DOWNLOAD PDF HELICOPTER ROTOR SYSTEM AND DESIGN

Chapter 1 : Rotor Blade Design

A helicopter main rotor or rotor system is the combination of several rotary wings (rotor blades) and a control system that generates the aerodynamic lift force that supports the weight of the helicopter, and the thrust that counteracts aerodynamic drag in forward flight.

We will, therefore, now look at several rotorblade designs. This ratio depends on the design of the aerofoil , and before we go on to discuss a number of types, we will first introduce the fineness ratio. This is the thickness of the airfoil as a percentage of the chord length. The types of aerofoils used with a rotorblade differ figure below. For a long time, most of them were symmetrical. Due to the greater internal forces occurring in these types of blades, they only came into existence when the appropriate composite materials were developed. These can cope with the high internal strain, while their weight is kept low. Blade twist and tapper When a blade rotates, each point on it travels at a different speed. The further away from the root, the higher the velocity. This means that the contribution to lift and drag of every point on the blade differs, with each aspect getting larger when moving closer to the rotor tip. Clearly, the lift distribution over the blade is not constant. This is not a desirable situation, because the contribution diminishes when getting closer to the root. To change this distribution, blades are twisted and, sometimes, also tapered. The twist is such that the angle of attack increases when travelling towards the root, producing more lift. Tapering the blade also contributes to achieving a more evenly spaced lift distribution. Both tapering and twisting can be observed when looking carefully at rotorblades at rest. Note that blade tapering is not always used especially on metal blades because of a more complicated fabrication process. Blade root cut out Blade twist and taper leads to large angles of attack and large blade surfaces at the root. However, close to the root, the blade is travelling over the hull, so the generated downwash does not contribute to helicopter thrust. For this reason, rotorblades are often cut out near the root. Another reason for rotor blade cut out is to reduce the effects of potential reverse flow on the retreating rotorblade when flying at high speeds. Twisting moments Rotorblades are constantly strained by moments that try to twist them. This twisting has its origins in the moments which exist between the centre of pressure due to the aerodynamic forces and the mass centroid over the chord line. The blade designer must take these twisting moments into account by designing a blade with high torsional stiffness. He must also ensure that the mass centroid is located ahead of the centre of pressure for all blade angles in its operational range. In this way, lift tends to lower the angle of attack: Blade tip speed and noise reduction When the blades are very long or the helicopter is designed with a high rotor RPM, the blade tip speed can become extremely high. When the tip speed reaches the sound of speed, pressure waves come into existence, which causes rotor drag. A high tip speed is also the single most important design parameter influencing generated noise levels. In this way, blade efficiency is traded off for noise reduction instead of better flight performance. Note that the weight of the rotor also has important consequences for both the necessary engine power and stored kinethic energy important for good auto-rotation performance. The early designs of rotorblades, which resemble early classic wing design, consisted of long steel tube spars, wooden ribs and some light surface material attached to them. From the s onwards, all metal aluminium alloy blades were introduced. These were constructed from long hollow leading edge D-spar extrusions, allied with some light probably aluminium trailing edge constructions. The use of extrusions made blade taper difficult to produce. Honeycomb constructions were added to achieve a stiff and light construction. These days, composite materials like fibreglass and carbon fibre are used for the fabrication of rotorblades. Stainless steel leading edge spars are also used, and all composite spar designs exist too. The fatigue life properties of composite materials are far better than those of metals. Fibreglass is used for its strength and chemical inertness. Carbon fibre layers, sandwiched at right angles, are used to add stiffness. A sample design might look like the figure below. At the leading edge, an often metal erosion shield is used. When using modern composite materials, lightning strikes have to be considered because these are more dangerous to composite constructions. This is because of the much greater electrical resistance of composite materials compared to all metal blades. In order to provide a low resistance electrical path, the solution is to have an outside skin that possesses low electrical resistance and connects all of the rotor segments.

Chapter 2 : Sikorsky Archives | S

Figure The major components of a helicopter are the airframe, fuselage, landing gear, powerplant, transmission, main rotor system, and tail rotor system.

X-Wing Conceptual Aircraft Background The X-Wing is one of a number of concepts proposed to combine the hovering capabilities of the helicopter with the speed potential of fixed wing aircraft. It has the promise of breaking the trend of VTOL aircraft where higher speed requires higher hovering disc loadings weight of the aircraft divided by the area of the rotor disc, expressed as lbs. Because of its low hovering disc loading plus the power to fly at high subsonic speeds, a two-engined X-wing aircraft could hover and fly a good portion of its flight envelope on only one engine. Cheesman employed the Coanda principal to create and then modulate the lift on a cylindrical rotor blade. The Coanda principle is that if air is blown tangentially over a surface it will adhere and follow the surface until the curvature gets too great and it detaches. Thus it can be used as a virtual flap on an airfoil. He believed that such a rotor could be stopped and started in flight if used on a winged vehicle, and employed only for takeoff and landing. The rotor would then be stopped and stowed for cruise efficiency. X-Wing promised high subsonic speeds with low disc loading Engineers at the U. Using available small turboshaft engines, a flight envelope of approximately Mach 0. Following the feasibility activity, a flight worthy rotor system design and fabrication was initiated in mid, with whirl tower testing commencing in late In the spring of , the test module entered the NASA Ames 40 x 80 wind tunnel for seven weeks of exhaustive testing. During this period the system was tested in helicopter, fixed-wing, and conversion flight modes with the moment feedback control system in open- and closed-loop operation. The blades also have to be extremely stiff since two of them become forward-swept wings in the stopped rotor flight mode. The starting and stopping sequence requires complex high-frequency manipulation of the circulation control valving system to provide controllable forces and moments during the conversion process. This requires the latest in the state-of-the-art in computation capability to control the process. Other technical challenges included the design of large compressor to provide the circulation control air, and a high energy clutch and a brake to start and stop the rotor. Hub moment feedback was required to control the rotor in conversion. Both the technical challenges and achievement of the full aircraft potential were major steps in the state-of-the-art. Two design teams were established at Sikorsky. The second worked on how to test these systems on the RSRA. Much detailed work was required on all the disciplines involved. A detailed 10 foot diameter wind tunnel model was developed to optimize the design. Testing with this model began in December, at Sikorsky. In June, it was tested in the United Technologies large-scale wind tunnel for forward flight tests prior to the actual RSRA flight test. Initial tests used dummy blades for development of the pnuemodynamic system from the compressor inlet to the blade root. Then the blades were installed for a full system test. The four computers were tied to a full set of aircraft sensors, hydraulics, electric power and actuation components, as well as a fixed-base cockpit. All the aircraft instrumentation was duplicated. Hundreds of operational hours were accumulated on the system prior to the start of the flight test program. This VMSL became the prototype for all subsequent Sikorsky flight control system integration laboratories. All of this came together on the RSRA test aircraft. After taxi tests, the aircraft was flown without the X-Wing blades installed to establish baseline date. RSRA was designed to fly new rotors when they were not producing lift, and to return to base in an emergency after the rotor blades had been severed from the rotor head. Thus it could fly as a fixed wing airplane without a rotor. When this test occurred it was a special event for the Sikorsky team. Igor Sikorsky spent his early career producing fixed-wing aircraft, including the large flying boats in the s. But a new Sikorsky-designed fixed-wing aircraft had not flown in almost a half of a century RSRA Flying in Fixed Wing Mode The plan was to then fly it first with two rotor blades, followed by four blades, with the rotors stopped. In the Government had funding issues and higher priorities, and decided to terminate the contract. The program was terminated due to this lack of funding rather than for any technical issues. The blades could not rely on centrifugal stiffening like a conventional helicopter since they had to operate when the rotor was stopped. Composites were used to provide this extreme stiffness at an acceptable weight. X-Wing blade compared to Sikorsky S Rotor hub flexbeam design Rotor flexbeam manufacture The blade manufacturing and tooling challenges were unprecedented in the rotary wing field and involved development of a unique curing process for the very thick composite components. New processes had to be developed to characterize the material, define the allowable void size and establish a quality control procedure. One of the test features of the RSRA was the ability to pyrotechnically sever the rotor blades in case of an emergency, and to return to base as a fixed wing aircraft. It was desired to keep this feature for X-Wing testing. Developing this system for the very thick composite flexbeams of the X-Wing became another large development project and a great achievement for the team. Circulation control was used to develop and modulate lift by blowing air out slots above the trailing edges which would attach to the surface and create virtual flaps. In the helicopter mode this provided the cyclic pitch, and had the additional advantage of being able to provide higher harmonic pitch which was required to control the rotor during the stopping and starting sequences. No mechanical cyclic control was needed, although a mechanical collective pitch mechanism was used similar to that used on conventional helicopters. Blade cross-section with air blowing out the trailing edge The following illustration shows the need for both leading and trailing edge blowing. In rotary wing mode, air is blown out the trailing edges of the blades. During conversion the aerodynamics get much more complicated, with circulation control blowing required out of both the leading and trailing edges at the same time. Need for both leading and trailing edge blowing To provide the air for the circulation control system a two-stage axial compressor was used driven off the main gearbox. It fed air to a plenum mounted below the rotor concentric with the rotor shaft. This was a pneumatic swashplate, with the stationary element collecting air from the compressor, valves to control the flow, and a rotating element which passed the air out to the blades. The circulation control valving system consisted of 48 valves, 24 for leading edge blowing and 24 for the trailing edge. Note the size of the plenum hardware in relation to the technician working on it Both a high energy clutch and brake were provided for the rotor starting and stopping operations. The clutch was developed by Allison. The clutch concept became the basis of the clutch design eventually used to manage the lift fan on the Joint Strike Fighter, the F This was done by controlling the pneumatic control valves in the plenum as well as the mechanical collective pitch change mechanism and the compressor. During the conversion process it also controlled the clutch, the brake, and the positioning index system. At the time it was the most sophisticated system of its kind other than the space shuttle. For the prototype aircraft a convertible engine was planned which could provide both shaft power for the rotor and compressor and thrust for high speed flight, and modulate between the two in a controlled fashion. A cross section of such an engine is shown below. In this design, variable inlet guide vanes control the mix between shaft power and thrust. It was a modified TFB engine and produced up to pounds of thrust with the inlet guide vanes open, and shp plus pounds of thrust with the inlet vanes fully closed.

Chapter 3 : Coaxial Rotor System: the future of helicopter design?

helicopter rotor system and design-sumeet -guide -mrs. ghodke s. k. veer basic introduction this is what helicopter is! actual helicopter.

The transmission takes the engine output torque at a certain angular velocity and transfers it to the rotors at another angular velocity and torque in order to prevent it from damaging the system. The other components being main and tail rotor gear boxes. The main rotor gear box serves to reduce the velocity at which the engine shaft rotates. This is to prevent the tips of the blades from spinning faster than the speed of sound. This is undesirable as it would require the blades to be extremly strong and would be very loud! Although clutches vary with model, the two most common are the belt-driven and centrifugal arrangements. As for example, in the R22 helicopter from Robinson, the clutch arrangement is belt-driven. In this arrangement, mainly seen on small helicopters, the pulley on the engine shaft is connected to a pulley on the driving shaft going to the main rotor gear box and tail rotor gearbox. In all, there are six pulleys and belts side-by-side. The belts are loosely fitted around the engine and driving shaft pulleys. In order to make the engine shaft pulley drive the top pulley, the pilot of the helicopter has to move an adjustable pulley, called the idler, and push it against the belts. This in turn tightens the belt and allows the engine shaft pulley to drive the driving shaft. The adjustable pulley is pushed against the belts by a pilot-activated lever on older models or by an electric motor on newer ones. On the top pulley, there is a sprag clutch. Whenever the engine shaft is driving the shaft in the top pulley, the rollers inside the clutch are forced to the outer drum and prevent the top pulley from exceeding engine shaft rpm. This clutch serves as a freewheeling unit. This characteristic of the sprag clutch could allow a pilot to land a helicopter safely if the engine stalled or simply stopped functioning. Figure 2 The collective and cyclic levers control the helicopter. These two control the motion of the swashplate system. It consists of two plates separated by ball bearings. The top plate rotates freely. The bottom plate is a non-rotating plate and can move vertically and tilt in any direction. The pilot can affect the vertical position of the plates by moving the collective lever and the tilt through the cyclic lever. The cyclic control lever can tilt the swashplates in any direction. The rotating plate has pitch links connecting it to the pitch horns on the blade. This allows the rotating plate to change the angle of each blade. By adjusting the collective control lever, the pilot can move the stationary plate up and change the angle of attack of the blade. If it is increased up to the stall angle , the helicopter rise. Figure 3 Something to notice is that the interaction between the rotating plate above the stationary plate creates a torque that causes the helicopter to spin opposite to the blades. On a conventional helicopter, this is where the tail rotor comes in. The tail rotor serves as an "anti-torque rotor" that counteracts the toque produced by the spinning rotating plate and blades. To turn, the pilot either increases the angle of attack on the tail rotor blades to spin one way or decreases it to spin the other way. To simplify this, think of the blade rotation as a rotating disc.

Chapter 4 : StopRotor | A Stop Rotor Aircraft | Unmanned Aerial Systems

Helicopter Rotor System and Design time to refine, the NOTAR system is simple in theory and works to provide antitorque the same way a wing develops lift. A variable pitch fan is enclosed in the aft fuselage section immediately forward of the tail boom and driven by the main rotor transmission.

Along the way there have been attempts to design the machine in order to: The servo-flap is one method that has been found to be of use in tackling some of these problems. The servo flap is a small airfoil located at about 75 percent span of the rotor blade, situated on the trailing edge of each rotor blade. These flaps are controlled by the pilot through push-pull control rods and their function is similar to that of an elevator on fixed wing airplanes. Moving the trailing edge of the flap upward moves the leading edge of the main rotor blade up. This increases the rotor pitch or the lift in very much the same manner as the elevator, on a fixed wing aircraft, changes the angle of attack on the wing. Thus the helicopter pilot can cause the angle of attack of the flap to increase or decrease in pitch, causing the helicopter to alternately dive or climb. In the conventional rotor design the pitch of the rotor blade is varied by the introduction of a hinge near the root of the blade, which can rotate the blade about the pitch change axis. As could be imagined, the moment arm near the root being smaller than at the three-quarter radius of the blade as it is for the servo-flap the forces required to produce the pitching moment will be much larger. The servo-flap does the work of more complex and heavy hydraulic control systems. Hence for this system the total control forces would be much lower because the work to move the blade happens right where lift is being generated. An accompanying advantage is the fact that this dampens out the vibrations that are generated in the blade due to varying lift and eliminates the transmission of these vibrations to the airframe. Vibrations being the cause for reduced life of the hub and blades and accompanying parts, due to fatigue, is now no longer a factor to contend with. This is what gives the helicopter blade and the hub in such a helicopter its well-touted infinite life, which essentially implies that the life of the rotor blade is equivalent to the life of the airframe. Consider this with the fact that for a conventional helicopter the rotor blade and hub has a far shorter serviceable life than the airframe. Furthermore since the servo flap uses energy drawn from the air-stream to pitch the blades up and down, the control forces need only be high enough to deflect the small servo flaps, thereby reducing the complexity of the control mechanism at the blade hub significantly. Also note the additional stability effect that is factored into such a system where the servo flap by contributing to additional rotational and flapping inertia, provides the system with angle of attack stability as also acts as a gust alleviation device. Thereby justifying the analogy between the servo flap and the elevator in a fixed wing airplane. So in the event of an engine failure, the servo flap responds automatically to increased angle of attack caused by the change in airflow through the rotor and decreasing rotor RPM. Although the pilot still has to lower collective to stabilize the autorotational descent, the servo flap provides the pilot additional reaction time before rotor RPM decays too low. An accompanying advantage is the ability of the system to provide for in-flight rotor blade tracking. This is made possible by an electric actuator in each tab control, which allows tracking in flight and on the ground. This simplified the rotor hub significantly. The first helicopter that Charles Kaman designed was the K in , and the servo-flap was a primary design feature in that. Since then servo flaps have been the method of pitch control in helicopters designed by the Kaman Aerospace Company. Interestingly the conception of pitch control took place at Sikorsky. In , Charles Kaman was working at Hamilton Standard, a division of United Aircraft in East Hartford Connecticut, on propellers and later on the aerodynamic design of the Sikorsky VS Working on the problem of stability and control, he started analyzing ways to overcome this. His initial attempts at providing a hinged surface similar to an aileron in fixed wing aircraft had to be abandoned when he realized the inherent flaw in his design. The assumption that the rotor blade was rigid was physically being violated by the fact that the blade was long and flexible and was unable to contain the lift generated by the lowered flap. As a result the blade twisted down each time the flap was deflected and remained that way until the flap was raised. He abandoned his attempt to reproduce the ailerons on helicopters and started work on the servo flap. While most helicopters control blade pitch by using mechanical force at the rotor hub, he found that servo flaps could change pitch by utilizing aerodynamic forces acting on the blade itself. By eliminating the pitch control mechanism at the hub, the hub could be simplified significantly since the smaller surface area of the servo flap required lower operating forces. The two flaps he designed were about the same size and looked much alike and Kaman bolted the servo to brackets, which extended from the front and back of the blade. The servo flaps separation from the blade was the key difference. After experimenting with different flap configurations he settled on placing the device at the trailing edge of the blade, at the three-quarter-radius point. When Kaman tried to get upper management at Sikorsky interested in the servo flap, he was given an interesting reply. His name is Igor Sikorsky. The Configuration of a Helicopter Using Servo Flaps A good way to understand the advantages of this system is to consider a helicopter that is designed applying this technology. Single seater, external lift intermeshing rotor helicopter and military multi-mission intermeshing rotor aircraft MMIRA. Kaman intermeshing rotor ensures all the engine power is produced for lift, in addition rotor disc loading is very low which provides greater lifting capability per helicopter. It has Kaman intermeshing two bladed contra-rotation rotors with separate inclined shafts emerging from a common transmission. Lifting power is increased because induced drag and downwash of the intermeshing rotor system is reduced and power drain of the tail rotor is eliminated. The blade centerline is offset from the hub and there is a single drag bearing with drag damper. Small trailing edge tabs set the blade pitch, light control loads and low feedback eliminate the need for powerful pitch change rods and levers and hydraulic powered controls, all bending and twisting is caused by pitch change accommodated by blade flexing. The engine is mounted horizontally behind the transmission. Minimum overhaul life for all parts except the engine is hrs. Blade angle of attack is controlled by trailing edge tabs and light control linkages, avoiding the need for hydraulic power. Normal powered flight turns at or near hover are effected by applying differential torque to the rotors by means of differential collective pitch commanded from the foot pedals. Intermeshing rotors cause pronounced pitch attitude change in response to collective pitch change, The K-Max tailplane is connected to the collective to alleviate this problem as well as to reduce blade stresses and to produce touchdown and lift off in level attitude. Light alloy airframe, composite main rotor blades and servo flaps. Tail assembly weighs Karon bearings, Kaflex couplings are used which require no lubrication and zero maintenance. Since the K-Max only requires SHP to operate at the maximum gross weight on a standard day at SL, there is plenty of power for hot and high days. The resulting helicopter can carry more payload for fuel used, maintained with minimum power and fewer parts are required to maintain and track. It can move more weight reliably with less support and lower operating cost. The intermeshing rotor configuration makes the K-Max one of the quietest helicopters. Comparison of the Rotor System with a Conventional Rotor Configuration The servo flap mechanism in essence operates the flap on the trailing edge of the rotor blade in order to change the pitch of the blade. Mechanical linkages from the rotor head run through the blade to this small flap and changing its pitch in much the same manner as that for conventional rotors. Flap and lag hinges are present as in the conventional helicopter blade. This mechanism is different in that it does not require any hydraulics between the pilot and pitch change mechanism because the moment arm is so large that suitable mechanisms can be designed such that pilot effort is low. The collective and cyclic pitch system differs in manner of operation from the conventional configuration due to the use of servo flaps. The primary components in this system are the collective stick, throttle and push-pull control rods connected to the servo flaps through the azimuth assembly. The prime function of the collective system is to control the pitch of all the rotors. Raising the collective lever causes the servo flap trailing edge on each rotor blade to move upward, increasing the pitch on all four blades, collectively and equally. This increases the lift causing the helicopter to rise. Conversely, lowering the collective decreases lift and the helicopter descends. Engine power is synchronized automatically with these pitch changes to hold the RPM constant. In a synchropter like the K-Max, the collective is mechanically linked to the moving elevators on the tail boom. Up collective results in the elevator leading edge to move up. This further reduces the pilot workload by minimizing pitch attitude changes with collective lever movement. The cyclic control system consists of the cyclic control stick and push pull rods connected through the azimuth assembly to the servo flaps. Movement of the cyclic stick in a given direction causes one - or for the intermeshing system - both rotors to tilt and fly the helicopter in the same direction and at speed relative to the amount of stick movement. When the cyclic stick is moved forward one or both the rotors tilt forward equally. The same is true of the aft cyclic stick movement. In the case of the intermeshing system the application of lateral cyclic does not result in both the rotors tilting sideways the same amount as the fore and aft movement. Moving the cyclic to the left cause the left rotor to tilt to the left in proportion to the amount of left control input and conversely for moving to the right. However in the synchropter the directional control system analysis is a bit more involved and will not be included here, as it does not directly allude to the topic at hand. In comparison the conventional rotor-hub design is fairly complicated. The blade in such a design rotates in pitch about a bearing, aligned in a radial direction, which can be a roller bearing stack or a composite flexure. The pitch is applied via an arm projecting forwards from the pitch bearing housing known as the pitch horn. The pitch horn is connected to its own individual track rod by a swivel bearing and vertical movement of the track rod will cause the change in blade pitch angle. The lower end of the track rod is connected to a spider or rotating star, which is constrained to rotate with the rotor. A movement of the spider in a direction parallel to the rotor shaft will cause all the blades to rotate in pitch by the same amount, have the same pitch angle, and hence effect a change in collective pitch. If the spider center maintains its location relative to the rotor shaft but its plane tilts, then it can be seen that as the blade rotates around the shaft as the rotor turns, the spider arm moves up and down once per rotor revolution. That is the blade pitch angle changes once per revolution and cyclic pitch is achieved. The majority of the helicopters achieve this using a swash plate. This is essentially a flat plate joined to the spider such that they remain locked together in the same plane. The swash plate and spider combination slides up and down the rotor shaft and tilts relative to its common center. The swash plate is held stationary relative to the fuselage and its position and orientation is determined by three actuators, or jacks connecting it to the top of the fuselage or main rotor gearbox casing. If the actuators move in unison the swash plate and spider maintain any tilt but slide along the rotor shaft and collective pitch is adjusted. If the actuators move unequally then the rotation plane of the swash plate and spider combination is altered and cyclic pitch is achieved. As can be deduced from the description the conventional hub design is very complicated. Compare this with the rotor hub for a servo-flap configuration. Evidently the use of the servo flap simplifies matters far more than can be conceived. By far the most notable feature in this system is in the simplicity it provides to the rotor hub. Consider the fact that the typical weight of a main rotor blade would be around lbs. Inevitably the amount of force required to operate the servo flap is far less. The servo flap hence obviates the need for the cumbersome design of conventional rotor hubs by getting rid of pitch change bearings and heavy hydraulics required to operate those bearings at the root.

Chapter 5 : Rotorcraft Fundamentals/Introduction to the Helicopter - Wikibooks, open books for an open wo

Rotor blade design covering aerodynamic aspects of airfoils, blade twist and tapper, blade root cut out, blade tip speed and noise reduction, and blade construction.

The Main Rotor System[edit] Figure Helicopters can have a single main rotor or a dual main rotor system. The rotor system found on helicopters can consist of a single main rotor or dual rotors. With most dual rotors, the rotors turn in opposite directions so the torque from one rotor is opposed by the torque of the other. This cancels the turning tendencies. There are variations and combinations of these systems, which will be discussed in greater detail in Chapter 5â€”Helicopter Systems. Fully Articulated Rotor System[edit] A fully articulated rotor system usually consists of three or more rotor blades. The blades are allowed to flap, feather, and lead or lag independently of each other. Each rotor blade is attached to the rotor hub by a horizontal hinge, called the flapping hinge, which permits the blades to flap up and down. Each blade can move up and down independently of the others. The flapping hinge may be located at varying distances from the rotor hub, and there may be more than one. The position is chosen by each manufacturer, primarily with regard to stability and control. Each rotor blade is also attached to the hub by a vertical hinge, called a drag or lag hinge, that permits each blade, independently of the others, to move back and forth in the plane of the rotor disc. Dampers are normally incorporated in the design of this type of rotor system to prevent excessive motion about the drag hinge. The purpose of the drag hinge and dampers is to absorb the acceleration and deceleration of the rotor blades. The blades of a fully articulated rotor can also be feathered, or rotated about their spanwise axis. To put it more simply, feathering means the changing of the pitch angle of the rotor blades. Semi-Rigid Rotor System[edit] A semirigid rotor system allows for two different movements, flapping and feathering. This system is normally comprised of two blades, which are rigidly attached to the rotor hub. The hub is then attached to the rotor mast by a trunnion bearing or teetering hinge. This allows the blades to see-saw or flap together. As one blade flaps down, the other flaps up. Feathering is accomplished by the feathering hinge, which changes the pitch angle of the blade. Rigid Rotor System[edit] The rigid rotor system is mechanically simple, but structurally complex because operating loads must be absorbed in bending rather than through hinges. In this system, the blades cannot flap or lead and lag, but they can be feathered. Anti-torque Systems[edit] Figure The anti-torque rotor produces thrust to oppose torque preventing the helicopter from turning in the opposite direction of the main rotor. Tail Rotor[edit] Most helicopters with a single, main rotor system require a separate rotor to overcome torque. This is accomplished through a variable pitch, antitorque rotor or tail rotor. You will need to vary the thrust of the antitorque system to maintain directional control whenever the main rotor torque changes, or to make heading changes while hovering. The fenestron antitorque system provides improved safety during ground operations. This system uses a series of rotating blades shrouded within a vertical tail. Because the blades are located within a circular duct, they are less likely to come into contact with people or objects.

DOWNLOAD PDF HELICOPTER ROTOR SYSTEM AND DESIGN

Chapter 6 : Radical dual tilting blade helicopter design targets speeds of over mph

A helicopter's main rotor is the most important part of the vehicle. It provides the lift that allows the helicopter to fly, as well as the control that allows the helicopter to move laterally, make turns and change altitude.

Bamboo-copter and Science and inventions of Leonardo da Vinci A decorated Japanese taketombo bamboo-copter The earliest references for vertical flight came from China. Since around BC, [8] Chinese children have played with bamboo flying toys or Chinese top. The spinning creates lift, and the toy flies when released. His notes suggested that he built small flying models, but there were no indications for any provision to stop the rotor from making the craft rotate. Experimental helicopter by Enrico Forlanini , In July , Russian Mikhail Lomonosov had developed a small coaxial modeled after the Chinese top but powered by a wound-up spring device [14] and demonstrated it to the Russian Academy of Sciences. It was powered by a spring, and was suggested as a method to lift meteorological instruments. In , Christian de Launoy , and his mechanic , Bienvenu, used a coaxial version of the Chinese top in a model consisting of contrarotating turkey flight feathers [14] as rotor blades, and in , demonstrated it to the French Academy of Sciences. Sir George Cayley , influenced by a childhood fascination with the Chinese flying top, developed a model of feathers, similar to that of Launoy and Bienvenu, but powered by rubber bands. By the end of the century, he had progressed to using sheets of tin for rotor blades and springs for power. His writings on his experiments and models would become influential on future aviation pioneers. One of these toys, given as a gift by their father, would inspire the Wright brothers to pursue the dream of flight. While celebrated as an innovative use of a new metal, aluminum, the model never lifted off the ground. Steam power was popular with other inventors as well. A movie covering the event was taken by Max Skladanowsky , but it remains lost. Edison built a helicopter and used the paper for a stock ticker to create guncotton , with which he attempted to power an internal combustion engine. The helicopter was damaged by explosions and one of his workers was badly burned. Edison reported that it would take a motor with a ratio of three to four pounds per horsepower produced to be successful, based on his experiments. On 5 May , his helicopter reached four meters 13 feet in altitude and flew for over 1, meters 4, feet. In , those experiments resulted in the Gyroplane No. Although there is some uncertainty about the date, sometime between 14 August and 29 September , the Gyroplane No. For this reason, the flights of the Gyroplane No. On 13 November , it lifted its inventor to 1-foot 0. Even though this flight did not surpass the flight of the Gyroplane No. It consisted of a frame equipped with two counter-rotating discs, each of which was fitted with six vanes around its circumference. After indoor tests, the aircraft was demonstrated outdoors and made several free take-offs. Experiments with the helicopter continued until September , when it tipped over during take-off, destroying its rotors. The rotor hub could also be tilted forward a few degrees, allowing the aircraft to move forward without a separate propeller to push or pull it. Pateras-Pescara was also able to demonstrate the principle of autorotation. His 2F fared better and set a record. His first prototype "flew" "hopped" and hovered in reality on 24 September , [33] with Dutch Army-Air arm Captain Floris Albert van Heijst at the controls. His relatively large machine had two, two-bladed, counter-rotating rotors. Control was achieved by using auxiliary wings or servo-tabs on the trailing edges of the blades, [41] a concept that was later adopted by other helicopter designers, including Bleeker and Kaman. Three small propellers mounted to the airframe were used for additional pitch, roll, and yaw control. Yuriev and Alexei M. Cheremukhin, two aeronautical engineers working at the Tsentralniy Aerogidrodinamicheskiy Institut TsAGI, the Central Aerohydrodynamic Institute , constructed and flew the TsAGI 1-EA single lift-rotor helicopter, which used an open tubing framework, a four-blade main lift rotor, and twin sets of 1. Florine chose a co-rotating configuration because the gyroscopic stability of the rotors would not cancel. Therefore, the rotors had to be tilted slightly in opposite directions to counter torque. Using hingeless rotors and co-rotation also minimised the stress on the hull. At the time, it was one of the most stable helicopters in existence. It was a coaxial helicopter, contra-rotating. After many ground tests and an accident, it first took flight on 26 June Within a short time, the aircraft was setting records with pilot Maurice Claisse at the controls. On 14 December , he set a record for closed-circuit flight with a meter 1,foot diameter. The aircraft was destroyed in by an Allied airstrike at Villacoublay airport. Young , American inventor, started work on model helicopters in using converted electric hover motors to drive the rotor head. Young invented the stabilizer bar and patented it shortly after. A mutual friend introduced Young to Lawrence Dale, who once seeing his work asked him to join the Bell Aircraft company. When Young arrived at Bell in , he signed his patent over and began work on the helicopter. In just 6 months they completed the first Bell Model 1, which spawned the Bell Model 30 , later succeeded by the Bell In he brought his C. This machine had a four blade rotor with flapping hinges but relied upon conventional airplane controls for pitch, roll and yaw. It was based upon an Avro K fuselage, initial rotation of the rotor was achieved by the rapid uncoiling of a rope passed around stops on the undersides of the blades. A major problem with the autogyro was driving the rotor before takeoff. Another approach was to tilt the tail stabiliser to deflect engine slipstream up through the rotor. The most acceptable solution was finally achieved with the C. The rotor clutch was then disengaged before the takeoff run. Most important was the development of direct rotor control through cyclic pitch variation, achieved initially by tilting the rotor hub and subsequently by the Austrian engineer Raoul Hafner , by the application of a spider mechanism that acted directly on each rotor blade. The first production direct control autogyro was the C. The production model, called the C. It carried small movable trimming surfaces. Each licensee used nationally built engines and used slightly different names. In all, production C. Between and , de la Cierva used one C. The Fw 61 broke all of the helicopter world records in , demonstrating a flight envelope that had only previously been achieved by the autogyro. During World War II, Nazi Germany used helicopters in small numbers for observation, transport, and medical evacuation. Lawrence LePage competed to produce the U. LePage received the patent rights to develop helicopters patterned after the Fw 61, and built the XR After experimenting with configurations to counteract the torque produced by the single main rotor, Sikorsky settled on a single, smaller rotor mounted on the tail boom. Total production reached helicopters before the R-4 was replaced by other Sikorsky helicopters such as the R-5 and the R The Model 30 was developed into the Bell 47 , which became the first helicopter certified for civilian use in the United States. Produced in several countries, the Bell 47 was the most popular helicopter model for nearly 30 years. Turbine age See also: Gas turbine and turboshaft In , at the urging of his contacts at the Department of the Navy, Charles Kaman modified his K synchropter â€" a design for a twin-rotor helicopter concept first pioneered by Anton Flettner in , with the aforementioned Fl piston-engined design in Germany â€" with a new kind of engine, the turboshaft engine. On 11 December , the Kaman K became the first turbine-powered helicopter in the world. Two years later, on 26 March , a modified Navy HTK-1, another Kaman helicopter, became the first twin-turbine helicopter to fly. This is largely due to higher engine power density requirements than fixed-wing aircraft. Improvements in fuels and engines during the first half of the 20th century were a critical factor in helicopter development. The availability of lightweight turboshaft engines in the second half of the 20th century led to the development of larger, faster, and higher-performance helicopters. While smaller and less expensive helicopters still use piston engines, turboshaft engines are the preferred powerplant for helicopters today. Today, helicopter uses include transportation of people and cargo, military uses, construction, firefighting, Search and rescue , Tourism , medical transport, law enforcement, agriculture, news and media , and aerial observation , among others. Aerial cranes are used to place heavy equipment, like radio transmission towers and large air conditioning units, on the tops of tall buildings, or when an item must be raised up in a remote area, such as a radio tower raised on the top of a hill or mountain. Helicopters are used as aerial cranes in the logging industry to lift trees out of terrain where vehicles cannot travel and where environmental concerns prohibit the building of roads. Hundreds of pilots were involved in airdrop and observation missions, making dozens of sorties a day for several months. A Bell dropping water onto a fire " Helitack " is the use of helicopters to combat wildland fires. Helibuckets, such as the Bambi bucket, are usually filled by submerging the bucket into lakes, rivers, reservoirs, or portable tanks. Tanks fitted onto helicopters are filled from a hose while the helicopter is on the ground or water is siphoned from lakes or reservoirs through a hanging snorkel as the helicopter hovers over the water source. Helitack helicopters are also used to deliver firefighters, who rappel down to inaccessible areas, and to resupply firefighters. Common firefighting helicopters include variants of the Bell and the Erickson S Aircrane helitanker. A United States

Navy Sikorsky HO3S-1 in action during the Korean War Helicopters are used as air ambulances for emergency medical assistance in situations when an ambulance cannot easily or quickly reach the scene, or cannot transport the patient to a medical facility in time. Helicopters are also used when patients need to be transported between medical facilities and air transportation is the most practical method. An air ambulance helicopter is equipped to stabilize and provide limited medical treatment to a patient while in flight. The use of helicopters as air ambulances is often referred to as " MEDEVAC ", and patients are referred to as being "airlifted", or "medevaced". This use was pioneered in the Korean war , when time to reach a medical facility was reduced to three hours from the eight hours needed in World War II , and further reduced to two hours by the Vietnam war. They are often mounted with lighting and heat-sensing equipment for night pursuits. Such helicopters are mounted with missile launchers and miniguns. Transport helicopters are used to ferry troops and supplies where the lack of an airstrip would make transport via fixed-wing aircraft impossible. The use of transport helicopters to deliver troops as an attack force on an objective is referred to as " air assault ". Unmanned aerial systems UAS helicopter systems of varying sizes are developed by companies for military reconnaissance and surveillance duties. Naval forces also use helicopters equipped with dipping sonar for anti-submarine warfare , since they can operate from small ships.

Chapter 7 : Helicopter rotor - Wikipedia

The design process is represented in Fig. www.nxgvision.com process also includes a sizing module. After setting the size of the helicopter, the helicopter rotor blade shape optimization process is performed as the next step of the design process.

In-flight transition between modes This combination in a single aircraft offers unprecedented flight capabilities. This aircraft design is a new solution to in-flight transition between rotary and fixed wing flight modes enabling stopped rotor aircraft designs. A new aircraft type means new opportunities for the aerospace industry: World first research opportunities A new solution for civil and Defence applications Unprecedented flight capabilities in a competitive market In-Flight Transiiton The StopRotor Innovation The use of high alpha flight controls to provide axial airflow to the rotor system enables transition between flight modes. The StopRotor design combines conventional flight envelopes with controlled, sustainable flight at high angles of attack to achieve axial airflow allowing aerodynamic control of the RotorWing to stop or start enabling transition between flight modes. Flying prototypes have been used to demonstrate this concept. The aerodynamic transition is viewed the same as an aerobatic manoeuvre, using vertical space to complete. Once the transition is complete the aircraft is flown out of the transition envelope and resumes normal fixed or rotary wing flight. High Angle of Attack high alpha flight is routinely performed by high performance military and aerobatic aircraft. Australian Popular Science Feb A StopRotor aircraft combines the ideal flight characteristics of the two most successful aircraft types in the world; the helicopter and aeroplane. The most efficient helicopters have large, slow turning rotors which provide optimum vertical lift. The requirement to achieve forward flight means that the rotor system vertical lift efficiency has to be compromised to generate aircraft movement and provide a useful flight envelope. Large, efficient rotors are subject to early onset asymmetric airflow limiting their forward flight capability. To solve this problem vertical lift capability is reduced in favour of designs that favour forward speed. Faster spinning, shorter rotors provide the control necessary for helicopter flight, but still suffer from the effect of asymmetric airflow as speed increases. As a result of asymmetric airflow, the fastest helicopters achieve speeds of around knots. A StopRotor aircraft overcomes the limitations of a helicopter in forward flight by stopping the rotor and thus can use a rotor system that can be more efficient in hover while allowing high speed, forward flight as a fixed wing. Transition Profile The Hybrid RotorWing transition profile is a paradigm shift but provides a stable predictable flight mode that allows reversible conversion in a controlled and sustainable manner between rotary and fixed wing modes of operation. The transition profile can be completed in multiple attitudes with a brief trade off in energy and or altitude. This profile is the key enabling feature that unlocks the potential of a StopRotor aircraft. It can be optimised for hover performance which also favors performance as a fixed wing. It can be optimised as a higher inertia rotor aiding autorotation performance. It allows a rotor disc loading similar to or lower than a conventional helicopter. Low rotor disc loading minimizes rotor down wash and ground erosion. The RotorWing does not require high blade twist to generate forward thrust in fixed wing modes of operation. It allows for potentially both single or multiple RotorWing configurations It can be designed to favor hover performance or maneuverability subject to the predominant flight mode. Multi Role Aircraft The StopRotor aircraft provides a wide range of performance capabilities, enabling diverse mission profiles, in-flight adaptability and allowing high speed, long range access to remote unprepared landing sites. For a helicopter style mission that involves hovering flight the aircraft would be operated as any other conventional helicopter where the rotor provides the lift and thrust requirements for vertical and horizontal movement. For short range missions the aircraft would be operated as compound helicopter where the rotor would be unloaded but not stopped with wings and forward thrust engine assisting in forward flight. At the destination the aircraft would revert to helicopter operations for a vertical landing or perform a short field landing as required. For long range high speed flight, the aircraft would convert to a fixed wing to take advantage of its high speed, high altitude capability allowing operations above weather like any other fixed wing aircraft. At the destination a conversion to rotary wing mode can be achieved for vertical landing or a conventional runway landing can be made whilst in fixed wing mode.

Chapter 8 : helicopter | Facts, History, & Types | www.nxgvision.com

The design combines the utility of the helicopter rotor system with the performance and efficiency of fixed wing flight. The unique design and method of operation enables inflight transition between modes and where the central wing is utilised as either a rotating or fixed wing.

A decorated Japanese taketombo bamboo-copter. The toy consists of a rotor attached to a stick. The first autogyro to fly successfully in The use of a rotor for vertical flight has existed since BC in the form of the bamboo-copter , an ancient Chinese toy. The spinning creates lift, and the toy flies when released. The Russian polymath Mikhail Lomonosov developed a rotor based on the Chinese toy. The French naturalist Christian de Launoy constructed his rotor out of turkey feathers. One of these toys, given as a gift by their father, would inspire the Wright brothers to pursue the dream of flight. De la Cierva is credited with successful development of multi-bladed, fully articulated rotor systems. This system, in its various modified forms, is the basis of most multi-bladed helicopter rotor systems. The first successful attempt at a single-lift rotor helicopter design used a four-blade main rotor, as designed by Soviet aeronautical engineers Boris N. Yuriev and Alexei M. This system was used in several Bell and Hiller helicopter models. In the late s, the making of helicopter rotor blades was a job that inspired John T. Parsons to be a pioneer of numerical control NC. NC and CNC turned out to be an important new technology that later affected all machining industries. Overview[edit] The helicopter rotor is powered by the engine, through the transmission, to the rotating mast. The mast is a cylindrical metal shaft that extends upward fromâ€”and is driven byâ€”the transmission. At the top of the mast is the attachment point for the rotor blades called the hub. The rotor blades are then attached to the hub, and the hub can have times the drag of the blade. There are three basic classifications: A rotor is a finely tuned rotating mass, and different subtle adjustments reduce vibrations at different airspeeds. This permits a lower downwash velocity for a given amount of thrust. The following are driven by the link rods from the rotating part of the swashplate. Pitch hinges, allowing the blades to twist about the axis extending from blade root to blade tip. Teeter hinge, allowing one blade to rise vertically while the other falls vertically. This motion occurs whenever translational relative wind is present, or in response to a cyclic control input. Scissor link and counterweight, carries the main shaft rotation down to the upper swashplate Rubber covers protect moving and stationary shafts Swashplates, transmitting cyclic and collective pitch to the blades the top one rotates Three non-rotating control rods transmit pitch information to the lower swashplate Main mast leading down to main gearbox Main article: Swashplate helicopter Controls vary the pitch of the main rotor blades cyclically throughout rotation. The pilot uses this to control the direction of the rotor thrust vector , which defines the part of the rotor disc where the maximum thrust develops. Collective pitch varies the magnitude of rotor thrust by increasing or decreasing thrust over the whole rotor disc at the same time. These blade pitch variations are controlled by tilting, raising, or lowering the swash plate with the flight controls. The vast majority of helicopters maintain a constant rotor speed RPM during flight, leaving the angle of attack of the blades as the sole means of adjusting thrust from the rotor. The swash plate is two concentric disks or plates. One plate rotates with the mast, connected by idle links, while the other does not rotate. The rotating plate is also connected to the individual blades through pitch links and pitch horns. The non-rotating plate is connected to links that are manipulated by pilot controlsâ€”specifically, the collective and cyclic controls. The swash plate can shift vertically and tilt. Through shifting and tilting, the non-rotating plate controls the rotating plate, which in turn controls the individual blade pitch. Fully articulated[edit] Diagram of fully articulated main rotor head Juan de la Cierva developed the fully articulating rotor for the autogyro. The basis of his design permitted successful helicopter development. In a fully articulated rotor system, each rotor blade is attached to the rotor hub through a series of hinges that let the blade move independently of the others. These rotor systems usually have three or more blades. The blades are allowed to flap, feather, and lead or lag independently of each other. The horizontal hinge, called the flapping hinge, allows the blade to move up and down. This movement is called flapping and is designed to compensate for dissymmetry of lift. The flapping hinge may be located at varying distances from the rotor hub, and there may be more than one hinge. The vertical hinge, called the lead-lag hinge or drag hinge, allows the blade to move back and forth. This movement is called lead-lag, dragging, or hunting. Dampers are usually used to prevent excess back and forth movement around the drag hinge. The purpose of the drag hinge and dampers is to compensate for acceleration and deceleration caused by the Coriolis effect. Later models have switched from using traditional bearings to elastomeric bearings. Elastomeric bearings are naturally fail-safe and their wear is gradual and visible. The metal-to-metal contact of older bearings and the need for lubrication is eliminated in this design. The third hinge in the fully articulated system is called the feathering hinge about the feathering axis. This hinge is responsible for the change in pitch of rotor blades excited via pilot input to the Collective or Cyclic. A variation of the fully articulated system is the "soft-in-plane" rotor system. The difference between a fully articulated system and soft-in-plane system is that the soft-in-plane system utilises a composite yoke. This yoke is attached to the mast and runs through the blade grips between the blades and the shear bearing inside the grip. This yoke does transfer some movement of one blade to another, usually opposing blades. While this is not fully articulated, the flight characteristics are very similar and maintenance time and cost are reduced.

Chapter 9 : The Heart of the Helicopter: The Rotor Assembly - How Helicopters Work | HowStuffWorks

The design and operation of helicopters have derived the same advances from computers and composites as have other aircraft, especially in the design and construction of the rotor blades. One of the more important improvements is in the simplification of flight-control systems, where a simple side stick controller, with the assistance of.

Helicopters occupy important niches in both military and civil aviation. Military models are of two kindsâ€"combat and transport. Combat helicopters are designed by manufacturers specifically for that military purpose, whereas helicopters for transportation frequently exist in both civil and military variants. Short-distance personnel transportation,â€¦ History One important characteristic of the history of vertical flight is the pervasive human interest in the subject; inventors in many countries took up the challenge over the years, achieving varying degrees of success. The history of vertical flight began at least as early as about ce; there are historical references to a Chinese kite that used a rotary wing as a source of lift. Toys using the principle of the helicopterâ€"a rotary blade turned by the pull of a stringâ€"were known during the Middle Ages. During the latter part of the 15th century, Leonardo da Vinci made drawings of a helicopter that used a spiral airscrew to obtain lift. The first scientific exposition of the principles that ultimately led to the successful helicopter came in from Sir George Cayley , who is also regarded by many as the father of fixed-wing flight. From that point on, a veritable gene pool of helicopter ideas was spawned by numerous inventors, almost entirely in model or sketch form. Many were technical dead ends, but others contributed a portion of the ultimate solution. In there were two significant steps forward. On September 29, the Breguet brothers, Louis and Jacques, under the guidance of the physiologist and aviation pioneer Charles Richet made a short flight in their Gyroplane No. The Gyroplane had a spiderweb-like frame and four sets of rotors. The piloted aircraft lifted from the ground to a height of about two feet, but it was tethered and not under any control. Breguet went on to become a famous name in French aviation, and in time Louis returned to successful work in helicopters. Another man who, like the Breguets, would flirt with the helicopter, go on to make his name with fixed-wing aircraft, and then later return to the challenge of vertical flight, was Igor Sikorsky, who made some unsuccessful experiments at about the same time. The next 25 years were characterized by two main trends in vertical flight. One was the wide spread of minor successes with helicopters; the second was the appearance and apparent success of the autogiro also spelled autogyro. The helicopter saw incremental success in many countries, and the following short review will highlight only those whose contributions were ultimately found in successfully developed helicopters. In the Danish inventor Jacob Ellehammer made short hops in a helicopter that featured contrarotating rotors and cyclic pitch control, the latter an important insight into the problem of control. On December 18, , a complex helicopter designed by George de Bothezat for the U. Army Air Force lifted off the ground for slightly less than two minutes, under minimum control. In Spain in the previous year, on January 9, , Juan de la Cierva made the first successful flight of an autogiro. An autogiro operates on a different principle than a helicopter. Its rotor is not powered but obtains lift by its mechanical rotation as the autogiro moves forward through the air. Autogiros were rapidly improved and were manufactured in several countries, seeming to fill such a useful niche that they temporarily overshadowed the helicopter. Ironically, however, the technology of the rotor head and rotor blade developed for the autogiro contributed importantly to the development of the successful helicopter, which in time made the autogiro obsolete. In Germany stepped to the forefront of helicopter development with the Focke Achgelis Fa 61, which had two three-bladed rotors mounted on outriggers and powered by a horsepower radial engine. The Fa 61 had controllable cyclic pitch and set numerous records, including, in , an altitude flight of 11, feet and a cross-country flight of miles. It was both a technical and a propaganda triumph. Germany continued its helicopter development during World War II and was the first to place a helicopter, the Flettner Kolibri, into mass production. In the United States , after many successes with commercial flying boats, Igor Sikorsky turned his attention to helicopters once again, and after a long period of development he made a successful series of test flights of his VS in â€" Essentially a test aircraft designed for easy and rapid modification, the VS was small weighing 1, pounds and was powered by a horsepower Lycoming engine. Yet it possessed the features that characterize most modern helicopters: As successful as the VS was, however, it also clearly showed the difficulties that all subsequent helicopters would experience in the development process. For many years, compared with conventional aircraft, helicopters were underpowered, difficult to control, and subject to much higher dynamic stresses that caused material and equipment failures. Yet the VS led to a long line of Sikorsky helicopters, and it influenced their development in a number of countries, including France , England , Germany , and Japan. After World War II the commercial use of helicopters developed rapidly in many roles, including fire fighting, police work, agricultural crop spraying, mosquito control, medical evacuation, and carrying mail and passengers. The Bell Aircraft Corporation , under the leadership of Arthur Young , began its long, distinguished history of vertical-flight aircraft with a series of prototypes that led to the Bell Model 47, one of the most significant helicopters of all time, incorporating an articulated , gyro-stabilized, two-blade rotor. Frank Piasecki created the Piasecki Helicopter Corporation; its designs featured a tandem-rotor concept. The use of twin tandem rotors enabled helicopters to grow to almost twice their previous size without the difficulty of creating very large rotor blades. In addition, the placement of the twin rotors provided a large centre of gravity range. The competition was international, with rapid progress made in the Soviet Union , the United Kingdom , France, Italy, and elsewhere. To an even greater extent than fixed-wing aircraft, the development of the helicopter had been limited by engine power. Reciprocating engines were heavy, noisy, and less efficient at high altitude. In conventional aircraft the power of the jet engine was used primarily for increased speed. In the helicopter the thrust of the jet turbine had to be captured by a gearbox that would turn the rotor. The jet engine had many advantages for the helicopterâ€”it was smaller, weighed less than a piston engine of comparable power, had far less vibration, and used less expensive fuel. It rapidly became one of the most influential helicopters in the world and started a trend toward jet-powered helicopters everywhere. There are now a vast number of helicopter types available on the market, ranging from small two-person private helicopters through large passenger-carrying types to work vehicles capable of carrying huge loads to remote places. There are other types of vertical-lift aircraft, whose controls and techniques are often a blend of the conventional aircraft and the helicopter. They form a small part of the total picture of flight but are of growing importance. Because the rotor is not powered, the autogiro does not have to contend with torque the tendency of the aircraft to turn in the opposite direction of the rotor and thus avoided many of the control problems that impeded the development of the helicopter. As the autogiro is propelled forward through the air, with a stream of air flowing upward through its rotor, lift is generated. Control is effected in part through a universal joint at the rotor head, which tilts the blades creating a force that pulls the autogiro in the direction of the tilt. An elevator and rudder are maintained within the propeller slipstream for additional control. They characteristically have the airframe and propulsion system closely integrated so that the propulsion system exhaust flow influences the aerodynamics of the airframe. They encompass a number of types; among the most successful are the vectored jet, the externally blown wing, and the externally blown flap. The most successful of all the alternatives to the helicopter is one of the most technically complex, the vectored jet, best exemplified by the Harrier , developed initially by Hawker Aircraft and brought to maturity by British Aerospace and McDonnell Douglas. In the vectored jet, nozzles are designed to rotate so that the thrust can be applied vertically for takeoff and then moved to a horizontal position for conventional flight. In an externally blown wing system, the exhaust from the jet engines is directed over the upper surface of the wing and in some cases over the outer surface of the flap area. Exhaust from the jet engines in the externally blown flap vehicle is directed against a large flap extension surface. Convertiplanes Other types of vertical-takeoff aircraft include convertiplanes. These are convertible rotorcraft and convertible airplanes. The V stemmed from more than three decades of development, which began with the Bell XV-3 in the early s. It represents a configuration offering the greatest promise for intercity air transportation, combining the utility of the helicopter with speeds approaching that of turboprop transports. The second type is the less frequently found compound helicopter, which has driven rotors and uses both an additional power source and an additional means of generating aerodynamic lift. In this test flight c. The first of these are the deflected thrust type, in which large propellers exert thrust against a wing deflected into a broad arc. The second type is the tilt wing. In these aircraft, the wing is rotated to point the propellers vertically for takeoff and landing, then adjusted for horizontal flight by bringing the wing to a normal angle of attack. The third is the tilt duct, in which propellers shrouded in ducts are rotated from one flight mode to the other. The fourth is the tilt propeller, perhaps the least successful of the group. The Curtiss-Wright Corporation built the X test-bed, which was successful enough to allow the building of the more advanced but ill-fated X-l9 prototype that crashed during testing. Fixed jet A number of attempts have been made to use the power of jet engines to lift an aircraft vertically from the ground and then shift to forward flight, but in every case the difficulties involved in recovery have inhibited the program. An early example, the Ryan X Vertijet, was launched from a trailer bed that was erected vertically prior to takeoff. The Ryan XV-5A Vertifan used a jet engine to drive horizontally mounted fans in the nose and wing; it was nominally successful. Another type of fixed jet used separate batteries of jet engines, some dedicated to vertical flight and some to horizontal flight, but this expensive technology was ultimately rejected. Over time there have been a host of miscellaneous attempts at vertical flight. These include propeller-driven tail-sitters, dusted disc platforms, ground-effect aircraft Hovercraft [trademark] , and deflected jet thrust. In most cases, the advantages sought were offset by the difficulties encountered, and the tilt rotor, the vectored jet, and especially the helicopter have remained the most successful means to vertical flight. In comparison to airplanes, the tail of a helicopter is somewhat elongated and the rudder smaller; the tail is fitted with a small antitorque rotor tail rotor. The landing gear sometimes consists of a pair of skids rather than wheel assemblies. The fact that the helicopter obtains its lifting power by means of a rotating airfoil the rotor greatly complicates the factors affecting its flight, for not only does the rotor turn but it also moves up and down in a flapping motion and is affected by the horizontal or vertical movement of the helicopter itself. Unlike the usual aircraft airfoils, helicopter rotor airfoils are usually symmetrical. The chord line of a rotor, like the chord line of a wing, is an imaginary line drawn from the leading edge to the trailing edge of the airfoil. Relative wind is always considered to be in parallel and opposite direction to the flight path. In considering helicopter flight, the relative wind can be affected by the rotation of the blades, the horizontal movement of the helicopter, the flapping of the rotor blades, and wind speed and direction. In flight, the relative wind is a combination of the rotation of the rotor blade and the movement of the helicopter. Like a propeller, the rotor has a pitch angle, which is the angle between the horizontal plane of rotation of the rotor disc and the chord line of the airfoil. The pilot uses the collective and cyclic pitch control see below to vary this pitch angle. In a fixed-wing aircraft, the angle of attack the angle of the wing in relation to the relative wind is important in determining lift. The same is true in a helicopter, where the angle of attack is the angle at which the relative wind meets the chord line of the rotor blade. Angle of attack and pitch angle are two distinct conditions. Varying the pitch angle of a rotor blade changes its angle of attack and hence its lift. A higher pitch angle up to the point of stall will increase lift; a lower pitch angle will decrease it. Individual blades of a rotor have their pitch angles adjusted individually. Rotor speed also controls liftâ€"the higher the revolutions per minute rpm , the higher the lift. However, the pilot will generally attempt to maintain a constant rotor rpm and will change the lift force by varying the angle of attack.