MODULE 12

FOR CAT-A CERTIFICATION

HELICOPTER AERODYNAMICS STRUCTURES AND SYSTEMS

Aviation Maintenance Technician Certification Series

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REVISION LOG

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MODULE EDITIONS AND UPDATES

ATB EASA Modules are in a constant state of review for quality, regulatory updates, and new technologies. This book's edition is given in the revision log above. Update notices will be available Online at *www.actechbooks.com/revisions.html*
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HELICOPTER AERODYNAMICS STRUCTURES AND SYSTEMS

SUB-MODULE 01
THEORY OF FLIGHT – ROTARY WING AERODYNAMICS

SUB-MODULE 02
FLIGHT CONTROL SYSTEMS

SUB-MODULE 06

AIR CONDITIONING (ATA 21)

SUB-MODULE 07
INSTRUMENTS/AVIONIC SYSTEMS

SUB-MODULE 08
ELECTRICAL POWER (ATA 24)

SUB-MODULE 09
EQUIPMENT AND FURNISHINGS (ATA 25)

SUB-MODULE 10
FIRE PROTECTION (ATA 26)

SUB-MODULE 11
FUEL SYSTEMS (ATA 28)

SUB-MODULE 12
HYDRAULIC POWER (ATA 29)

SUB-MODULE 13
ICE AND RAIN PROTECTION (ATA 30)

SUB-MODULE 14
LANDING GEAR (ATA 32)

SUB-MODULE 15

LIGHTS (ATA 33)

SUB-MODULE 16

PNEUMATIC/VACUUM (ATA 36)

SUB-MODULE 17
INTEGRATED MODULAR AVIONICS (ATA 42)

SUB-MODULE 18
ON BOARD MAINTENANCE SYSTEMS (ATA 45)

SUB-MODULE 19
INFORMATION SYSTEMS (ATA 46)

camber the same, and are known as symmetrical airfoils. These airfoils control how much pressure difference there is between the top and bottom, and therefore lift, by controlling the angle of attack (***Figure 1-8***).

The ideal situation is to have an equal amount of lift be created along the entire length of the helicopter rotor blade. If the force of lift is noticeably different along the blade's length, the blade will try to bend and it will be subjected to forces that could cause it to fail. Because the rotor blades are spinning, the tip will always be at the greatest velocity because it is moving through the greatest circumference of circle. The inner part of the blade, known as the root end, is moving through the smallest circumference and therefore has the lowest velocity. Due to the difference in air velocity, the blade tips would try to develop the most lift and the inner parts of the blade would produce the least. To compensate for this, the blades are manufactured with a twist that causes the blade angle to be lower at the tip and greater at positions closer to the root end. By matching the velocity of the blade position to the proper blade angle, the workload along the length of the blade is evened out. The twist in the rotor blades can be seen in ***Figure 1-9A***. In ***Figure 1-9B*** the increased blade angle closer to the root can be seen at position "A" and the lesser blade angle closer to the tip at position "C".

Figure 1-9 (A). Helicopter main rotor blade twist.

TERMINOLOGY

Rotorcraft: A rotorcraft is a type of aircraft that uses a rotating wing to generate the force (lift) necessary to support it while it is in flight. The type of rotorcraft known as a helicopter also uses the rotating wing to generate the force (thrust) necessary to propel it horizontally. Two other types of rotorcraft are the gyroplane and the gyrodyne. The gyroplane's main rotor is not engine driven, and it uses a conventional propeller for forward flight. The main rotor spins as a result of the air moving over the blades as the gyroplane moves forward. The gyrodyne's main rotor is engine driven, but its forward motion is accomplished by using a conventional propeller or the thrust from a turbine engine.

Cabin: The cabin of a rotorcraft, like that of an airplane, houses the pilots and the passengers. The cabin controls seen by the helicopter pilot include the throttle connected to the powerplant, a cyclic pitch lever connected to the main rotor blades, a collective pitch lever connected to the main rotor blades, and two floor mounted pedals that control the tail rotor.

Landing Gear: The landing gear of a rotorcraft, like that of an airplane, supports it when it is not in flight. The landing gear can be skids, as shown in ***Figure 1-10***, floats, like those used on a seaplane, or traditional wheels and tires like those used on most airplanes.

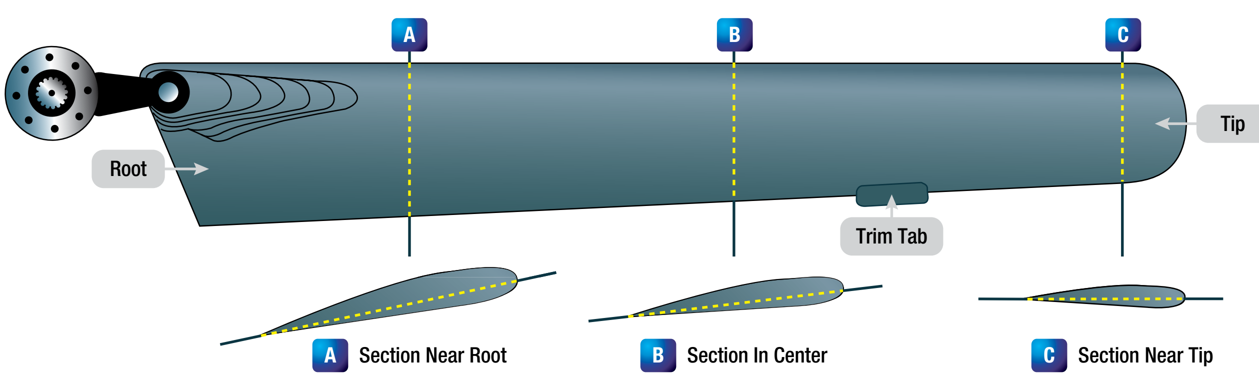

Figure 1-9 (B). Rotor blade angle and thickness.

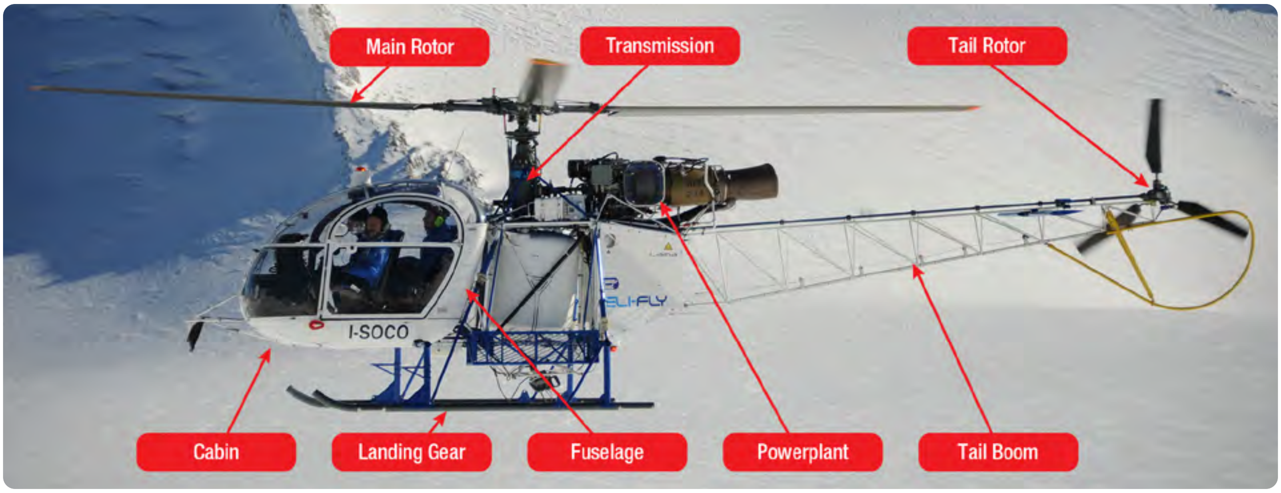

Figure 1-10. Principle parts of a helicopter.

Fuselage: The fuselage is what forms the main body of the rotorcraft, and provides it with the necessary structural integrity. The fuselage can be enclosed by being covered in sheet metal, like the Sikorsky R-4 shown in ***Figure 1-6***, or it can be mostly open tubing like the helicopter shown in ***Figure 1-10***.

Powerplant: The powerplant is the source of energy used to make flight possible. For the helicopter, it drives the main rotor(s), and when applicable the tail rotor. For a gyroplane it drives a conventional propeller and for a gyrodyne it drives the rotors and acts as an energy source for whatever provides horizontal motion. Some rotorcraft are powered by a piston engine, but the majority utilize a turboshaft gas turbine engine. (***Figure 1-10***)

Tail Boom: The tail boom connects the fuselage of the rotorcraft to the most aft location, where the tail rotor is positioned. On a type of helicopter known as a NOTAR (no tail rotor), the tail boom acts as a passageway for air to flow through on its way to being ejected out the back to counteract the torque of the main rotor.

Main Rotor: The main rotor of a rotorcraft is the rotating wings. The rotating wings are airfoils, and they are referred to as rotor blades. On a helicopter and gyrodyne they are driven by the powerplant, and on a gyroplane they are free spinning and driven by the action of the air flowing through them.

Fully Articulated Main Rotor: This type of main rotor has blades that are hinged, so they are able to pivot up and down or fore and aft. This allows the blades to respond to different aerodynamic and mechanical forces that are acting on them, and change their position as they rotate through a full 360 degrees. When the blades pivot up and down it is referred to as blade flap, and when they pivot fore and aft it is referred to as lead/lag. The blades can also change their pitch angle.

Semi-Rigid Main Rotor: This type of main rotor has the blades firmly attached to a rotating hub, with the blades and hub able to teeter like a seesaw. As the blades experience different aerodynamic and mechanical forces acting on them, the entire hub and blade assembly is able to pivot, effectively changing how the blades see the relative wind during their 360 degrees of rotation. The blades can also change their pitch angle.

Rigid Main Rotor: This type of main rotor has the blades firmly attached to a rotating hub that does not pivot, and the blades are able to change their pitch angle. The blades are extremely strong, but they are also flexible. When subjected to aerodynamic and mechanical forces, the blades are able to bend and therefore change the way they see the relative wind during their 360 degrees of rotation.

Tandem Main Rotor: A rotor system that has two main rotors, one located at the front of the helicopter and one located in the back. The use of a tandem rotor cancels out the torque reaction and does away with the need for a tail rotor.

Coaxial Main Rotor: A rotor system that has two main rotors, with one mounted above the other and rotating on concentric shafts with the same axis of rotation. (***Figure 1-11***) The two main rotors rotate in opposite

Figure 1-11. Coaxial main rotor helicopter.

directions, so each main rotor cancels out the torque of the other and no tail rotor is needed. Because of the two counter-rotating main rotors, there is always an advancing blade on each side of the helicopter, meaning the force of lift is equal on both sides.

Transmission: The transmission is driven by the rotorcraft's powerplant, and a shaft coming out of the transmission drives the main rotor. When a rotorcraft has a tail rotor, it is also driven by a shaft coming from the transmission. The RPM of the rotorcraft's powerplant is much too high to drive the main rotor directly, so the transmission acts as a reduction gearbox.

Tail Rotor: The tail rotor consists of two or more airfoils (blades), which act like a propeller to create thrust at the back of the rotorcraft. The tail rotor is also known as the antitorque rotor. When the main rotor blades are driven by the rotorcraft's powerplant, for example in a clockwise direction, there is an equal and opposite force that will try to rotate the aircraft in a counterclockwise direction. This equal and opposite force is known as torque, and the tail rotor counteracts the torque. The thrust from the tail rotor is controlled by the pilot moving the two pedals on the floor of the rotorcraft. (***Figure 1-12***)

Collective Pitch Control: When the pilot lifts up on the collective pitch control (***Figure 1-12***), the blade angle (pitch) of all the main rotor blades increases equally and all the blades create an equal amount of lift. Once the force of lift becomes greater than the weight of the helicopter, the helicopter takes off vertically.

Throttle: The throttle is located on the end of the collective pitch lever (***Figure 1-12***), and operates with a twist of the hand. As the collective pitch lever is lifted up, the throttle rotates to an increased fuel flow position, causing the engine to create more power.

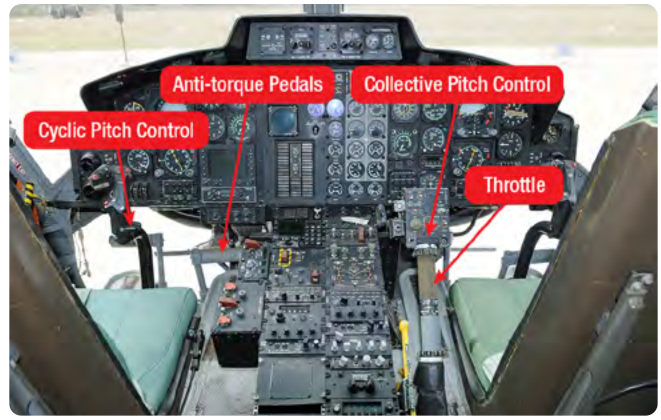

Figure 1-12. Helicopter Flight Deck Controls.

Cyclic Pitch Control: The cyclic pitch control is what causes the helicopter to move horizontally. (***Figure 1-12***) When the cyclic pitch lever is moved forward, the blade angle of the main rotor blades will be greater as they pass by the rear of the helicopter, increasing the lift in this portion of the full rotation. The increased lift in the rear propels the helicopter forward.

Antitorque Pedals: The antitorque pedals (***Figure 1-12***) control the blade angle (pitch) of the blades in the helicopter tail rotor. As the pitch of the blades is increased or decreased, the amount of air they move changes with a corresponding increase or decrease in thrust. When additional engine power is sent to the helicopter's main rotor blades, the pitch of the tail rotor blades has to increase to create more thrust and counteract the torque.

EFFECTS OF GYROSCOPIC PRECESSION

When talking about the aerodynamics of a helicopter main rotor system, it is necessary to first identify which direction the blades rotate when viewed from the top looking down. Unless it is stated otherwise, the concepts presented in this text will be based on the rotor blades turning counterclockwise when viewed from the top. For most helicopters manufactured in the United States, the United Kingdom, Italy, Germany and Japan, the main rotor blades turn counterclockwise. For most helicopters manufactured in France and Russia, the main rotor blades turn clockwise.

When the main rotor blades of a helicopter are spinning they act like a gyroscope, and they experience a characteristic of gyroscopes known as precession. Precession occurs when a force is applied to a rotating object, such as a helicopter main rotor, and the effect is not fully realized until the object has rotated another 90 degrees. When the cyclic pitch control is used to produce horizontal movement of the helicopter (***Figure 1-12***), pitch change rods increase the blade angle on one side and decrease the blade angle on the other side. In order to move forward, there needs to be more lift toward the back of the helicopter and less lift toward the front. Looking at ***Figure 1-13***, the cyclic pitch input to increase blade angle would occur slightly past position #1, and the blade would be at its maximum rise (called flapping up) slightly past position #2. The cyclic pitch input to decrease blade angle would occur slightly past position #3, and the blade would be at its maximum fall (called flapping down) slightly past position #4.

In ***Figure 1-14*** the tilt of the main rotor can be seen, indicating the helicopter is in forward flight.

TORQUE REACTION AND DIRECTIONAL CONTROL

TORQUE REACTION

The horsepower of the engine, which powers the helicopter's transmission and ultimately the main rotor shaft, drives the blades of a helicopter's main rotor. According to Sir Isaac Newton's Third Law, for every action there is an equal and opposite reaction. When the output power at the main rotor shaft causes the blades to rotate in a counterclockwise direction (the action), there is an equal and opposite reaction that tries to make

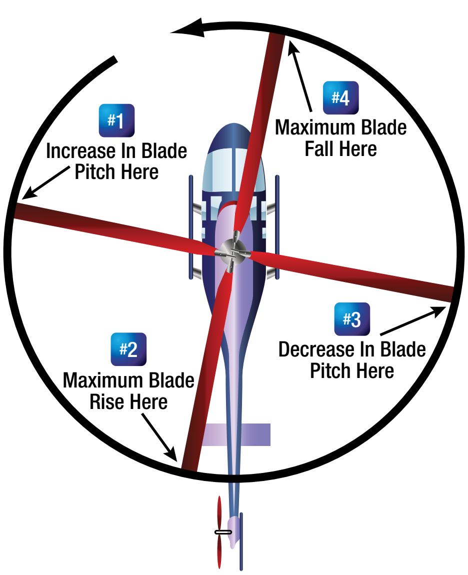

Figure 1-13. Gyroscopic Precession effect on a helicopter main rotor.

Figure 1-14. Tilt of main rotor during forward flight (Sikorsky H-60).

the helicopter rotate the opposite way. This equal and opposite reaction is known as torque, and the helicopter must have a means of counteracting it or the helicopter will spin out of control when power is supplied to the main rotor blades.

For a helicopter that has a single main rotor, which is what the majority of today's helicopters have, thrust developed by a tail rotor is the most common method used to counteract torque. The tail rotor is also known as the antitorque rotor. The tail rotor is a set of variable pitch rotating blades located at the end of a tail boom, and driven by a shaft coming from the helicopter's transmission. (***Figure 1-10***) The pilot controls the pitch of the blades by using the pedals located on the floor in front of their seat. (***Figure 1-12***)

When a helicopter pilot is ready to take off vertically, they rotate the throttle on the end of the collective pitch control and simultaneously lift up on the collective pitch control. This increases the engine's power and increases the blade angle of the main rotor blades all at the same time. The increase in blade angle of the main rotor blades creates the lift necessary to support the helicopter, but the force necessary to rotate the blades also creates an enormous amount of torque. To counteract the torque, the pilot will also need to move the floor-mounted pedals that control the blade angle of the tail rotor blades. (***Figure 1-12***)

Depending on the size of the helicopter, between 5 and 25 percent of the engine's power may be needed to drive the helicopter's tail rotor system. This means there is less power available to drive the main rotor that provides the lift for flight, so a limitation is imposed on how much weight the helicopter can carry. Helicopters typically have a vertical fin, much like the vertical stabilizer used on an airplane, and this fin can help compensate for the torque of the main rotor when the helicopter is in forward flight.

A second method of counteracting the torque on a single main rotor helicopter is a technique called the "No Tail Rotor" system, or NOTAR. This system uses a high volume of air that is ejected out of the end of the tail boom, which creates the thrust necessary to counteract the torque. This system will be covered in greater detail in chapter two. Helicopters that have two main rotors spinning in opposite directions do not need a supplemental system to counteract torque, because the two rotors spinning in opposite directions cancel out each other's torque.

DIRECTIONAL CONTROL

For a single main rotor helicopter, control around the vertical axis is handled by the tail rotor (antitorque rotor) or from the fan's airflow on a NOTAR type helicopter. Like in an airplane, rotation around this axis is known as yaw. The pilot controls yaw by pushing on the antitorque pedals located on the cabin floor, in the same way the airplane pilot controls yaw by pushing on the rudder pedals. The antitorque pedals can be seen in ***Figure 1-12***.

The tail rotor is used to control the heading of the helicopter while hovering or when making hovering turns, as well as counteracting the torque of the main rotor. Hovering turns are commonly referred to as "pedal turns." At speeds above translational lift, the pedals are used to compensate for torque to put the helicopter in longitudinal trim so that coordinated flight can be maintained. The cyclic control is used to change heading by making a banked turn to the desired direction.

The thrust of the tail rotor depends on the pitch angle of the tail rotor blades. This pitch angle can be positive, negative, or zero. A positive pitch angle tends to move the tail to the right, which matches the direction of blade rotation and is opposite to the torque effect. As the pitch angle approaches zero degrees, there is not enough thrust to counteract the torque and the tail starts moving to the left. At zero degrees of pitch or a negative pitch angle, the tail of the helicopter will move rapidly to the left and cause the fuselage to spin. The maximum positive pitch angle of the tail rotor is greater than the maximum negative pitch angle available. This is because the primary purpose of the tail rotor is to counteract the torque of the main rotor, which is done with positive pitch. The capability for tail rotors to produce thrust to the left (negative pitch angle) is necessary because during autorotation the drag of the transmission tends to yaw the nose to the left, or in the same direction the main rotor is turning.

From the neutral position, applying right pedal causes the nose of the helicopter to yaw right and the tail to swing to the left. (***View A in Figure 1-15***) Pressing on the left pedal has the opposite effect: the nose of the helicopter yaws to the left and the tail swings right. (***View C in Figure 1-15***) When the antitorque pedals are in the neutral position (***View B in Figure 1-15***), the tail rotor has a medium positive pitch angle. In medium positive pitch, the tail rotor thrust approximately equals the torque of the main rotor during cruise flight, so the helicopter maintains a constant heading in level flight.

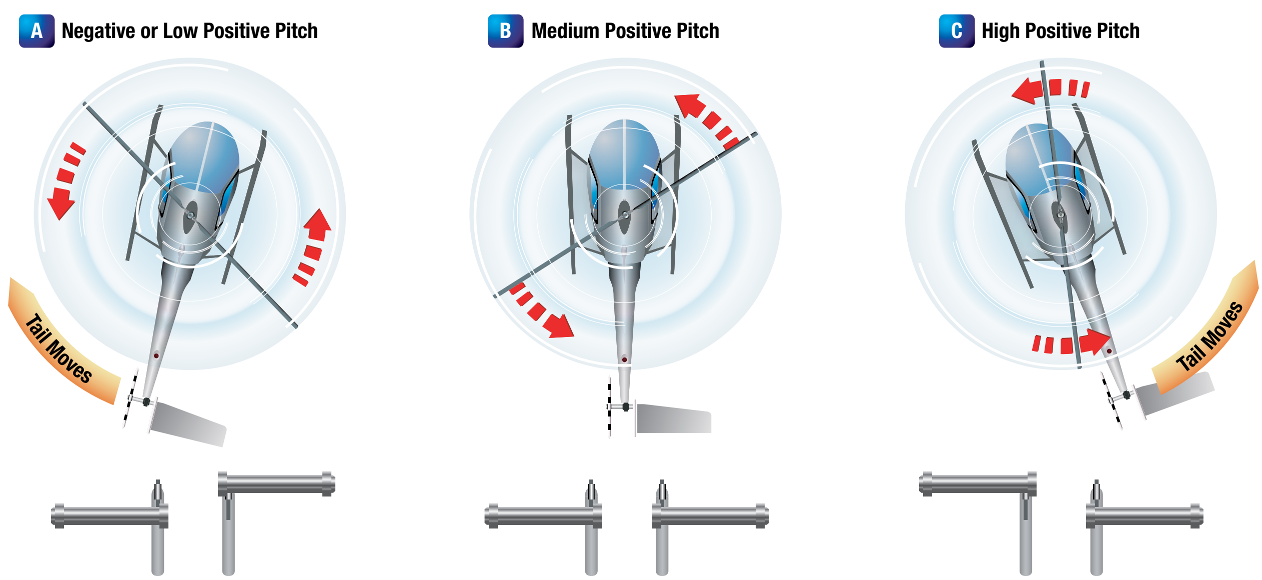

Figure 1-15. Tail rotor pitch angle and helicopter movement in relation to pedal position.