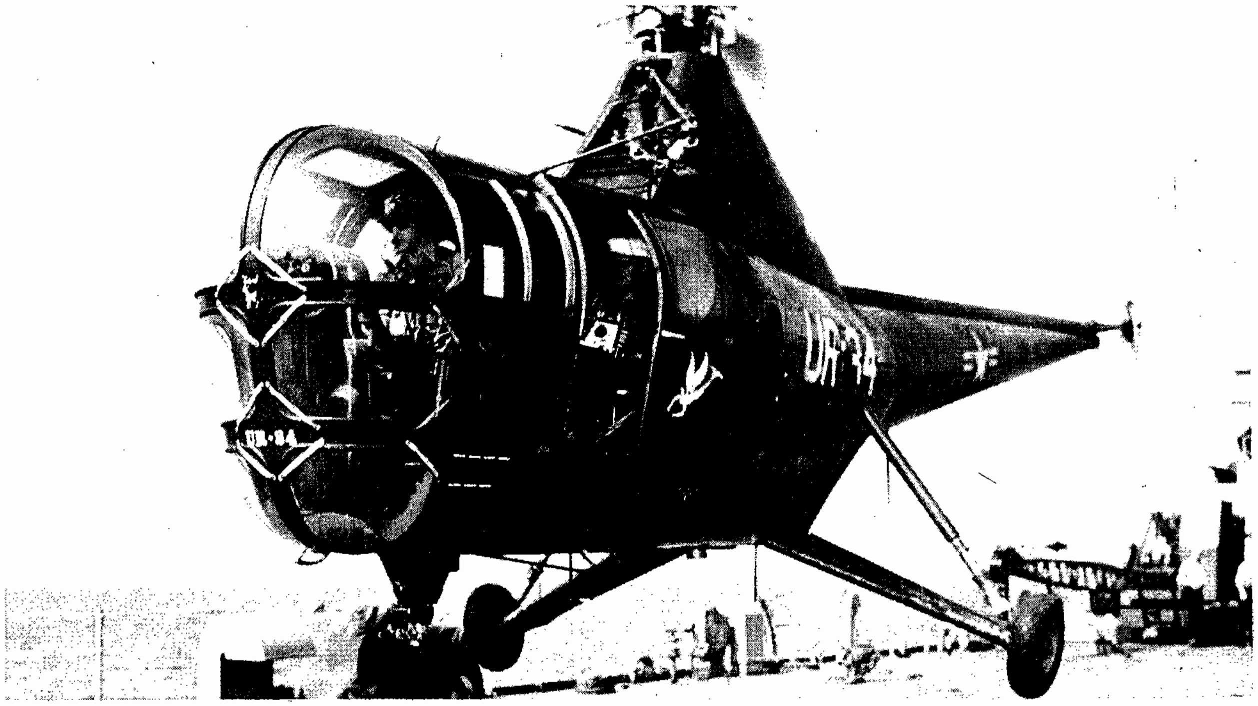


Figure 6-32

landings and transport work from the category of miscellaneous to a major use.

Time will undoubtedly change many of the techniques now followed. The ability to fly helicopters in marginal weather will make assault landings more effective.

At present, operations taking advantage of hills, trees and other natural cover make helicopters much less vulnerable to attack than might have been expected. Because the men can be moved quickly up hills and over rugged countryside with full equipment, the attack can be launched by men physically rested. A limited number of helicopters shuttling back and forth can transport the same number of men in the same time as a much larger number of ground vehicles. This is also true in landings from ships where the greater speed of the helicopter over landing craft helps to equalize the smaller capacity of the airborne vehicle.

FLIGHT REGULATIONS

It is assumed that every helicopter flight student is familiar with flight regulations applying to conventional airplanes. However, there are certain additional regulations that apply specifically to the helicopter. Some of the most important of these regulations follow:

CONVERGING FLIGHT

The helicopter pilot should keep in mind the general rule that when two helicopters or a helicopter and a conventional airplane are flown on converging paths, the craft approaching from the right has the right of way. These craft are in the same category. That is, they are both power driven and are considered to be equally maneuverable. Where the helicopter is approaching an aircraft of a different category, it follows the rule that the less maneuverable craft always has the right of way. Since airships, gliders, and balloons are less maneuverable than the helicopter, they have the right of way under all conditions. As aircraft towing other aircraft are less maneuverable than they would otherwise be, they, too, must be given the right of way by the helicopter pilot.

FLIGHT OVER CONGESTED AREAS

Over congested areas of cities, towns, and settlements, and over open air assemblies, the conventional airplane is required to maintain an altitude of 1000 feet.

The pilot is considered as being over such a point if it lies within a radius of 2000 feet from the plane. Helicopters may be flown over congested areas at less than this minimum altitude if the flight can be conducted without danger to persons and property.

FLIGHT OVER AREAS NOT CONGESTED

The helicopter may be flown at altitudes less than 500 feet over persons, vessels, vehicles or structures in non-congested areas, provided that the flight can be made without danger to persons or property. The operation of the helicopter below the usual minimum altitudes is subject to the caution and good judgment of the pilot.

FLIGHT VISIBILITY

When outside of control zones and control areas, the conventional airplane should be operated only when the flight visibility is one mile or more. However, under certain conditions, helicopters may be flown at or below 700 feet above the surface when flight visibility is less than a mile. Operating at this low altitude, the helicopter should be flown at a reduced speed which will permit the pilot to see other air traffic or obstructions in time to avoid collision.

VISUAL REFERENCE TO GROUND

Due to their peculiar aerodynamic characteristics and the lack of flight instruments meeting the requirements of this type of aircraft, present fleet helicopters should not be operated unless visual reference with the ground can be maintained. Because of the conditions mentioned, the following instrument flight restrictions are imposed:

(1) Helicopters are not to be operated where visibility is less than one mile and the ceiling is less than 500 ft., except under *emergency conditions*. Visual reference to the ground should be maintained.

(2) Since night operations may require unplanned instrument flight even in CAVU weather, present fleet helicopters shall not be operated at night except in emergencies, and then only when equipped with cockpit and landing lights.

In addition to present instrumentation, the following items are considered a minimum necessity to permit instrument flight for limited periods, and at speeds of more than 40 knots.

(1) Gyro horizon
(2) Directional gyro
(3) Turn and bank indicator
(4) Landing lights
(5) Cockpit lighting system

BAILOUTS

Bailouts can be made successfully from the helicopter under most conditions. (See Figure 6-34.) There is no noticeable downwash effect

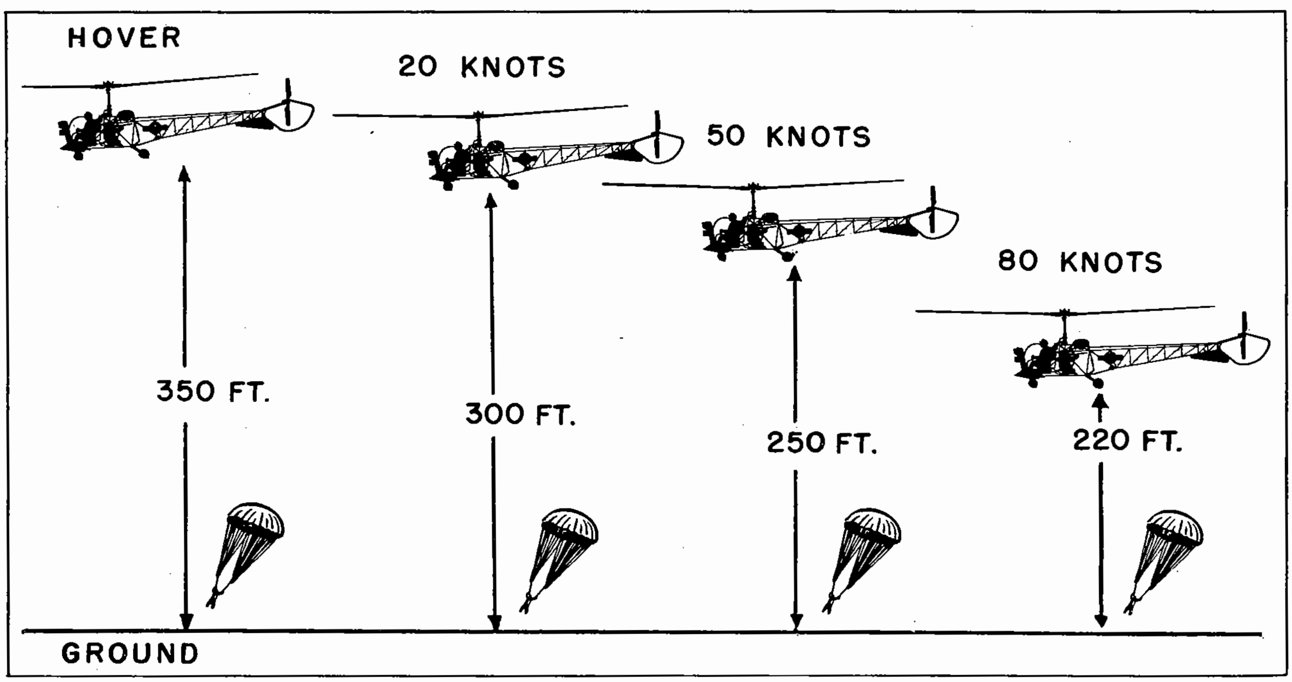


Figure 6-33

from the main rotor. The pilot and passengers should bail out almost at the same instant from a single rotor helicopter, before control is lost due to the change in the center of gravity. It has been shown that parachutes will open in ample time at 350 feet altitude with no forward speed, at 300 feet with a forward speed of 20 knots, at 250 feet at 50 knots, and at 220 feet at 80 knots. (See Figure 6-33.) The figures do not include the time required for the individual to react to the emergency and to make his exit from the aircraft. The time varies with such factors as:

Reaction time of pilot
Type of helicopter
Type of seats
Position of seats.

A time of three to six seconds is considered a reasonable average. This extra time must be taken into account if the helicopter is falling, and the proper allowance in minimum altitude for bailout must be made. For general conditions, 500 feet is considered the minimum safe altitude for bailouts from helicopters. In general, the same Navy requirements apply to use of parachutes by helicopter pilots as to their use by pilots of conventional planes.

However, if the flight is not to exceed 250 feet altitude, the use of parachutes is left to the discretion of commanding officers. Likewise, in light training type helicopters, commanding officers may dispense with the use of parachutes when the added weight would jeopardize safety

Figure 6-34

CHAPTER 7
WEIGHT AND BALANCE

WEIGHT AND THE CENTER OF GRAVITY

The force which attracts everything on earth toward the earth is called gravity. Every particle of a helicopter is attracted by this force. The sum of the force of gravity on all particles is the weight of the helicopter. It is this force which must be overcome by the lift to cause the helicopter to be airborne. The sum of the individual forces on all of the particles acts at the center of mass of the helicopter. This point is called the *center of gravity*, or C.G. (See Figure 7-1.) As structure or equipment changes are made, or as the number of passengers, amount of fuel, cargo and other removable items changes, the location of the center of gravity changes.

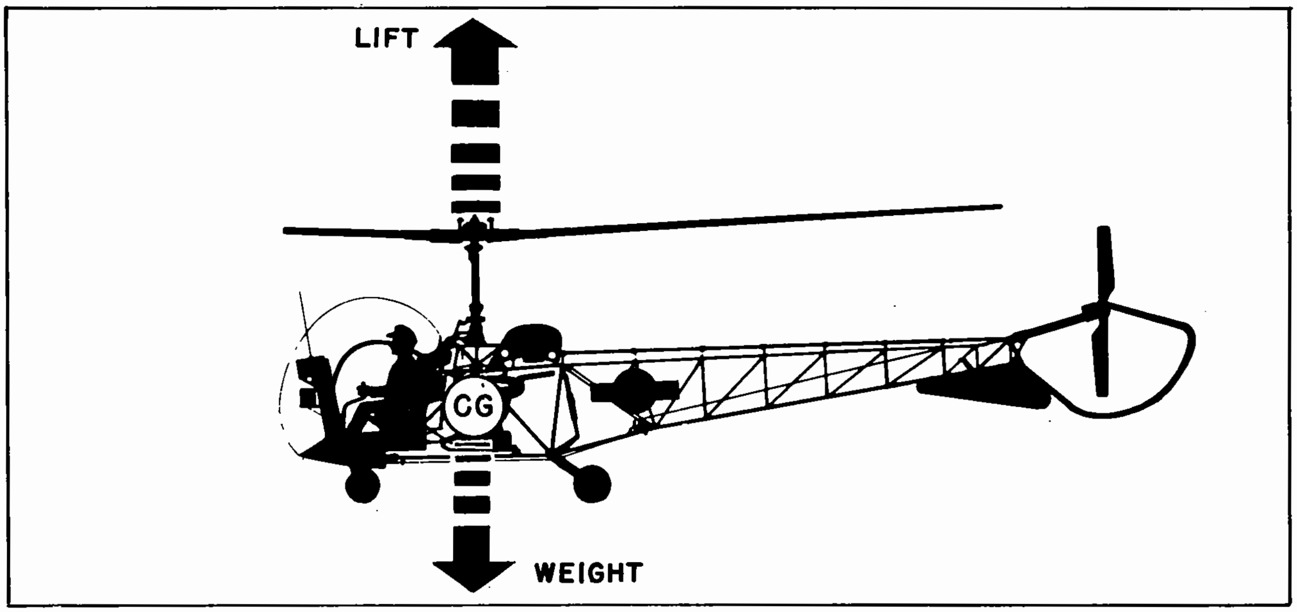


Figure 7-1

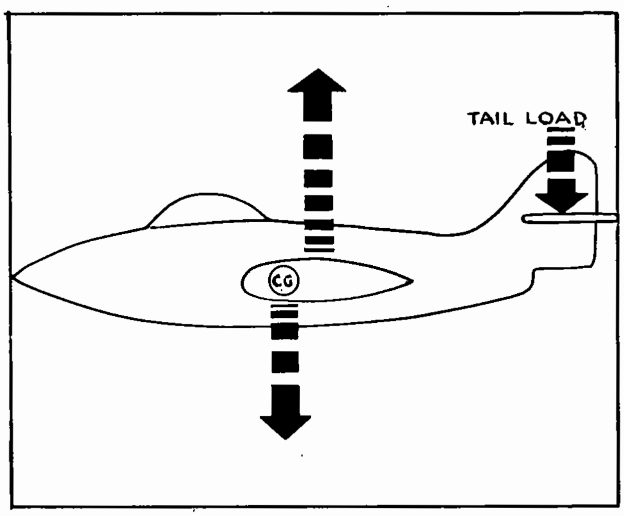


Figure 7-2

For most types of helicopters, the location of the center of gravity must be kept within much narrower limits than in conventional aircraft. Because of this, greater care must be exercised in loading helicopters.

In the conventional aircraft, fore and aft shifts in the weight of passengers, fuel loading, and other removable items which change the location of the center of gravity are balanced out by changes in the air loads on the tail. Because the lever arm of the tail is so long in relation to changes in location of the center of gravity, a small air load change on the tail will restore balance.

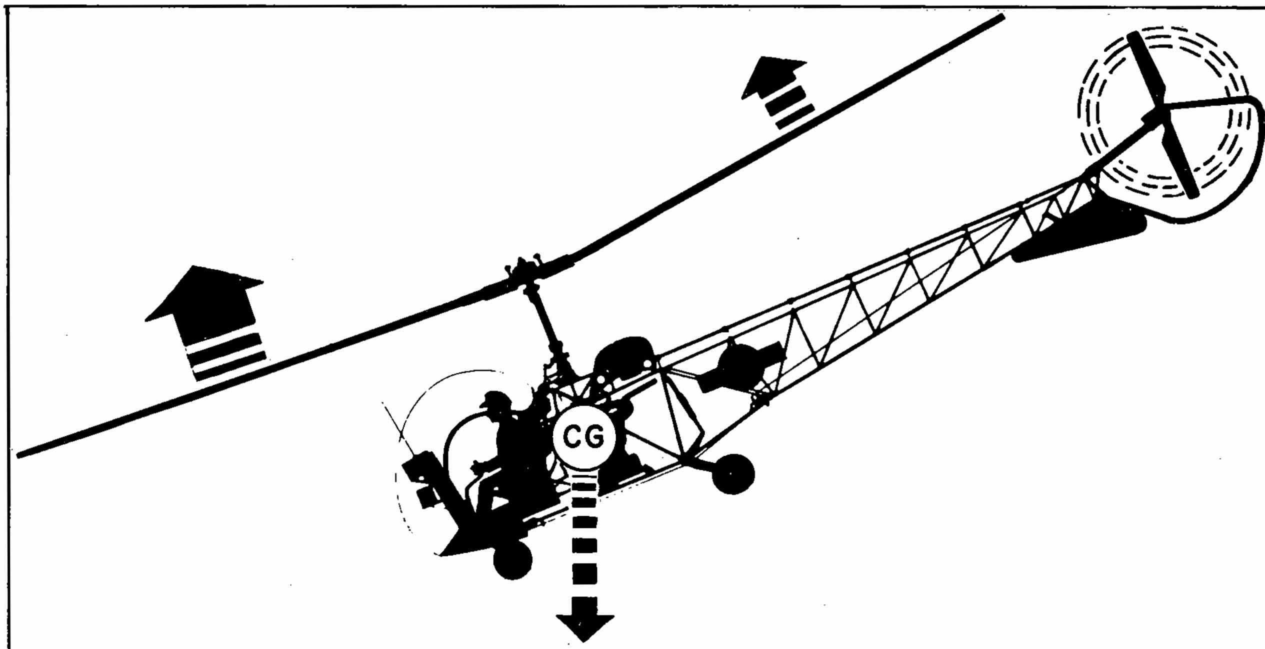
(See Figure 7-2.) This change in air load is controlled by moving the elevators up or down as required. Lateral changes in center of gravity are corrected by use of the ailerons.

But the single rotor helicopter has no counteracting force with a long lever arm. Its suspension is from a single point: the mast on which the rotor turns. And there is only one means of correction if the center of gravity is displaced, and that is a counteracting force in the rotor itself, which acts with practically no lever arm. This force is controlled by changes in cyclic pitch. A nose-heavy condition means that more pitch must be put on the blades through the forward half of the rotor circle by movement of the cyclic stick. (See Figure 7-3.) This reduces the stick travel remaining for control of the helicopter. In dual rotor helicopters, the rotor toward which the center of gravity is shifted must supply an increased lifting force to obtain proper balance. It should be kept in mind that the ideal condition is to have the helicopter in such perfect balance that the fuselage will remain horizontal in hovering, with no cyclic pitch control necessary except that which may be made necessary by wind.

OUT OF BALANCE LOADING OF THE HELICOPTER MAKES CONTROL MORE DIFFICULT, AND DECREASES MANEUVERABILITY.

On the problem of location of center of gravity, Raymond Young in "Helicopter Engineering," says:

"The fuselage of a single rotor helicopter acts as a pendulum suspended from the rotor, and any change of center of gravity changes the angle at which the fuselage hangs from this one-point support. If the center of gravity is moved aft of the mast, the nose tilts up. If it is moved forward of the mast, the nose tilts down. If there is greater moment on one side of the longitudinal center line than on the other, the fuselage tilts in that direction. To correct any out-of-balance condition, the pilot must apply cyclic pitch in a direction to level the fuselage. If too much cyclic control has to be applied, there is danger of not having enough margin of control left to maneuver the helicopter."



NOSE-HEAVY CONDITION CORRECTED BY INCREASING LIFT ON BLADES THROUGH FORWARD HALF OF ROTOR CIRCLE.

Figure 7-3

It is readily apparent that there is a shift of the center of gravity with relation to the point of suspension whenever the attitude of the helicopter changes. That is, if the center of gravity is just forward of the mast when the helicopter is hovering, with the fuselage level, it will shift aft when the craft is flying forward, due to the fact that the fuselage is in a nose down condition.

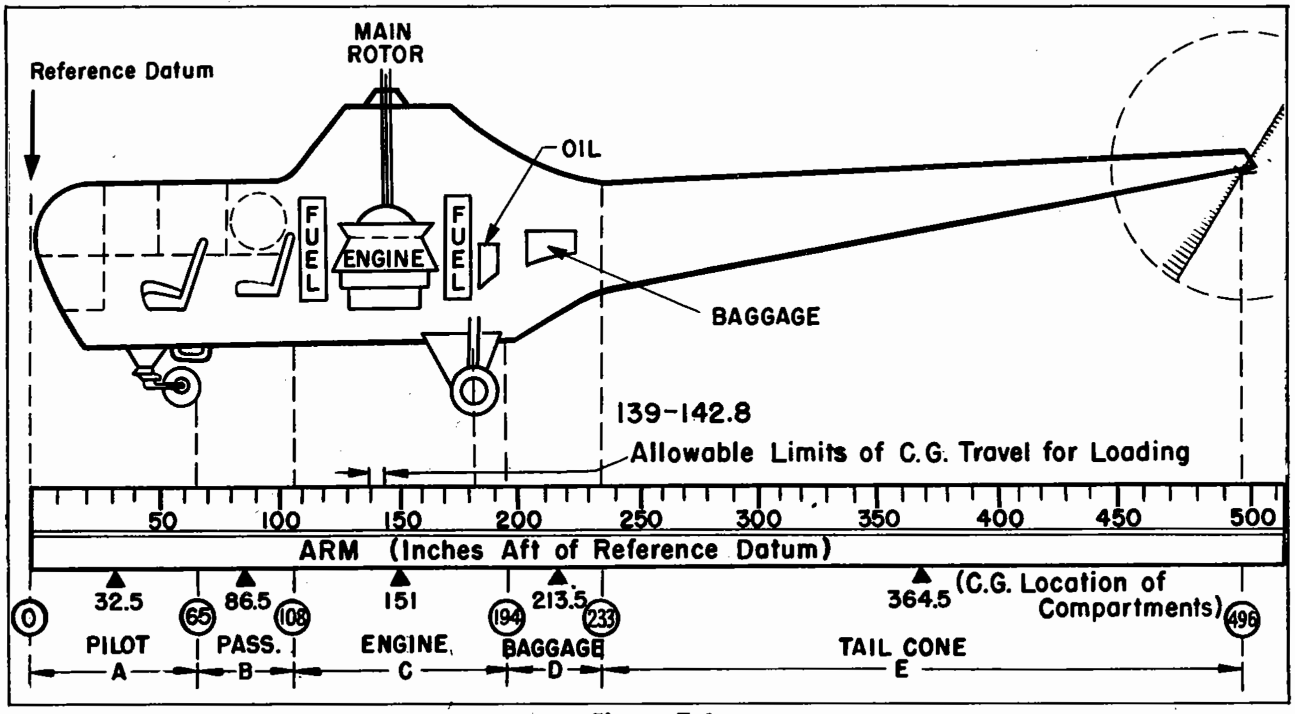


Figure 7-4

In loading the HO3S-1, the allowable C.G. travel is from 139 to 142.8 inches aft of the reference datum, a total range of only 3.80 inches. Toward the extreme limits of this range, it is still possible to run out of stick movement under certain unusual conditions. It is obvious that the loading and balance of the helicopter must be carefully controlled.

WEIGHT AND BALANCE OF HELICOPTERS

The pilot should learn the balance characteristics and load limitations on the model of the helicopter he is flying. Each helicopter is an individual in the sense that its basic weight and balance may differ from others of the same model. The pilot decides how to load his machine by one of three means:

(1) Using the Weight and Balance Handbook, AN 01-1B-40.

(2) Using a Balance Computer (Load Adjuster or "Slip-Stick"), where provided.

(3) Using standard loadings which were pre-computed by one of the above methods and recorded on Form NAVAER 2300.

By limiting the "load" carried, the gross weight can be kept below the recommended maximum gross weight; and by proper placement of passengers, cargo, fuel, movable equipment, and ballast (if any), the center of gravity can be maintained within the allowable limits.

The method of balancing, by shifting weight or adding ballast, is essentially the same for any helicopter. The Sikorsky HO3S-1 will be used for our discussion of the solution of a loading problem because it is the first Navy helicopter to be provided with a Load Adjuster. A "slip-stick" will be provided only for such helicopter models as have sensitive balance limits or a wide variety of possible loadings. The HO3S-1 is a single rotor helicopter with a fairly long cabin and the allowable C.G. travel is very limited.

PROBLEM

Assume that three passengers are to be carried a distance of 60 miles; then the passengers are to be unloaded and the helicopter is to return with only the pilot. This type of problem represents the extremes in loading conditions, and therefore will clearly demonstrate the procedures.

(1) SOLUTION WITH HANDBOOK OF WEIGHT AND BALANCE DATA. A Weight and Balance Handbook, AN 01-1B-40, is made up for each individual aircraft as it leaves the factory. This publication contains forms and charts for loading computations, and instruc-

tions for their use. Chart A lists the items included in the current basic weight. Chart C furnishes the current basic weight and corresponding moment and index. Chart E consists of several sheets and includes the aircraft diagram (See Figure 7-4), loading tables of weights and moments for crew, passengers, baggage, cargo, fuel, oil, etc. We will assume that Chart C for our helicopter shows a basic weight of 4000 pounds and a moment/100 of 5896, and use these figures in our solutions.

To plan our loading from the handbook we use a Weight and Balance Clearance Form F (DD365F). (See Figure 7-5.) First, enter the basic weight and moment/100 from Chart C. The weight of the oil and its moment/100, from Chart E, are entered next. The data from Chart E for our pilot, three passengers, and, if they had any, their baggage, are entered in the spaces provided. The sum of these weights and moments/100 are entered as Item 5, Operating Weight. The fuel weight and moment/100 is entered as Item 7, and added to the operating weight to give the take-off condition (uncorrected), Item 10. The reason that the form provides for a total (Item 5) prior to adding fuel entries is to permit the determination of the maximum gas allowable within gross weight limitations, if desired. Our trip is so short that we do not require maximum fuel. Item 13 calls for take-off C.G. in "% M.A.C." For helicopters we use "Arm" instead of "% M.A.C." Arm is the distance from the reference datum, usually the nose of the helicopter, to the C.G. The arm is found by dividing the moment by the gross weight. Item 10 shows a gross of 5220 lbs. and a moment/100 of 7239. By division we find the arm is 138.7. Since the forward limit is 139, our arm is too "short" so we are nose-heavy. We are still within 80 lbs. of the allowable maximum gross weight. So we try 70 lbs. of ballast in the baggage compartment, listing this under "corrections" on the Form F. Normally we would not use ballast, but would shift baggage or cargo, if possible. Adding this correction, we get a new total weight of 5290 lbs. and a moment/100 of 7388 (Item 12). These figures give an arm of 139.7, which is within allowable limits.

Next, the fuel to be used *en route* is computed. From this calculation, the arm at landing (Item 16) is determined. The pilot must be sure to use fuel as directed by the operating instructions so as not to invite a nose-heavy or tail-heavy condition.

To eliminate actual long division to find the arm, the C.G. tables in Chart E may be used to find out whether a loading is within "safe" limits and to determine the approximate arm. The helicopter loading is "safe" if the moments for the take-off and landing gross weights are within the limiting moments corresponding to these gross weights as listed in the C.G. table of Chart E. For example, we find this listing in Chart E for our gross weight of 5290 pounds:

Gross Wt.	Fwd. Limit	Moment/100			Aft Limit
	Arm: 139	Arm: 140	Arm: 141	Arm: 142	Arm: 142.78
5290	7353.1	7406.0	7458.9	7511.8	7553.1

By inspection, a moment of 7388 will be safe and the arm will be about 139½.

(2) SOLUTION WITH BALANCE COMPUTER. The Balance Computer or Load Adjuster is simply a slide rule type device, graduated and marked for a particular aircraft, and identified by a plate number. The Load Adjuster enables the balance check to be made without lengthy calculations. The Computer used in our example is Plate No. E-952. Start with the basic weight of 4000 pounds, as was done before, from Chart C of the Handbook and enter this weight on the clearance form, Form F. Instead of the moment, however, use the index given on Chart C to determine the balance. By using the basic weight and moment/100 scales on the Load Adjuster, it can be seen that an index of 87.0 results from the basic weight and moment of our example.

Begin by placing the indicator hairline over the basic index. (See Figure 7-6.) Start with the fuel. Place the zero of the "forward fuel" scale under the hairline. Keep the hairline at the basic index. Then move the slide to the amount of fuel to be placed in the forward tank, in this case, 40 gallons. Under the hairline find the new index of 73.5. (See Figure 7-7.) Hold the hairline slide at this point, then move the scale so that the zero of the "aft fuel" scale is again under the hairline. The slide is

WEIGHT AND BALANCE CLEARANCE FORM F
- TACTICAL -
(USE REVERSE FOR TRANSPORT AND CARGO MISSIONS)

FOR USE IN AN 01-1B-40

DATE 27 Sept. 1952	AIRPLANE H03S-1	FROM NAS Anacostia
MISSION TRAINING	SERIAL NUMBER 123456	TO NAS Patuxent

REMARKS

COMPUTER PLATE NUMBER *(If used)* (NONE)

Pertinent instructions to the pilot for shifting load and crew during take off and landing should be noted above.

REF	ITEM	WEIGHT	1/INDEX OR MOM/~~100~~
1	BASIC AIRPLANE *(From Chart C)* ( )	4000	5896
2	OIL (8 Gals)	60	112
3	DISTRIBUTION OF LOAD		
	COMPT. A — CREW NO. 1 — WEIGHT 170 — BAGGAGE — CARGO AND MISC.	170	80
	COMPT. B — CREW NO. 3 — WEIGHT 510	510	454
4	AMMUNITION — COMPT / ROUNDS / CALIBER		
5	OPERATING WEIGHT	4740	6547
6	BOMBS, ROCKETS, ETC. — FORWARD		
	AFT		
	EXTERNAL		
	ROCKETS		
7	FUEL — ~~WING TANK~~ AFT 40 *(Gals)*	240	417
	~~BOMB BAY~~ FWD 40 *(Gals)*	240	275
	EXTERNAL (*Gals)*		
8	WATER INJ. FLUID (*Gals)*		
9	JATO OR RATO		
10	TAKE OFF CONDITION *(Uncorrected)*	5220	7239
11	CORRECTIONS *(If required)*	70	149
12	TAKE OFF CONDITION *(Corrected)*	5290	7388
13	TAKE OFF ~~C.G. IN % M.A.C.~~ ARM 139.7		
14	LESS EXPENDABLES — JATO OR RATO		
	BOMBS		
	AMMUNITION		
	FUEL AFT 19 gal	-114	-198
	FWD 11 gal	-66	-76
15	ESTIMATED LANDING CONDITION	5110	7114
16	ESTIMATED LANDING ~~C.G. IN % M.A.C.~~ ARM 139.2		

CORRECTIONS *(Ref. 11)*

COMPT	ITEM	CHANGES (+ or -) WEIGHT	1/INDEX OR MOM/
D	BALLAST	70	149
	TOTAL WEIGHT REMOVED	-0	-0
	TOTAL WEIGHT ADDED	+70	+149
	NET DIFFERENCE *(Ref. 11)*	+70	+149

LIMITS

2/ GROSS WT. TAKE OFF *(lbs)* 5300	2/ GROSS WT. LANDING *(lbs)* 5300	
3/ PERMISSIBLE C.G. TAKE OFF	FROM 139	TO ~~(% M.A.C.)~~ 142.8
4/ PERMISSIBLE C.G. LANDING	FROM 139	TO ~~(% M.A.C.)~~ 142.8

1/ Enter constant used.
2/ Enter values from current applicable TO.
3/ Applicable to gross weight (Ref. 12).
4/ Applicable to gross weight (Ref. 15).

COMPUTED BY John Dilbert Ens USNR
WEIGHT & BALANCE TECHNICIAN Russell Roe LT(jg) USN
PILOT John Dilbert Ens. USNR

DD FORM 1 AUG 50 365F

Figure 7-5

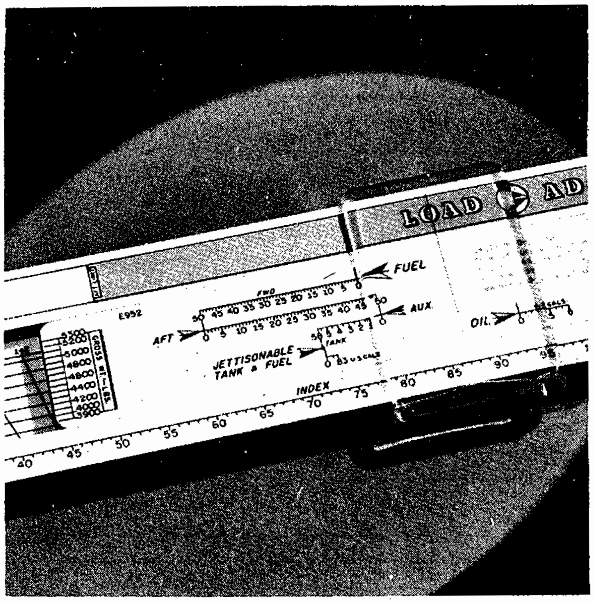


Figure 7-6

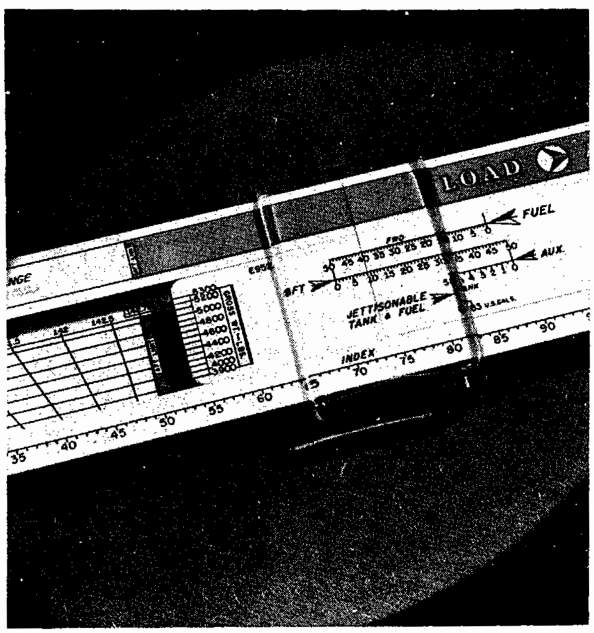


Figure 7-7

then moved to the amount of fuel to be placed in the aft tank, and a new index appears under the hairline. This process is repeated until the weight of all persons, fuel, cargo, or other load have been added. The final index at the end of this procedure is the take-off index. The take-off index must be within the safe loading range as indicated by the white area on the top of the Load Adjuster. If it isn't the loading must be changed.

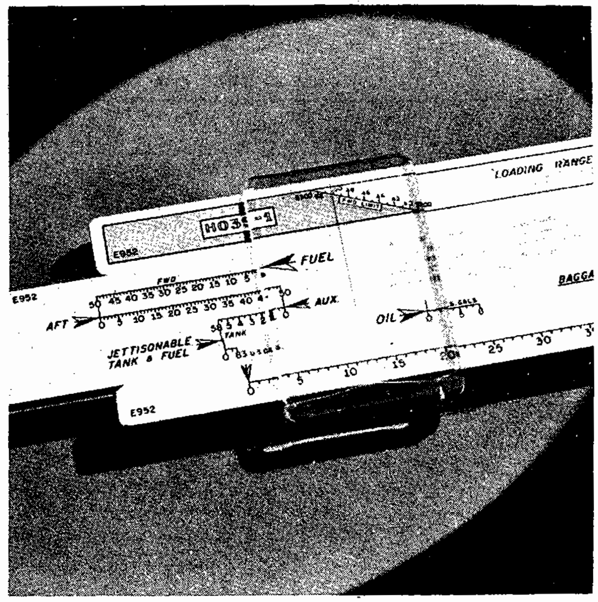


Figure 7-8

If the index is not within safe limits, two methods may be used to correct the difficulty. The usual and preferable method is to relocate passengers, cargo, or equipment. The second way is to add ballast. Where to place them will depend on whether the craft is nose-heavy or tail-heavy after all the load is aboard. In our problem, we get the following result, with an index too far forward:

LOAD	WEIGHT	INDEX
Basic Aircraft	4000	87.0
Fuel (Fwd.) 40 gal.	240	73.5
Fuel (Aft) 40 gal.	240	88.2
Oil 8 gal.	60	93.6
Pilot	170	61.0
Passengers (3 @ 170 lbs.)	510	7.2
Proposed Take-Off:	5220	7.2

Our gross weight is still under the maximum of 5300 allowed for our helicopter, but the index shows the craft is nose-heavy. Since we cannot seat the passengers anywhere else and have no cargo or baggage to move, we decide to add ballast. Some helicopters have provision for adding small weights at the end of the tail boom which gives a large balancing moment for a small increase in gross weight. The HO3S-1 is not one of these. We will use sand bags. 25 to 35 pound bags are better than larger bags because of the ease of handling and stowage.

To find out how much ballast to use, start with the hairline at the index (7.2). Since the

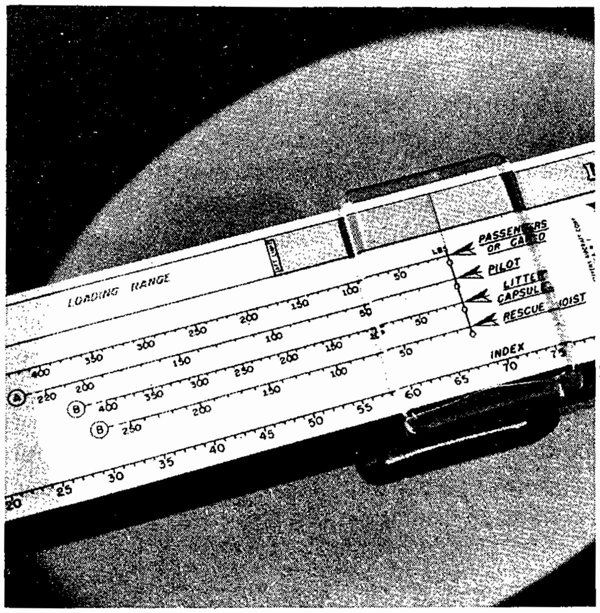


Figure 7-9

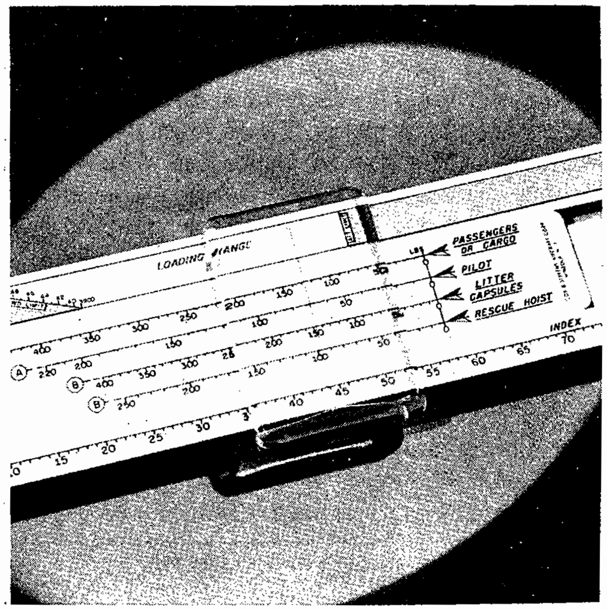


Figure 7-10

ballast must go in the baggage compartment (the farthest aft compartment which can be loaded) set the zero of the baggage compartment scale under the hairline. Then move the hairline slide into the safe loading range. This shows that 70 pounds of ballast will give a safe index of 17.1. The take-off weight becomes 5290 lbs., which is within maximum limits.

To determine whether a given index is within the safe loading limits, we must consider the gross weight. Referring to the safe-loading range area on the slip-stick, it will be seen that the allowable forward index may be numerically lower for heavier gross weights than for lighter ones. At 3900 pounds the HO3S-1 is nose-heavy with any index less than 20.1. At 5000 pounds, an index as low as 12 would not be nose-heavy. (See Figure 7-8.)

It is still necessary to make a check of the balance condition after the *en route* fuel is gone to insure a safe condition at landing. During the one hour flight planned in the problem there will be a consumption of about 30 gallons of fuel. If the fuel selector valve is placed in the "BOTH ON" position, fuel will drain unevenly, leaving at the end of the trip about 29 gallons in the forward tank and 21 gallons in the aft tank. Since the original quantity was 40 gallons in each tank, the figure "40" on the front tank scale is placed under the hairline at the take-off index of 17.1, and the indicator is moved back to 29 on the front tank scale. The procedure is repeated for the rear tank, and a landing index of 13.8 is shown, which is still in the safe loading range for a weight of 5110 pounds; this will be the weight after the expenditure of 180 pounds (30 gallons) of fuel. If the index had indicated an *unsafe* condition, fuel could have been selected initially from the front tank only, which would have brought the index farther back into the safe loading range, and selected from the rear tank later in the flight. The sequence in which the fuel should be used can be predetermined based on the particular load being carried.

After discharging the passengers, it will be necessary to recompute the balance condition for take-off. This is done by setting 510 (the weight removed) on the passenger compartment scale under the hairline at the landing index of 13.8 and moving the indicator to zero. This shows an index of 67.4, which is beyond the aft limit. (See Figure 7-9.) Therefore the 70 pound ballast is removed from the baggage compartment and placed in the pilot's compartment. Making the change on the Load Adjuster it is found that the index is 44.1, which is well within the loading range. (See Figure 7-10.)

As noted, this problem represents an extreme situation, but one that can easily occur. Where one or two passengers are to be carried around the field or on a round trip with essentially unchanged loading, it may be unnecessary to determine any loading change.

(3) USE OF STANDARD LOADINGS. Technical Order 82-45 permits the use of "Authorized Standard Loadings," Form NAVAER 2300, for class 1B aircraft, a class which includes most helicopters. These loadings are determined by the use of either the Weight and Balance Handbook or the Load Adjuster, as explained above, and should be planned for typical squadron operations. This form permits rapid loading without the dangers inherent in guesswork. Figure 7-11 shows typical loadings of an HO3S-1 with different numbers of passengers and amounts of fuel. These loadings are correct only so long as the basic weight of 4000 pounds and moment 100 of 5896 remain unchanged. The gross weight, moment and arm are shown for each loading. Column 6 of Figure 7-11 shows the same loading used in the above problems. A major advantage of using the NAVAER 2300 Form is that an expert can work out the loadings, rather than placing this duty on a pilot who may find it difficult and time-consuming. It is most important however, to be sure to re-compute standard loadings every time a change is made in the basic weight or moment.

Accidents occur every year which are caused by overloading or unbalanced loading. The helicopter, which flies at very low altitudes, is especially likely to have trouble from careless loading. It does not pay to ignore the proper procedure in loading. The minutes you save may be paid for in eternity.

AUTHORIZED STANDARD LOADINGS
NAVAER-2300 (8-15)

IMPORTANT: A new form must be prepared whenever a change in the basic weight and/or moment/constant shown on bottom line renders these loadings incorrect.

ACTIVITY	MODEL	BUREAU SERIAL No.	DATE
HU-29	HO3S-1	123456	11 July 1952

RECOMMENDED MAXIMUM GROSS WEIGHTS — TAKE-OFF: 5300
FROM TECHNICAL ORDER No. T.O. 000-00 — LANDING: 5300

CENTER OF GRAVITY LIMITS
FORWARD 139 inches AFT 142.8 inches

Compt. ITEM		1	2	3	4	5	6	7	8	9	10
A-Pilot		170	170	170	170	170	170				
A-Ballast		50	-	-	-	-	-				
B-Passengers	Number	0/	1/	1/	2/	2/	3/				
	Weight	-	170	170	340	340	510				
C-Fuel Fwd. Tank		300	300	300	240	300	240				
C-Fuel Aft Tank		240	300	300	240	300	240				
C-Oil 8 gal.		60	60	60	60	60	60				
D-Baggage or Ballast		-	50	-	50	50	70				
F-Aux. Fuel (Ext. Tank)		-	-	300	-	-	-				
GROSS WEIGHT		4520	5050	5300	5100	5220	5290				
MOMENT/CONSTANT		6872	7211	7504	7192	7364	7388				
C. G. (% M. A. C.)		142.5	142.8	141.6	141.0	139.7	142.5				

SAMPLE ONLY

DATE OF CHART C ENTRY (AN 01-1 B-40 Handbook): 10 May 1952
CALCULATED BY: Russell Roe LT. USN — WT. AND BAL. OFFICER
BASIC WEIGHT: 4000 (Incl. Ext. Tank) — MOMENT/CONSTANT: 5896
APPROVED BY: John Doe CDR. USN — COMMANDING OFFICER

U. S. GOVERNMENT PRINTING OFFICE 16—49059-1

Figure 7-11

CHAPTER 8
HANDLING THE HELICOPTER

INTRODUCTION

Controls for helicopters have been standardized just like the controls for conventional aircraft. However, because there is considerable difference in the size and type of helicopters and their engines, specific details for handling all helicopters cannot be given here. However, there is considerable information common to most helicopters which will be covered in this chapter.

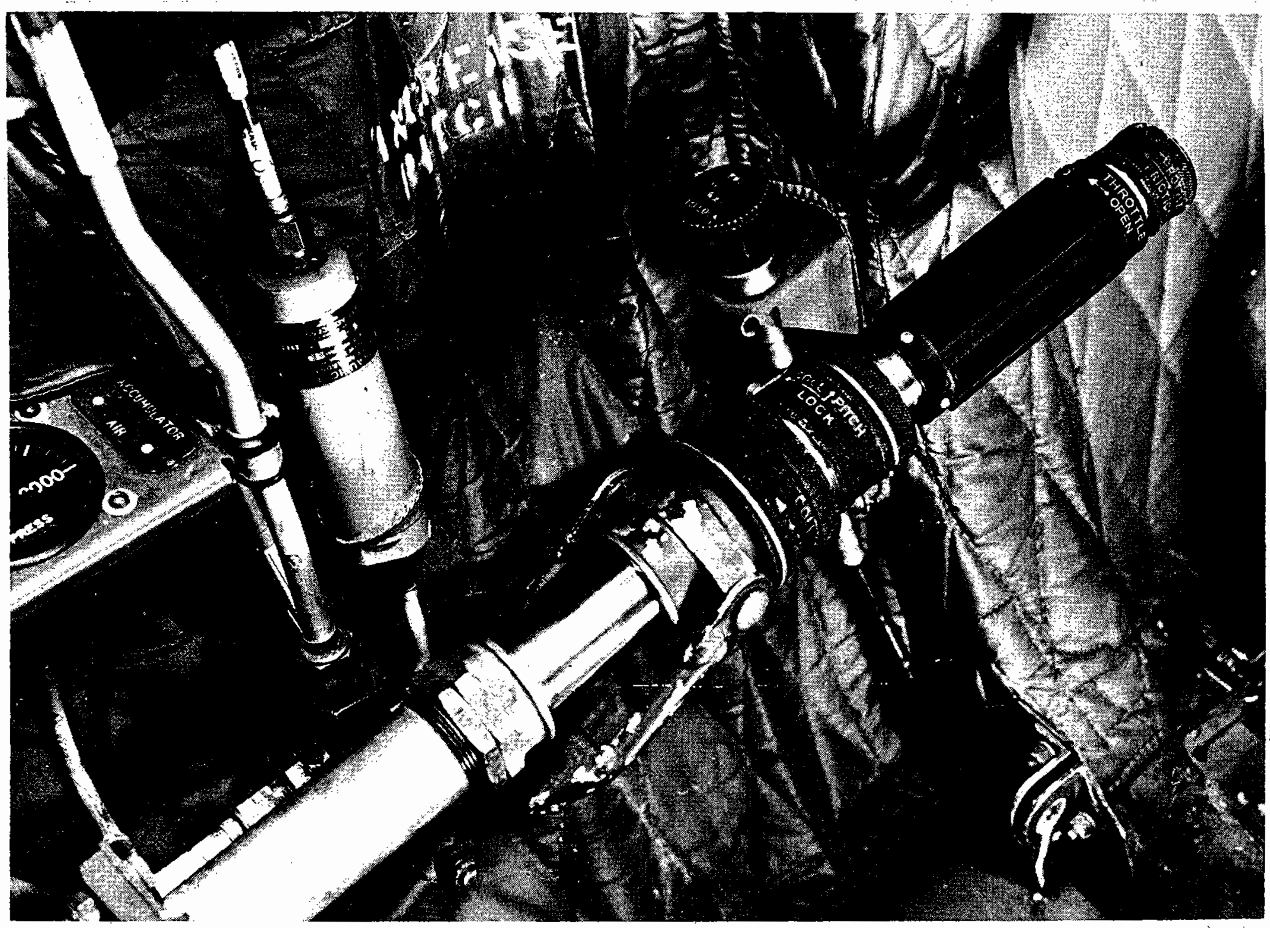


Figure 8-1

STARTING

Once the engine is running, it must *never be left unattended.* The left foot may be placed on the collective pitch lever to hold it down or if there is a collective pitch lock, it should be used instead. (See Figure 8-1.) The throttle should be regulated to prevent the engine from going fast enough to cause the clutch to take hold. Before engaging the rotor, the rotor brake should be released and the plane captain given the turn-up signal. When he returns this signal, the rotor can be engaged. The throttle is opened for more speed which automatically engages the clutch. The cyclic pitch stick should be neutralized, and as the rotor gains momentum, slight adjustments should be made to find the point of least vibration. After the clutch is eased in, the engine should be brought up to a speed that will prevent disengaging of the clutch and consequent dragging.

Starting the engine with the rotor brake "ON" is recommended, particularly if wind velocities are above normal.

TAXIING

A three-wheel chassis like that of the HO3S-1 makes taxiing a more hazardous operation than with the four-wheel HTL, for example. Taxiing cross-wind or down-wind should be avoided whenever possible. If it is necessary to taxi cross-wind, the cyclic control stick, (See Figure 8-2) should be held into the wind, and turning should be done with the rudder pedals. The main rotor disc of single rotor helicopters like the HO3S-1 is tilted to port when the cyclic pitch stick is laterally centered. This compensates for the starboard push of the tail rotor. A greater displacement is therefore necessary for a starboard cross wind than for a port wind. This is not true of tandem rotor helicopters. Taxiing should always be done slowly and with a view of taking off at any moment.

Figure 8-2. Cyclic control stick held over to the side by the pilot. The stick is held into the wind for cross-wind taxiing.

TAKE-OFF

When ready for take-off, rpm and manifold pressure should be synchronized at the readings specified for the particular helicopter being flown. Then collective pitch is increased until the hover point is reached. The throttle and collective pitch are synchronized so that a specified rpm and manifold pressure are reached in the hover. This engine speed should be maintained for any further pitch increase. Speed of the engine must be as specified before leaving the deck, and at all times during the hover. The throttle should be used as necessary. Left rudder will have to be applied to compensate for torque in a single rotor helicopter.

CLIMB

To enter a climb from hovering, the nose of the helicopter should be depressed slightly and the collective pitch increased as necessary to gain air speed and altitude. As soon as practical after take-off (on reaching twenty to twenty-five knots) pitch and power should be reduced to the manifold pressure recommended for extended operations. When air speed has increased to between forty and fifty knots, the nose should be adjusted to maintain air speed and continue the climb until the desired altitude is reached.

It is not considered good practice to depress the nose excessively on take-off as there is danger of hitting the nose gear or forward structure when the helicopter moves off the air cushion. (See Figure 8-3.) Also, it is not a good plan to obtain high speeds close to the deck; if the engine happens to cut out, there may be insufficient altitude to "flare off" the excess speed.

HOVERING

The critical operation in helicopter flight is hovering. This requires the complete concentration of the pilot. The first requirement is that the helicopter be loaded so that the center of gravity is within the allowable limits. The pilot is responsible for safe loading. The amount and position of the load have a great effect on stick forces and control limits.

When hovering for any hoisting operation, the pilot should be informed by placard or other means if the load to be lifted weighs more than fifty pounds. (See Figure 8-4.) Pilot approval must be obtained before attaching the load to the hoist. Under no circumstances should a line from a helicopter be secured to any part of a ship's structure.

Figure 8-3

LANDING WITH POWER "ON"

A normal landing with a helicopter is made with power on. This gives more complete control than is possible with power off.

The glide for the approach should be made by decreasing collective pitch and reducing power. A speed of approximately fifty knots should be held until an altitude of 100 feet is reached. (See Figure 8-5.) Then speed should be cut by gentle application of back stick. When down to recommended speed the nose should be kept level, and the rate of descent slowed by gradual addition of collective pitch. This will not only check rate of descent but will also kill off forward speed. The object is to reach hover-

Figure 8-4

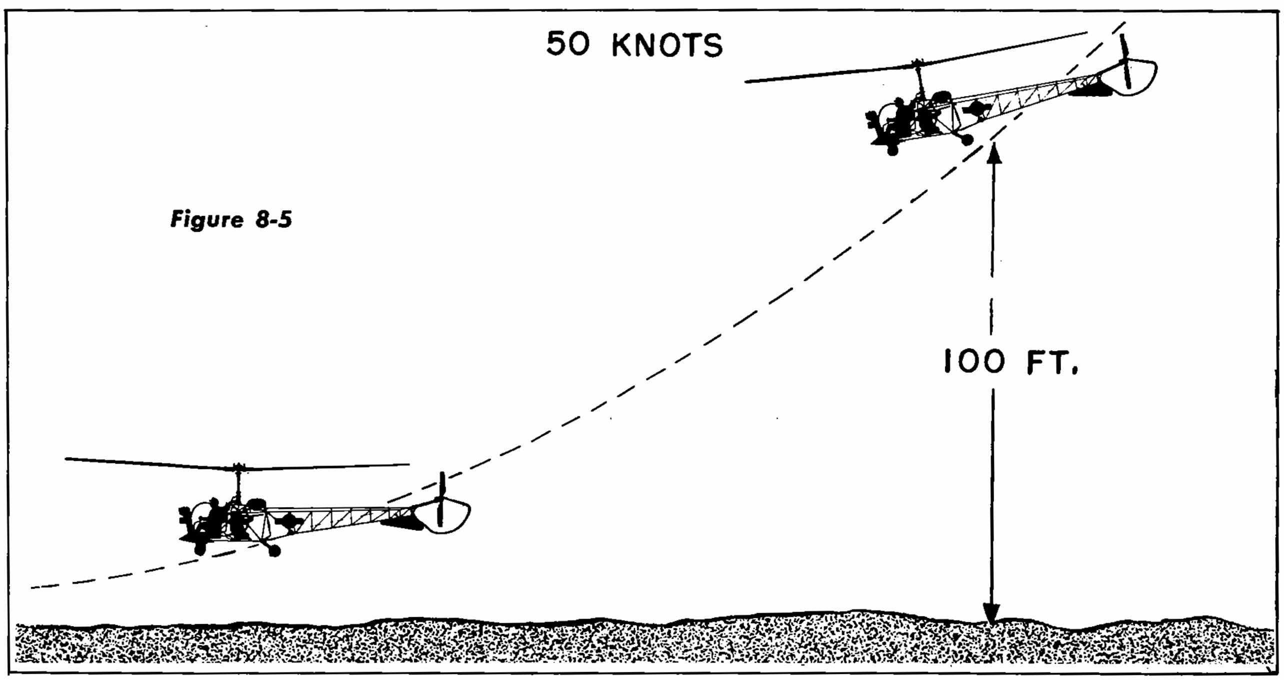


Figure 8-5

ing altitude with hovering manifold pressure and zero ground speed. Pulling the nose up when close to the ground to decrease air speed should be avoided.

Having arrived at a hover, the pitch should be reduced and the helicopter should be allowed to settle slowly to the deck. Immediately on making contact with the deck the pitch should be reduced smartly and throttle added to maintain 1500 rpm. Simultaneously right rudder should be applied to counteract reduced torque in single rotor helicopters. The wheels should never be allowed to rest lightly on the deck so that the helicopter is supported partly by the rotor and partly by the landing gear. This is a condition that contributes to ground resonance. Never land while moving sidewise or backward.

LANDING WITH POWER "OFF"

In landing without power, an autorotative landing must be made. If the engine is stopped through accident or the power is turned off, the first action is to decrease collective pitch by pushing the collective pitch lever down. The cyclic pitch stick is then moved to control the angle of descent. (See Figure 8-6.) The rotor is kept turning by the force of the air stream on the blades.

As the pitch is low and the rotor is running free it will build up considerable speed as it comes down. The rotor is storing up kinetic energy for later use. As the helicopter approaches the deck the cyclic pitch stick is pulled back to execute a "flare." Then as the helicopter starts to settle, the collective pitch lever is pulled up to increase pitch. This is the point where the kinetic energy of the rapidly turning rotor begins to be used. This energy is applied to slow down the descent of the helicopter. The energy that is generated by autorotative rotation is turned into energy in the form of lift. In other words, the rpm of the rotor is exchanged for momentary lift by increasing the collective pitch.

Figure 8-6

If the landing is on a ship's deck, the "flare" must bring the helicopter to a stationary position. (See Figure 8-7.) If the landing is on an airfield where there is room for a run, a more moderate "flare" is sufficient, and the landing may be made at a speed of up to twenty knots.

Figure 8-7

As soon as the autorotative landing is completed, the collective pitch stick should be fully depressed. If left in high pitch there is a tendency for the helicopter to go over on its side, especially if there is a cross-wind, or if the wind is gusty.

USE OF THROTTLE

A good rule which may well be followed in flying all helicopters, is "never close the throttle all the way to idling position." Collective pitch may be reduced as rapidly as desired, but engine rpm should be maintained at higher than idling speed. A minimum speed of 1000 rpm is recommended for the HO3S-1. During autorotation the engine and tachometer needles need be split by only approximately 200 engine rpm to assure the pilot that no power is being applied to the rotor. This technique greatly reduces the possibility of engine stoppage. Engine stoppage with closed throttle is always possible, due to the low engine inertia. Quick stops, autorotation "flares" and similar maneuvers should be practiced *only* over areas such that a safe landing can be made in the event of engine stoppage.

LOW ALTITUDE FLIGHT

Helicopters are normally operated at comparatively low altitudes, and at speeds much lower than those of fixed-wing aircraft. These two operating conditions present certain difficulties that the pilot does not meet in the operation of fixed-wing aircraft. As a large part of combat flying is done at minimum altitudes, every pilot operating helicopters should familiarize himself with low altitude flying.

Figure 8-8

Wind should be plotted in advance, and the indicated heading should be flown as closely as possible. On account of the slow speed the helicopter will be under way for a longer time, and will be blown further off course if wind calculations are incorrect.

The most important single factor in low altitude navigation is undoubtedly the use of closely spaced check points. This is true particularly in combat zones where flights are generally of short duration. Check points should be planned in advance with particular care for behind-the-lines rescue work. These points should be kept in mind and checked as the pilot progresses along his flight path. (See Figure 8-8.) It is much easier to keep check points in mind and be on the watch for them than it is to fly a heading for a specified time and then watch for a check point from which position may be figured.

418490 O - 57 - 9

CHAPTER 9

THE HELICOPTER OF THE FUTURE

If the early experimenters in the helicopter field had been asked to forecast the developments of the twenty years ahead of those early times, some might have made a close guess, but the chances are that most of them would have been far off in their estimate of what future years would bring. It is impossible to tell today with any more certainty just what is ahead in the way of helicopter improvement and development.

But it is generally agreed that there will be great improvement in ease of control, in economy, in stability and in carrying capacity. First among the probable improvements is ease of control and better stability. It is generally admitted that under any condition the helicopter in flight requires all of a pilot's attention and needs the best possible co-ordination. Because of the need for this complete concentration and also because of the vibration of the helicopter, fatigue is far greater than in the operation of the conventional airplane. There is no such thing as flying the average helicopter "hands off" for any appreciable amount of time. This situation will undoubtedly be corrected by means of improved control methods or by the use of automatic pilots such as are used in some Sikorsky and Piasecki helicopters. (See Figures 9-1a and 9-1b.)

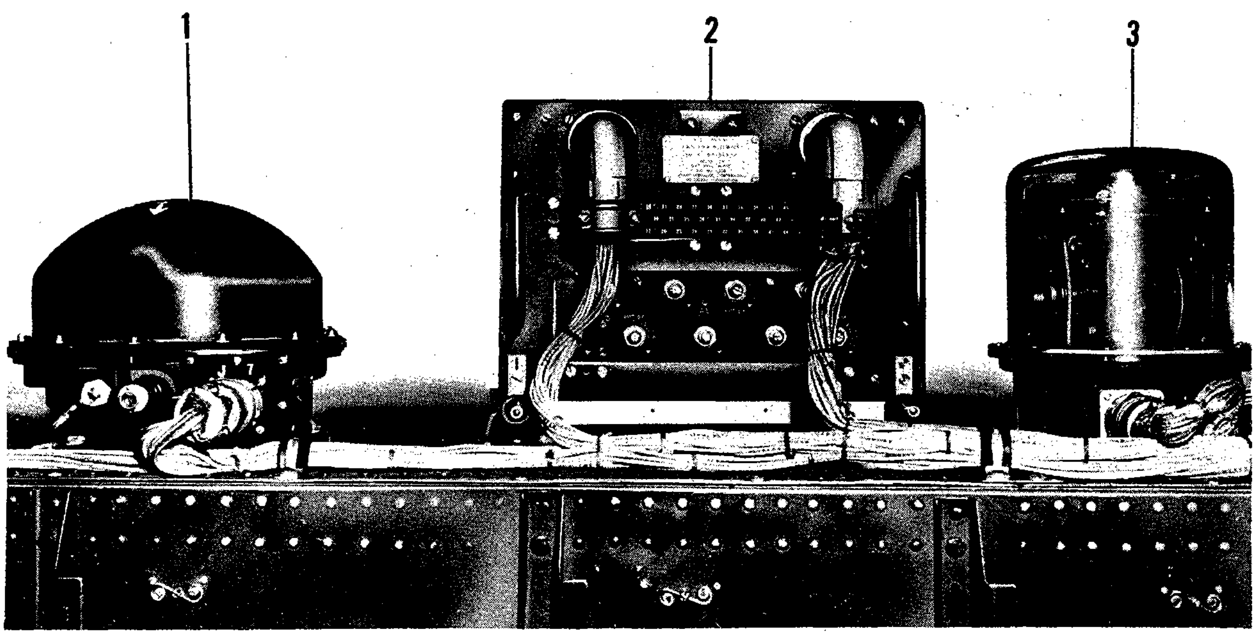


Figure 9-1 (a)

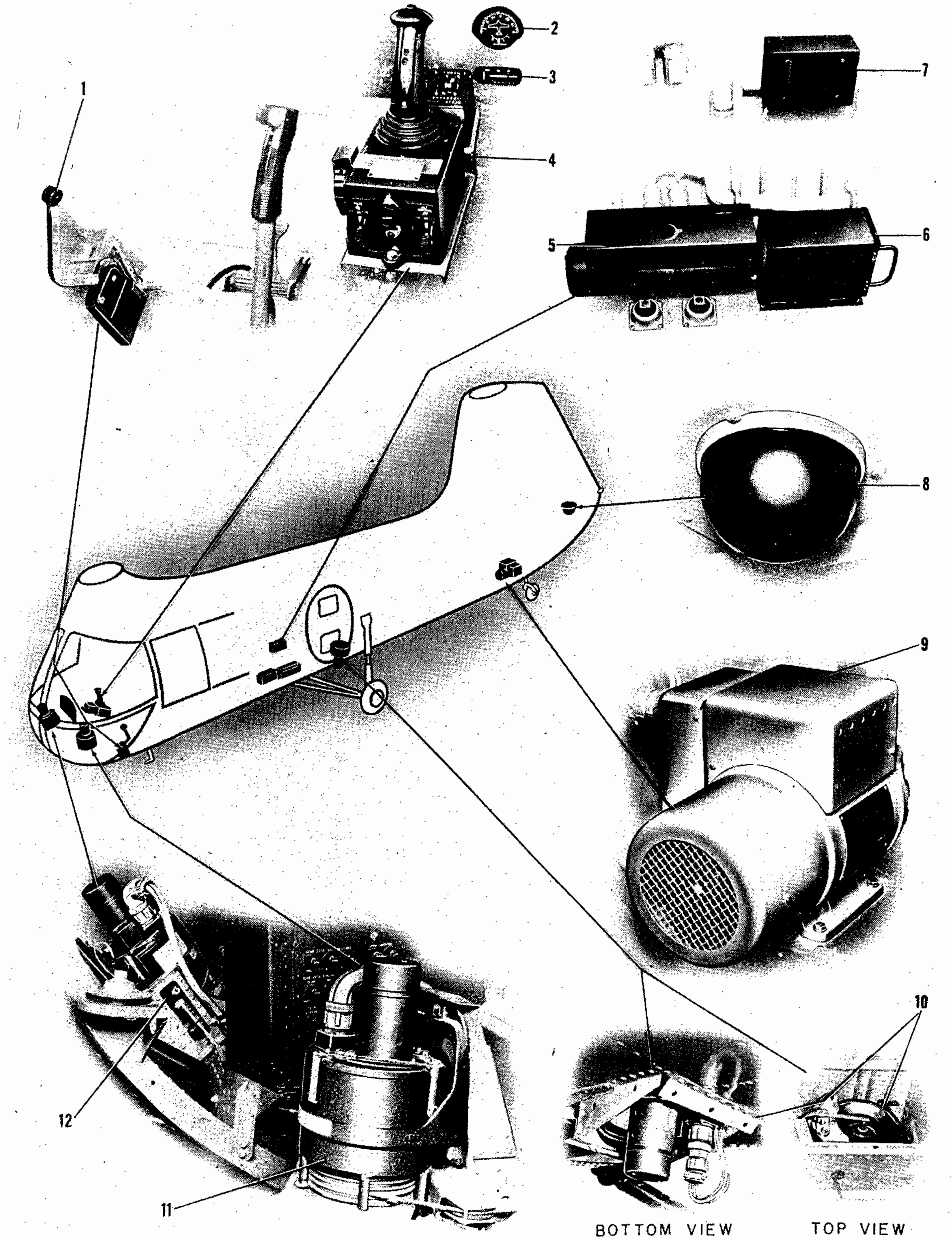


Figure 9-1 (b). The automatic pilot in the Piasecki helicopter. The top photo shows the automatic pilot units on the cabin shelf, as follows: (1) vertical gyro, (2) amplifier assembly, and (3) gyrosyn compass. The bottom photo shows the automatic pilot units throughout the helicopter, as follows: (1) pilot's engage lever, (2) compass repeater, (3) trim indicator, (4) pilot's controller, (5) serve control, (6) repeater amplifier, (7) phase adapter, (8) flux valve, (9) inverter, 10) longitudinal serve, (11) lateral serve, and (12) directional serve.

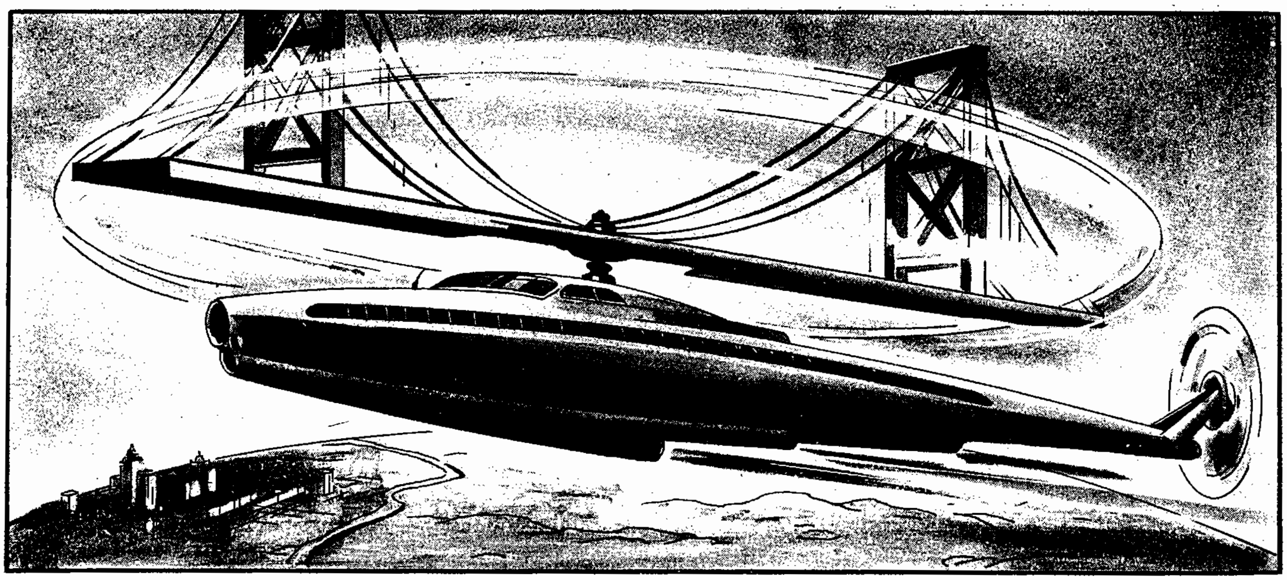


Figure 9-2

Design of larger model helicopters with multiple rotors will no doubt be one of the developments of the future. The construction of large helicopters seems to present even greater difficulties than the construction of conventional planes of large size. There are definite mechanical and structural limits to the length of rotor blades. (See Figure 9-2.)

In the case of single rotor helicopters, it would be desirable to eliminate the tail rotor which would make more power available to the main rotor and would make landing on uneven terrain less hazardous. One possibility is the use of jet powered rotors since this type of drive does not transmit engine torque to the fuselage.

Two types of jet rotors have already been the subject of experiment: the ram-jet type and the pulse-jet type. In both types the jet engine is fixed to the rotor blade at the tip. (See Figure 9-3.) Fuel is brought in through the hub and is carried out to the jet through a fuel line extending from the hub to the engine. In the ram-jet type, oxygen for combustion is supplied by the flow of ram air to the flame. The reaction force of the jet drives the rotor just as the same force drives the jet airplane. In the pulse-jet type the engines are similarly located at the tip of the blades, but the engine is similar to that of the "World War II—Buzz Bomb" so that power is developed as a series of pulses rather than as a continuous flow.

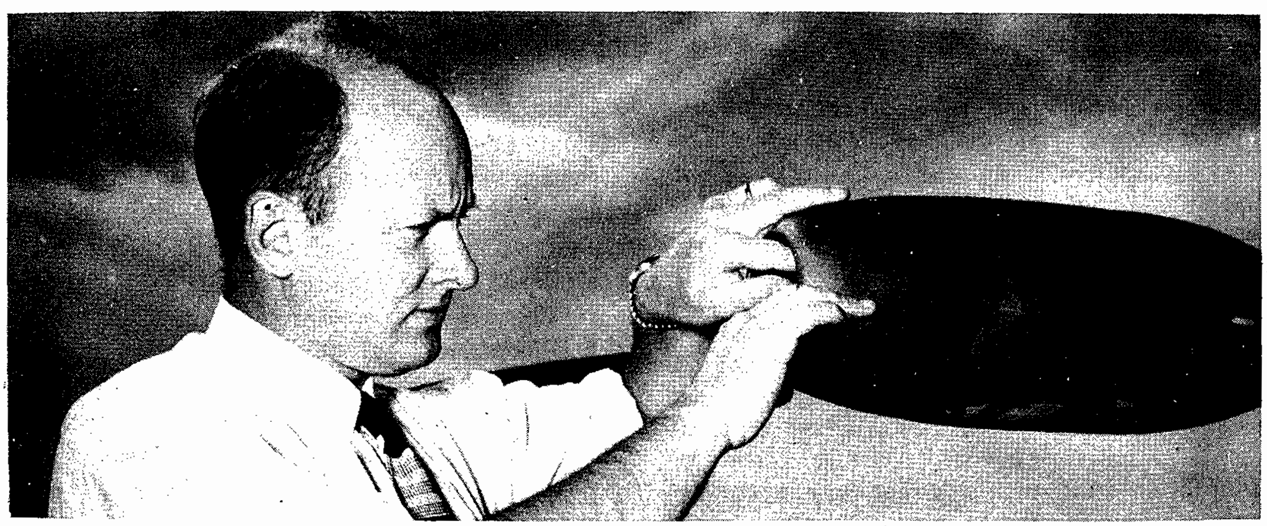


Figure 9-3

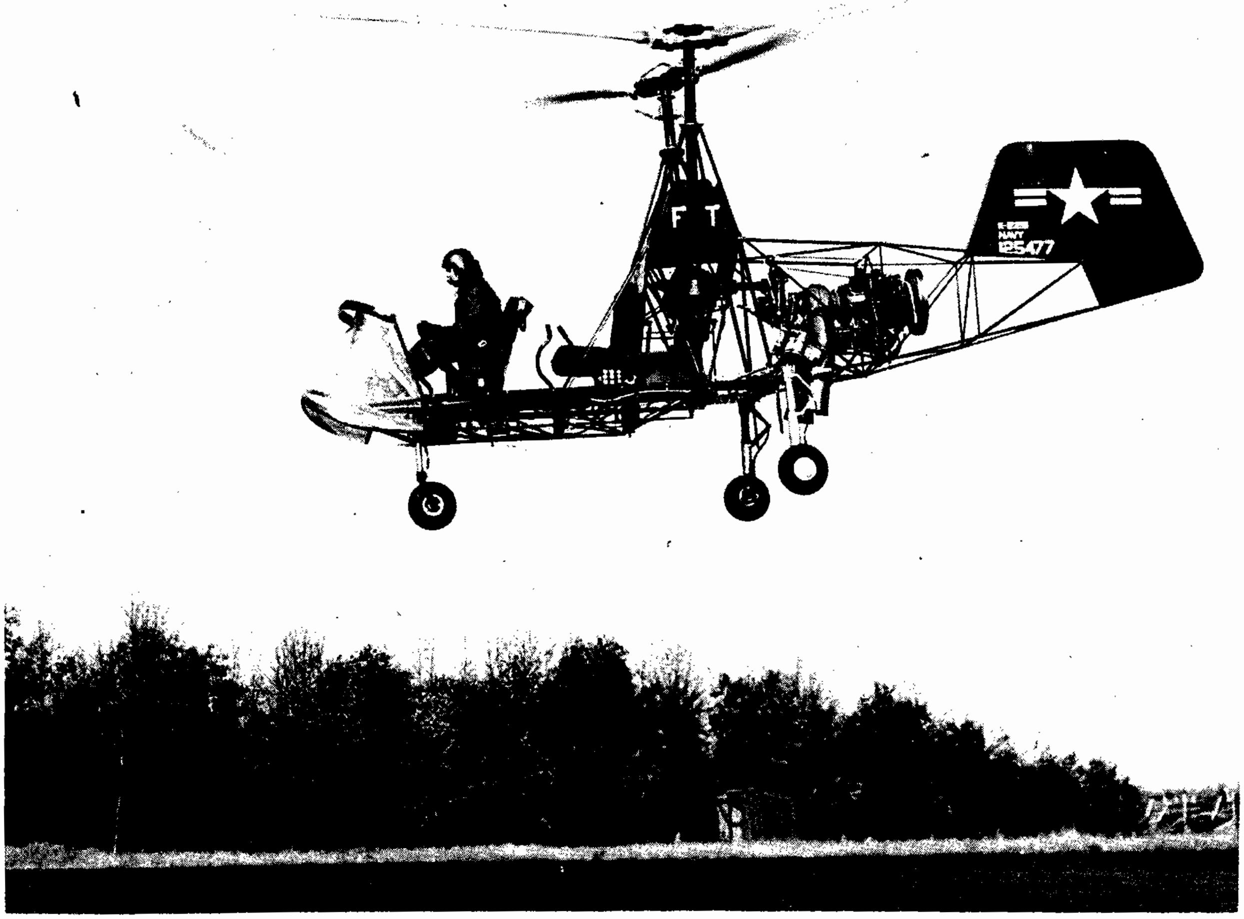


Figure 9-4. The K-225 helicopter developed by the Kaman Aircraft Company and powered by a Boeing XT-50 gas turbine.

Another interesting development is the use of gas turbines for power directly to the rotors. (See Figure 9-4.) The engine in the K-225 is similar in principle to the gas turbine engines now used to power jet planes, but the installation differs in the application of power. Instead of using the velocity of exhaust gases for direct thrust, the power is used to turn the shaft of the rotor blades. The gas turbine does not require a centrifugal clutch or a cooling fan.

If a helicopter is considered as an aircraft that is capable of rising vertically, there are many other configurations that have been suggested. Many of these are in one stage or another of development. One of the significant types is called the convertiplane. (See Figures 9-5 and 9-6.) In this case rotors are used to rise vertically and then are either rotated to a horizontal position for translational flight or propellers are used to give translational motion at higher speeds than are possible with the conventional helicopter configuration.

Undoubtedly the field of the helicopter will become much greater as production increases and manufacturing costs go down. In the armed forces their place is firmly established, and their application by the Navy and other branches is constantly being extended. Their use in rescue work at sea and ashore has been

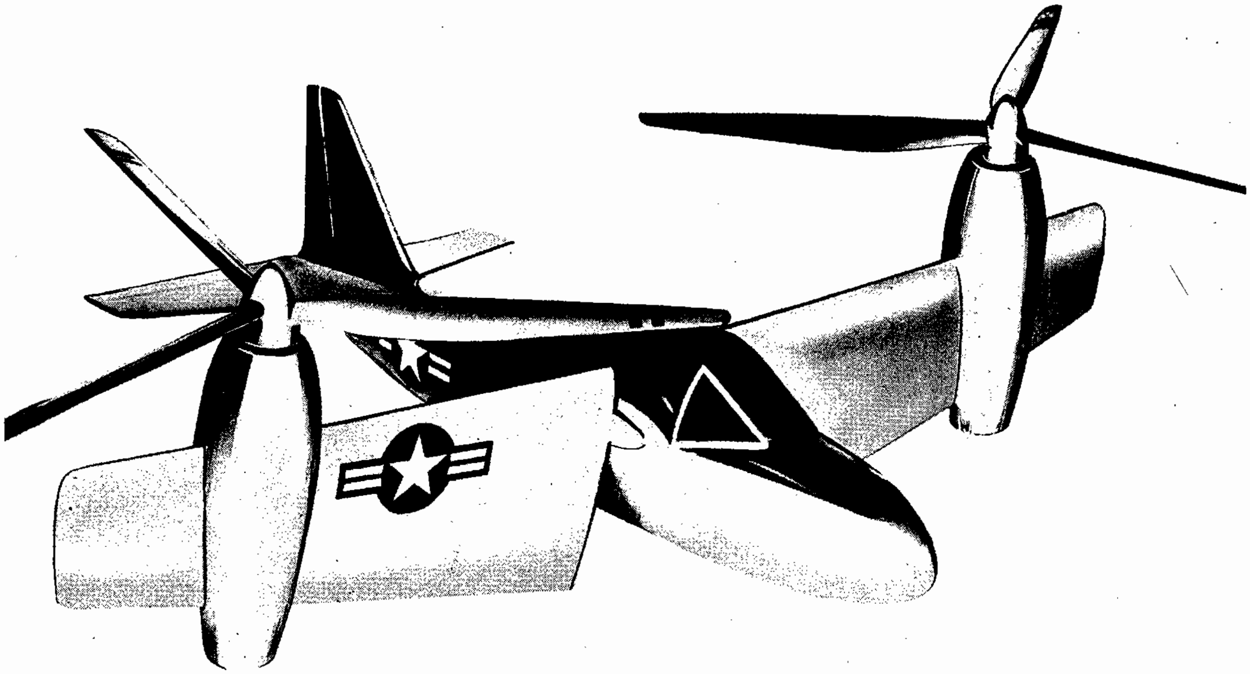


Figure 9-5. Convertiplane designed by Franklin A. Dobson.

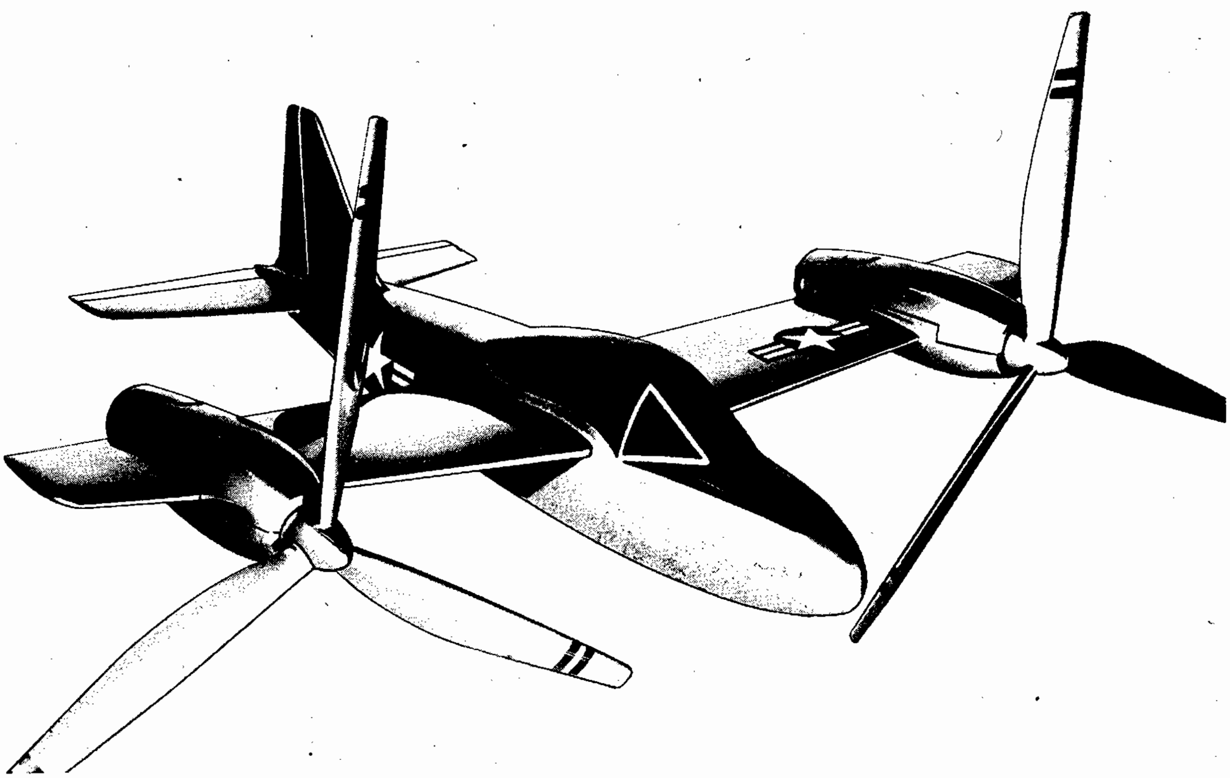


Figure 9-6

featured in newspapers, magazines, and technical publications as one of the great developments in modern aviation. For plane guard work the helicopter has no equal. (See Figure 9-7.) It is the only aircraft that can successfully lift downed pilots from the water. In spotting submarines and mines its low speed and hovering ability give it obvious advantages over the conventional airplane.

Experience has shown that the use of helicopters makes assaults on enemy held heights quicker and less arduous on the men and therefore leaves them in better physical condition to make the attack. Also, the practicability of ship to shore movement of troops by helicopter has been demonstrated.

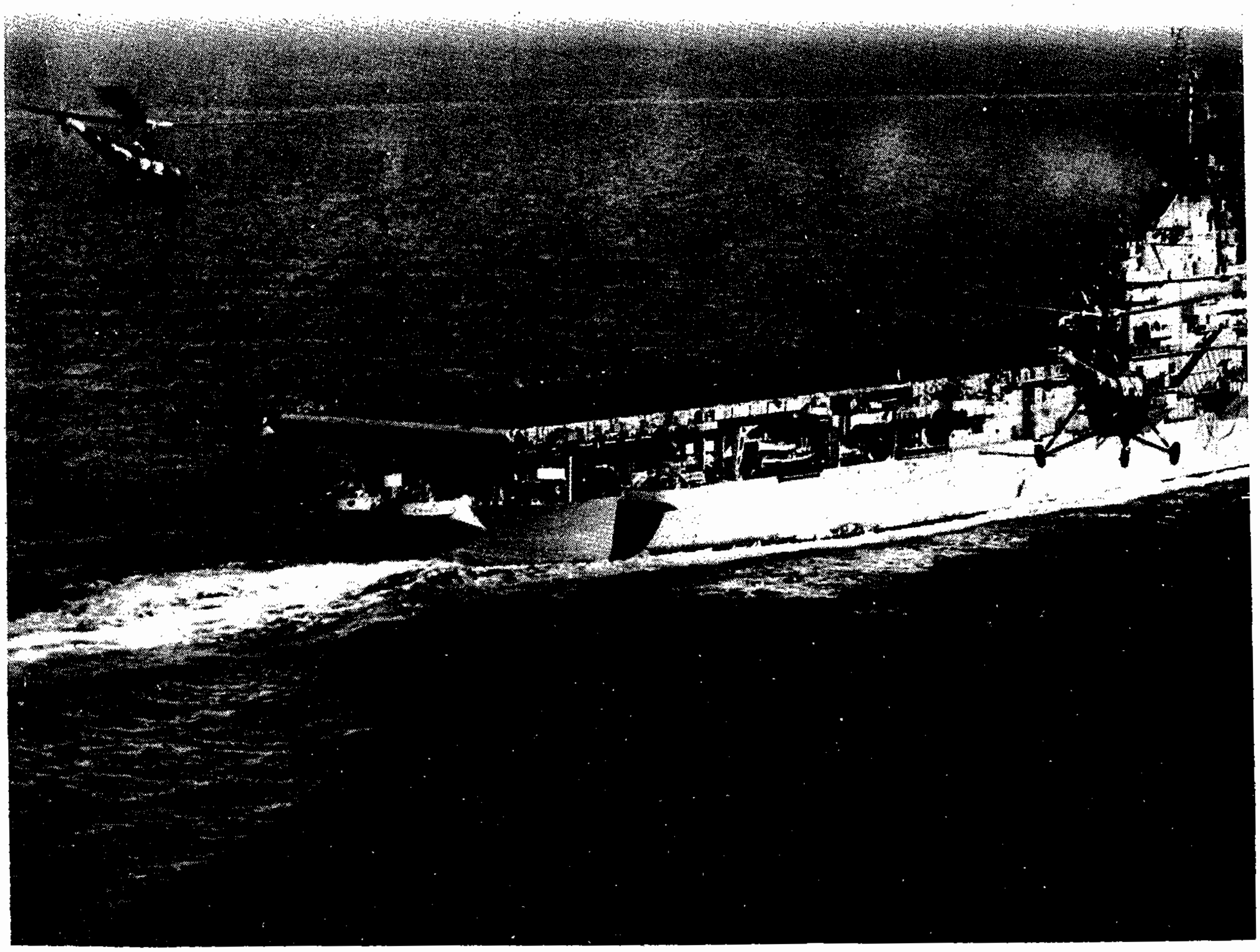


Figure 9-7

Figure 9-8

In photographic service, radar calibration, and many other important duties the helicopter has done an outstanding job. Among other tasks it is used for transfer of personnel, for making hydrographic surveys, checking depth of water, and securing data for making charts and maps of all types. (See Figure 9-8.)

In civilian use the helicopter is especially well adapted to crop inspection and to crop and orchard dusting. (See Figure 9-9.) It has also

Figure 9-9

found use in the oil fields in locating areas suitable for the drilling of wells, and it promises to have extensive future use in prospecting. Without incurring expense for the preparation of runways, the helicopter can go into back country, land vertically, and come out with a vertical take-off. It can serve efficiently in putting pilots aboard incoming ships and taking them from outgoing craft, thus saving the expense involved in the use of a pilot tug.

Many uses, some of them widely publicized, have been made of the helicopter's unusual abilities. They have served for example, in connection with Arctic explorations and observations. (See Figure 9-10.) In this work, they are used to go ahead of the icebreaker and check the apparent thickness of ice, noting the location of gaps and cracks that can be followed by the icebreaker as the most practical route.

Their use in flood disasters has earned headlines for them in newspapers all over the world. New services are being discovered daily that only the helicopter can fill. (See Figure 9-11.)

Commandant M. Lame, in a book "Le Vol Vertical" (Vertical Flight) sums up the case of the helicopter, which his words express as well today as when they were written in 1926:

"Thus we are fully convinced that in the near future we will see realized the dream of the bird man . . . a machine subservient to his will, doing whatever he demands, like the stories of the fabulous thousand-and-one nights; pushing a button to rise, descend, stop and go in one or another direction as he may desire. In other words, an obedient machine which he can operate without fear of having it throw him out by failure or by chance, precipitating him from the heights to the ground, leaving him gasping, unconscious, paying with his life for his imprudence in having wished to fly too soon, with inadequate wings.

"To fly, certainly . . . but to fly comfortably without risk, and according to your own wishes . . . that is the goal. Nobody can possibly deny the utility, the interest, and the nobility of such a goal."

The helicopter of today is the result of the experience, effort, knowledge, and skill of many men adding their efforts to those of a comparatively small number of outstanding leaders. The helicopter of the future is being developed by many of these same far-seeing pioneers. And working with these veterans are many new helicopter enthusiasts now entering the field, who will beyond question contribute by their efforts and ingenuity to the science of vertical flight.

Figure 9-10

Figure 9-11

GLOSSARY OF TERMS

Advancing blade. The rotor blade that is moving against the relative wind.

Alpha hinge. The rotor blade hinge which permits the blade to lag in the plane of rotation.

Angle of attack. The angle formed by the relative wind and the chord of the airfoil. The advancing and retreating blades of the helicopter vary their angles of attack in making a cycle of rotation.

Angle of incidence. The angle formed between a plane at right angles to the rotor shaft and the chord of the rotor blade. This angle changes continually while the helicopter is in flight.

Articulated rotor. A rotor with blades that are individually hinged so that each blade has freedom of motion in both the flapping plane and the plane of rotation.

Aspect ratio. The square of the mean chord divided by the area of the surface of a rotor blade. For straight rotors this becomes the span divided by the chord.

Autogiro. An aircraft having rotary airfoils which act only as a means of support. "Autogyro" is a trade name for the Cierva-type aircraft. Engine power is not delivered to the overhead rotors while in flight, lift being provided by flow of air upward through the rotor blades, causing them to rotate at a high rpm. Engine power is delivered to a conventional type propeller in the nose of the aircraft, which provides the forward thrust.

Autorotation. A flight condition in which the lifting rotor is driven by the action of the relative wind only. No mechanical power is applied.

Autorotative landing. Any landing of an aircraft with rotors in which the entire maneuver is accomplished without application of power to the rotor.

Blade dampers. Spring or hydraulic cushioning devices to absorb shock and to reduce the oscillations of the rotor blade around the vertical hinge connecting it with the rotor hub.

Blade element. A chordwise cross section of a rotor blade.

Blade loading. Total weight of the helicopter divided by the area of the rotor blades.

C.A.S. (Calibrated air speed). The air speed indicator reading, corrected for position and instrument error. Equal to true air speed, (T.A.S.) in standard atmosphere at sea level.

Center of gravity. An imaginary point where the resultant of all forces of gravity may be considered to be concentrated.

Center of pressure. The imaginary point where the resultant of all aerodynamic forces of an airfoil may be considered to be concentrated.

Centrifugal force. A force created by revolving a system around an axis, and characterized by its tendency to pull away from the axis. In a helicopter centrifugal force tends to pull the rotating blades away from the rotor head, to form a flat disc area.

Coaxial rotor configuration. A helicopter configuration in which two concentric rotors turning around the same axis, rotate in opposite directions. Opposite concentric rotation is used to compensate for torque reaction.

Collective pitch change. A mechanical means of simultaneously increasing or decreasing the pitch of the main rotor blades. The angular change is equal on all blades.

Coning. Lift on the rotor blades causes them to flex upward to form a cone. This lifting force on the blades is counteracted by centrifugal force. Coning is the resultant of these two forces on the blade.

Coning angle. The angle between the plane of rotation and the spanwise axis of the rotor blade. Sometimes called the beta (B) angle.

Coriolis force. The force normal to the path of a given mass moving in a rotating plane. A cyclic force that tends to cause oscillation of the rotor blade in the plane of rotation.

Cyclic pitch change. A mechanical means employed to change the pitch of the main rotor blades as they move through their cycle of rotation. This change produces the tilt in the tip-path-plane that gives directional motion to the helicopter.

Delta hinge. The "flapping" hinge, which permits the rotor blade to adjust itself to various combinations of centrifugal force and lift forces. Permits movement of the rotor blade in a plane perpendicular to that of the rotor disc.

Density altitude. Density altitude is that altitude at which the air density is the same as at true altitude in a standard atmosphere. Conversion of true altitude to density altitude is based on field air conditions, barometric pressure and air temperature. Conversion of *pressure altitude* to density altitude is based upon temperature only.

Disc area. The area swept by the blades of the rotor. This is a circle with its center at the hub axis and a radius of one blade length.

Disc loading. The weight supported per unit of rotor area. Total weight divided by the rotor disc area.

Dissymmetry of lift. The unequal lift across the rotor disc resulting from the difference in the velocity of air over the advancing and retreating halves of the disc area.

Drag. The force which tends to resist movement of an airfoil through the air. It is always parallel to the relative wind and perpendicular to the lift. Drag varies as the square of the velocity of the airfoil with respect to the relative wind.

Dynamic stability. The ability of the helicopter to dampen oscillations imposed by external forces, and to return to a condition of steady flight.

Feathering action. Action that changes the angle of incidence of the rotor blades periodically by turning them around their spanwise axis.

Figure of merit. The ratio between the power required to turn the rotor and the thrust output of the rotor. Mathematically expressed as

$$M = .0707 \left(\frac{C_T{}^{3/2}}{C_Q} \right)$$

Flapping. The movement of a blade vertically about a horizontal hinge. One reason for "flapping" action is the dissymmetry of lift that exists between the advancing and retreating sections of the blade cycle.

Flapping plane. The plane, perpendicular to the rotor disc, which contains the blade-span axis as it moves upward or downward to balance forces imposed on the blade.

Flight path. The path along which the center of gravity of the helicopter moves with reference to the earth.

Freewheeling unit. A component part of the main transmission, which permits the main rotor to turn free when its speed exceeds that of the engine.

Ground cushion. The stream of air passing down through the rotor appears to build a circular volume of air more dense from the ground up. It is fully effective up to ½ the rotor diameter, and partially effective up to one rotor diameter.

Gyrodyne. Trade name of a rotor aircraft in which power is supplied both to the horizontal helicopter type rotor and to a vertical propeller similar to that used in conventional aircraft.

Gyroplane. Trade name of a rotor aircraft which depends principally for its support upon the lift generated by one or more rotors which are not power driven except for initial starting, and which are caused to rotate by action of the air when the aircraft is in motion. The propulsion is independent of the rotor system and usually consists of conventional propellers.

Gyroscopic precession. A characteristic of all rotating bodies. Such bodies will be uniformly displaced 90° in the direction of rotation from which a force is applied.

Helicopter. An aircraft sustained in flight by one or more overhead rotors. Power is delivered to the overhead blades by an engine, the air moving from the top down through the revolving blades under power. The airflow is upward during autorotation. Propulsion is obtained by tilting the tip-path-plane in the direction of flight.

Hovering. Type of flight that maintains a fixed position over a spot on the ground. While hovering in a zero wind condition, lift equals gross weight.

Hovering with ground effect. The flight of a helicopter with zero air speed, near enough to a ground or water surface to compress a cushion of high-density air between the main rotor and the ground or water surface and therefore increase the lift produced by the main rotor. Usually the main rotor must be within one half of the rotor diameter to produce a fully effective ground cushion.

I.A.S. (Indicated air speed). The pitot static airspeed indication reading, without correction for airspeed indicator errors.

Inertia. That property by virtue of which a body at rest remains at rest; or if moving continues in motion in the same straight line unless acted upon by some external force.

Main rotor. All the blades and parts which make up the lifting and propelling system of the helicopter.

Rigid rotor. A rotor system with blades fixed to the hub in such a way that they can feather only, but cannot flap or drag.

Semi-rigid rotor. A two-blade rotor system with blades fixed to the hub with a gimbal, so that they are free to flap and feather.

Solidity. The ratio of blade area to rotor disc area.

Standard atmosphere. An atmosphere in which: (1), the air is a dry, perfect gas; (2), the temperature at sea level is 59° (F.); (3), the pressure at sea level is 29.92″ Hg.; (4), the temperature gradient from sea level to the altitude of which the temperature equals −67° F. is 0.003566° F./ft. and 0 thereabove.

Swash plate. A device by means of which cyclic pitch control is applied to the rotor blades. Consists essentially of a nonrotating inclinable plate centered around the mast, a rotating plate tilting as the fixed plate tilts, and a roller bearing between the two plates to transmit angular motion from the fixed to the rotating plate. When the nonrotating plate is moved it acts as a cam, producing reciprocating motion of pitch control arms connected by linkage or other means to bell cranks which change the angle of attack of the rotor blades as they rotate.

Tail rotor. A rotor mounted so that its blades turn in a vertical plane and located in the aft section of the helicopter to offset the torque effect of the main rotor. Control of the pitch of the blades makes it possible to compensate for the torque of the main rotor, or to over-compensate or under-compensate, thus controlling the azimuth position of the helicopter.

Tip-path-plane. The imaginary circular surface formed by a plane passed through the average tip path of the rotor blades.

Tip speed. The velocity of the rotor blade at its tip.

Torque. A force or combination of forces that tend to produce a rotating or twisting motion. In a single rotor helicopter where the rotor turns counterclockwise the fuselage tends to turn clockwise. In this case, torque is compensated for by the tail rotor.

Tracking. A term denoting the satisfactory relationship of the rotor blades to each other under dynamic flight conditions. The relationship is established whenever the blade tips rotate in the same plane. ("Tracking" through usage connotes the mechanical procedure used to bring the blades to the above satisfactory flight condition.)

Translational lift. The lift supporting the helicopter resulting from the translational displacement of the craft through the air; that is, through air speed. When the helicopter is hovering or has zero air speed, under no wind conditions, it has no translational lift.

True altitude. The actual altitude or elevation above sea level.

Wobble plate. Same as Swash Plate.

BIBLIOGRAPHY

A Balsa-Dust Technique for Air-Flow Visualization and Its Application to Flow Through Model Helicopter Rotors in Static Thrust. Marion K. Taylor, NACA TN 2220

A General Theory of the Autogyro. H. Glauert, Aeronautical Research Committee, (England), R & M No. 1111

Aerodynamics of the Airplane. Clark B. Milikan, John Wiley & Sons Inc., N.Y. 1941

Aircraft Designer's Data Book. Leslie E. Neville, McGraw-Hill Book Co., N.Y. 1950

An Analysis of the Autorotative Performance of a Helicopter Powered by Rotor-Tip Jet Units. Alfred Gessow, NACA TN 2154

An Introduction to the Physical Aspects of Helicopter Stability. Alfred Gessow and Kenneth B. Amer, NACA TN 1982

Anything a Horse Can Do. (The Story of the Helicopter) Col. F. H. Gregory, Reynal & Hitchcock, N.Y. 1944

Autogyros, Helicopters, Cyclogyros and Gyroplanes. U.S. Works Progress Administration, 1938

Basic Factors of Helicopter Design. R. H. Prewitt, Presented Detroit Meeting SAE, Jan. 4, 1945

Bibliography, Rotary Wing Aircraft. Engineering Div. Wright Field; Ohio 1944

Copters in Korea. G. W. Fry, Aero Digest, Nov. 1950

Desirable Longitudinal Flying Qualities for Helicopters and Means to Achieve Them. F. B. Gustafson, Aeronautical Eng., June 1951

Dynamic Stability of a Helicopter with Hinged Rotor Blades. Kurt Hohenemser, NACA TM No. 907

Effect of Rotor-Tip Speed on Helicopter Hovering Performance and Maximum Forward Speed. Gustafson and Gessow, NACA Rep't No. L6A16

Engine-Off Landings. O. L. Fitzwilliams, "Flight," Nov. 1947

Faster Helicopters are Future Goal. I. Sikorsky, SAE Jl., Dec. 1950

Full Scale Investigation of the Aerodynamic Characteristics of a Typical Single-Rotor Helicopter in Forward Flight. Richard C. Dingeldein and Raymond F. Schaefer, NACA TR 905

Full-Scale-Tunnel Investigation of the Static-Thrust Performance of a Coaxial Helicopter Rotor. Robert D. Harrington, NACA TN 2318

Ground Vibrations of Helicopters. N. L. Deutsch, Jour. of Aeronautical Sciences, May 1946

Helicopter Drives: Mechanical Transmission Systems. D. W. Botstiber, Machine Design, April 1951

Helicopter Engineering. Raymond A. Young, Ronald Press, N.Y. 1949

Helicopter Stability via Automatic Control. D. N. Meyers and E. G. Vanderlip, Aero Digest, June 1951

Helicopters of Tomorrow. Bernard J. Hurren, Staples Press, N.Y. 1947

Helicopters, Present and Future. I. Sikorsky, Aeronautical Eng., Feb. 1951

Horizontal Flight of the Helicopter. H. Glauert, Aeronautical Research Committee (England) R & M No. 1157

Hovering and Low-Speed Performance and Control Characteristics of an Aerodynamic-Servo Controlled Helicopter Rotor System. Carpenter and Paulnock, NACA TN 2086

In the Helicopter After Dark: Night Flying Tests. A. Klemin, Aero Digest, Dec. 1949

Introduction to Helicopter Aerodynamics. Wieslaw Z. Stepniewaki, Rotocraft Pub. Co., Morton, Pa. 1950

Jet Propulsion Applied to Helicopter Rotors. R. H. Miller, Jour. of Aeronautical Sciences, December 1946

Limitations in Helicopter Design, J. A. J. Bennett, American Helicopter, May 1947

Longitudinal Flying Qualities of Several Single-Rotor Helicopters in Forward Flight. Gustafson, Amer, Haig and Reeder, NACA TN 1983

Method of Improving the Inherent Stability and

Control Characteristics of Helicopters. R. H. Miller, Jour. of Aeronautical Sciences, June 1950

McCulloch Tandem Rotor Helicopter, Automotive Industries, April 15, 1951

New Helicopter Powered by Twin Ram Jet Engine. Automotive Ind., Mar. 1, 1951

Notes on Helicopter Design Theory. Alexander A. Nikolsky, Princeton University Press, Princeton, N.J., 1944

Performance of Rotary Wing Aircraft. Kurt Hohenemser, NACA TM No. 871

Pioneering the Helicopter, Lester Morris, McGraw-Hill Book Co., N.Y. 1945

Ramjets Power Hornet Helicopter. Aviation Week, Feb. 19, 1951

Report on Helicopter Developments in Germany. R. H. Prewitt, SAE, N.Y. 1945

Rotating Wing Activities in Germany During the Period (1939-1945). R. N. Liptrob, H. M. Stationery Off, London, 1948

Rotary Wing Aircraft. J. A. J. Bennett, Aircraft Engineering 1940

Stability of the Parachute and Helicopter. Harry Bateman, NACA TR 80, 1920

Summary of Airfoil Data. Abbott, von Doenhoff and Stivers, NACA, ACR LSE21

The Helicopter Flying Machine. James R. Porter, D. Van Nostrand Co., N.Y. 1911

The Helicopters are Coming. Clinton B. Macauley, McGraw-Hill Book Co., N.Y. 1944

The How of the Helicopter. Alfred Hull Stevens, Jr., Cornell Maritime Press, 1946

The Problem of Vertical Flight. Parlee C. Gross, General Pub. Co., McComb, Ohio 1931

The Rotating Wing in Aircraft. H. E. Wimperis, Aeronautical Research Committee (England) R & M No. 1108

The Story of the Helicopter. D. E. Francis, Coward-McCann Inc. N.Y. 1946

The Story of the Winged-S. Igor F. Sikorsky, Dodd, Mead & Co., N.Y. 1948

Theory of Helicopter Damping in Pitch or Roll and a Comparison with Flight Measurements. Kenneth B. Amer. NACA TN 2136

Type of Lifting Rotor with Inherent Stability. K. Hohenemser, Aeronautical Science, Sept. 1950

U.S. Rotary Wing Aircraft, Tabulation. Automotive Industries, March 15, 1951

Up With the Helicopter. Fortune, May 1951

Vertical Flight. Parlee Clyde Gross, General Pub. Co., McComb, Ohio, 1947

What's Wrong With Today's Helicopters? F. N. Piasecki, Aeronautical Eng., Sept. 1950

U. S. GOVERNMENT PRINTING OFFICE : 1957 O -418490