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HELICOPTER AERODYNAMICS
STRUCTURES AND SYSTEMS

12



EASA 2023-989 COMPLIANT

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VERSION	EFFECTIVE DATE
002	2025.04

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ISBN-13: 978-1951275686
9 781951 275686

REVISION LOG

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VERSION	EFFECTIVE DATE	DESCRIPTION OF REVISION(S)
001	2016.01	Module creation and release.
002	2025.04	Regulatory update for EASA 2023-989 compliance.

Module was reorganized based upon the EASA 2023-989 subject criteria. Enhancements included in this version 002 are:

12.7.2 *Test Equipment For Avionics* - Added topic.
12.10 *Portable Fire Extinguishers* - Added topic.
12.12 *Servicing Hydraulic Systems* - Added topic.
12.16 *Pneumatic/Vacuum Systems* - Submodule deleted per EASA 2023-989.
12.18 *Printing, Structural Monitoring* - Content deleted per EASA 2023-989.

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Flight Control Systems (ATA 67)

SUBMODULE KNOWLEDGE DESCRIPTIONS		LEVEL
		A3/A4
12.2	**Flight Control Systems (ATA 67)** Cyclic control; Collective control; Swashplate; Yaw control: antitorque control, tail rotor, bleed air; Main-rotor head: design and operation features; Blade dampers: function and construction; Rotor blades: main and tail-rotor blade construction and attachment; Trim control, fixed and adjustable stabilisers; System operation: manual, hydraulic, electrical, fly-by-wire; Artificial feel; Balancing and rigging.	2

12.2 FLIGHT CONTROL SYSTEMS (ATA 67)

INTRODUCTION

There are three major controls in a helicopter used by the pilot during flight: the collective pitch control, the cyclic pitch control, and the anti-torque pedals or tail rotor control. Sometimes in addition to these major controls, the pilot must also use the throttle control, which is usually mounted directly to the collective pitch control for controlling engine power. [**Figure 2-1**]

The control systems described in this chapter are not limited to the single main rotor type helicopter but are used in one form or another in most helicopter configurations. All examples refer to a counterclockwise main rotor blade rotation, such as viewed from above. If flying a helicopter with a clockwise rotation, left and right references must be reversed, particularly in the areas of rotor blade pitch change, anti-torque pedal movement, and tail rotor thrust.

CYCLIC CONTROL

The cyclic pitch control is usually projected upward from the cockpit floor, between the pilot's legs or in some models between the two pilot's seats. [**Figure 2-2**]

The purpose of the cyclic-pitch control is to cause the tip-path plane of the main rotor to tilt as required to provide for movement of the helicopter in a desired direction: forward, rearward, left, and right.

As discussed in *Submodule 1*, the total lift force is always perpendicular to the tip-path plane of the main rotor. The main rotor tilts in the direction called for by the control, and the helicopter moves as directed. When the control stick is in neutral, the helicopter remains stationary in the air (hover). If wind is present, the helicopter drifts in the direction of wind unless sufficient cyclic movement (rotor thrust) is applied to cancel the effect of the wind.

The rotor disk is also subject to the effect of gyroscopic precession as described in *Submodule 1*. To counteract this effect, the mechanical linkages for the cyclic control rods are rigged in such a way that they decrease the pitch angle of each rotor blade at approximately 90° in the point of the rotor's rotation as it reaches the direction of cyclic displacement and increases the pitch angle of the rotor blade at approximately 90° after it passes the direction of displacement. An increase in pitch angle increases the angle of attack; a decrease in pitch angle decreases the angle of attack. When the cyclic is moved forward, the angle of attack decreases as the rotor blade passes the right side of the helicopter and increases on the left side (on the retreating blade). This results in a maximum downward deflection of the rotor blade in front

Figure 2-1. Helicopter controls on the flight deck.

of the helicopter and a maximum upward deflection behind it, causing the rotor disk to tilt forward.

COLLECTIVE CONTROL

The collective pitch control (or simply "collective" or "thrust lever") is located on the left side of the pilot's seat and is operated with the left hand. The collective is used to make changes to the pitch angle of the main rotor blades and acts simultaneously, or "collectively". Through a series of mechanical linkages, as the collective lever is raised, there is a simultaneous and equal increase in pitch angle of all main rotor blades. As it is lowered, there is an equal decrease in pitch angle. The amount of movement in the collective lever determines the amount of blade pitch change. [**Figure 2-3**] An adjustable friction control helps prevent inadvertent collective lever movement.


Figure 2-2. Location of cyclic pitch control.

With a change in pitch angle comes a change in the load on each blade, which affects the speed or Revolutions Per Minute (RPM) of the main rotor. As the pitch angle increases, the blade takes a bigger bite of air that increases the load on the blade, and so the rotor RPM decreases. Decreasing pitch angle decreases the load on the blade, and RPM increases. To maintain a constant rotor RPM, which is essential in helicopter operations, a proportionate change in power is required to compensate for the change in load on the blades. This is accomplished with the throttle control or governor, which automatically adjusts engine power according to the position of the collective.

In **Figure 2-3A** the collective pitch control is lowered, which causes the blade angle and the amount of lift created to decrease along with applying a proportional decrease in engine power. [**Figure 2-3B**]. In **Figure 2-3C** the collective is raised to increase the lift created by the blades **Figure 2-3D**, and the governor or throttle increases the engine power to maintain the rotor RPM.

THROTTLE CONTROL

The function of the throttle and the governor is to regulate engine RPM by increasing or decreasing fuel flow towards the engine when the collective is raised or lowered. If the governor is an automatic system, to maintain RPM the throttle must be moved manually with the twist grip. The throttle control is much like a motorcycle throttle and works the same way. Twisting the throttle to the left increases RPM. Twisting to the right decreases RPM. As with any aircraft control, large adjustments of either collective pitch or throttle should be avoided. All corrections should be made using smooth pressure.

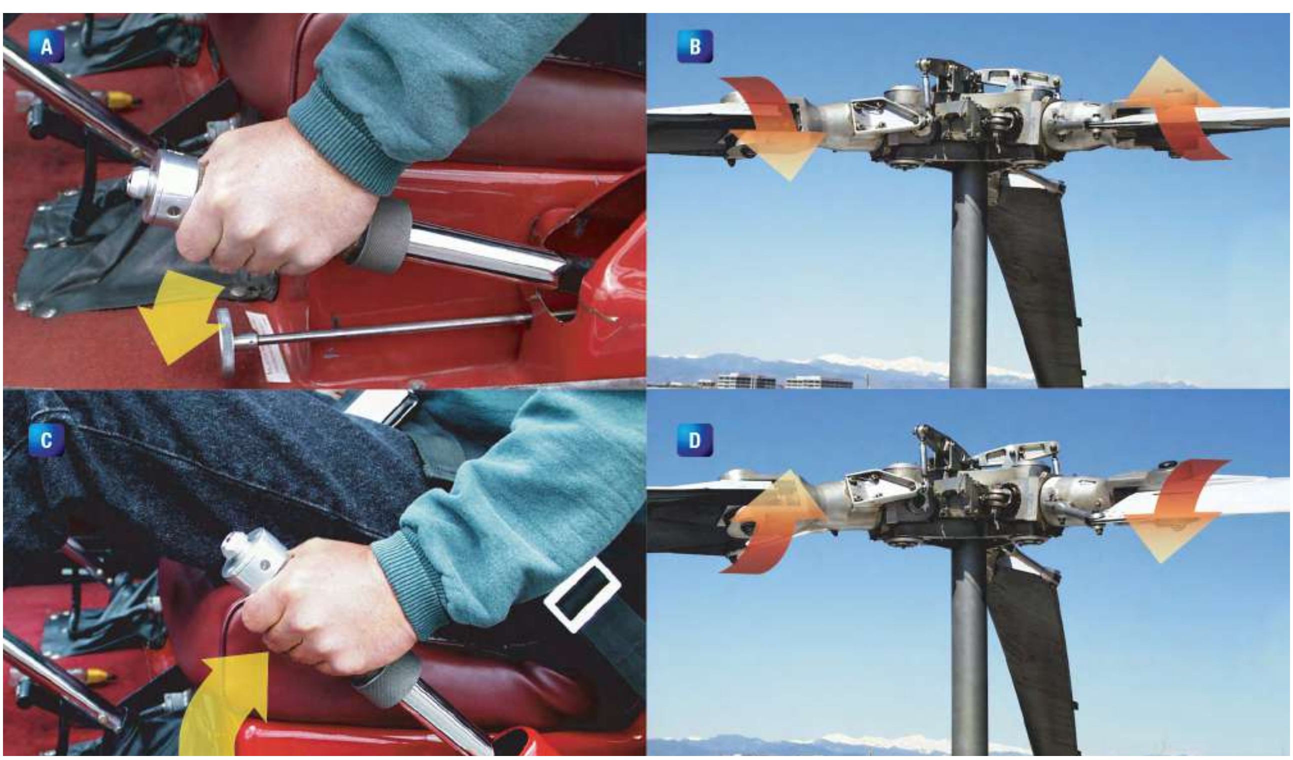

Figure 2-3. Movement of collective pitch control-throttle and effect on rotor blades.

CORRELATOR

A correlator is an automated mechanical connection between the collective lever and the engine throttle. When the collective lever is raised, power is automatically increased; when lowered, power is decreased. This system maintains RPM close to the desired value, but still requires adjustment of the throttle for fine tuning.

GOVERNOR

A governor is a sensing device that monitors rotor and engine RPM and makes the necessary adjustments to keep rotor RPM constant. In normal operations, once the rotor RPM is set, the governor keeps it constant and there is no need to make any throttle adjustments. Governors are common on all turbine powered helicopters as they are a function of the fuel control system and are used on some piston engine helicopters.

SWASHPLATE

When a pilot moves the collective or cyclic controls on the flight deck, a signal is sent to the main rotor blades to cause them to change their angles. From the flight deck, the signal can originate as the movement of cables and pulleys, push/pull tubes, or even an electronic signal. The command for a change in blade or rotor angle must start from the non rotating fuselage and find its way to the main rotor blades which are rotating. The device which permits these changes is called a swashplate. [**Figure 2-4**]


Figure 2-4. Light helicopter swashplate.

The swashplate is made of two circular plates, one on the bottom that is attached to the frame of the helicopter and does not rotate, and one on the top that is attached to the rotating blade assembly. The plates are separated by a set of bearings allowing the top plate to rotate over the bottom plate while physically being in contact with it, so forces can be transferred. **Figure 2-5** shows a simplified swash plate as part of a main rotor system.

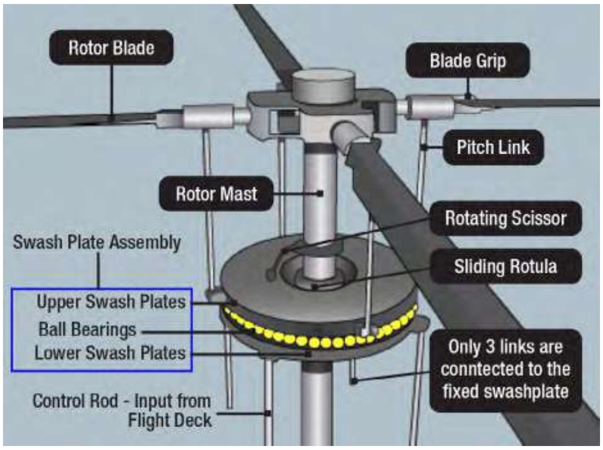

Figure 2-5. Simplified figure of a helicopter swashplate.

A swashplate assembly consists of the parts shown in **Figure 2-6**. The lower swashplate is locked in rotation by the fixed scissor. This scissor is connected between the top of the main gearbox and the lower swashplate. This plate is actuated by the control rods of the cyclic and collective linkages and has two possibilities of movement.

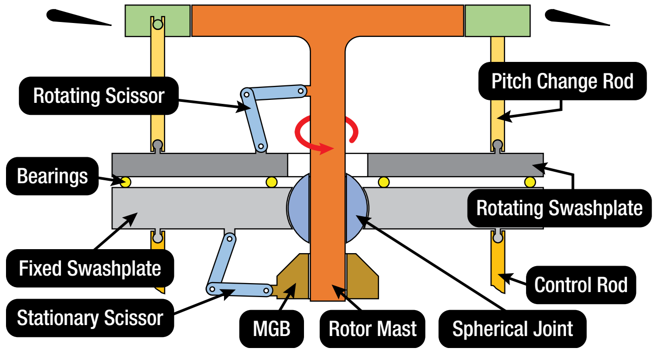

Figure 2-6. Swashplate component.

As each blade rotates through the tip spath plane, the variation of the blade pitch is accomplished through the tilting of a fixed swashplate and its mechanical linkages (pitch angle rods).

THE CYCLIC MOVEMENT AND THE SWASHPLATE

When the pilot moves the cyclic pitch control, this command sends the lower swashplate around a ball joint and tilts the upper swashplate which remains in parallel with the rotor due to its two bearings. The rotary swashplate now spins in an inclined circle. This means that the pitch change rods are constantly undergoing up and down movements. As they are attached to the rotor they will constantly change the blade pitches between high to low values with each revolution, thus creating high lift at one point on the rotating disc and low at 180° from that point. [**Figure 2-7**]

In other words, the swashplate will tilt the main rotor in the requested direction and therefore the helicopter will also move in this desired direction. To define the plane represented by the swashplate, it is necessary to connect three points which define the different tilting axis. [**Figure 2-8**]

THE COLLECTIVE MOVEMENT AND THE SWASHPLATE

The lower swashplate is connected to a ball joint that slides up and down along the rotor mast. When the pilot pulls the collective control, a command is sent to the lower swashplate by three connecting rods as shown in **Figure 2-5** as "input from flight deck".

These three rods push the lower swash plate in parallel upwards, which also pushes the upper swashplate and ball joint as one unit. The upper swash plate, through these links, applies force to the rotor blades and so changing the angle of attack of all the blades in the same direction regardless of the inclination of the swashplate. [**Figure 2-9**]

It is possible to operate the cyclic stick and the collective stick simultaneously. In that case all the bellcranks move, transmitting a specific movement to the swashplate which acts to control the angle of attack of each blade as the pilot wishes.

YAW CONTROL: ANTI-TORQUE CONTROL, TAIL ROTOR, BLEED AIR

ANTI-TORQUE CONTROL, TAIL ROTOR

Yaw for an aircraft (helicopter or airplane) is a movement that takes place around the vertical axis. The three axes of rotation for a helicopter are shown in **Figure 2-10**. For a helicopter with a single main rotor yaw control is accomplished by the tail rotor (anti-torque rotor).

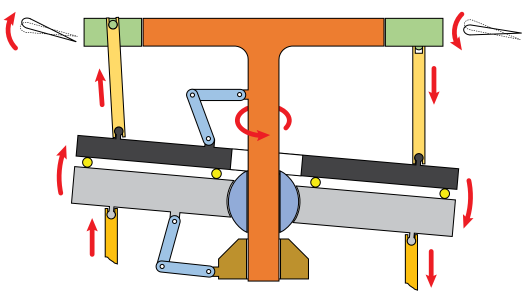

Figure 2-7. Cyclic movement.

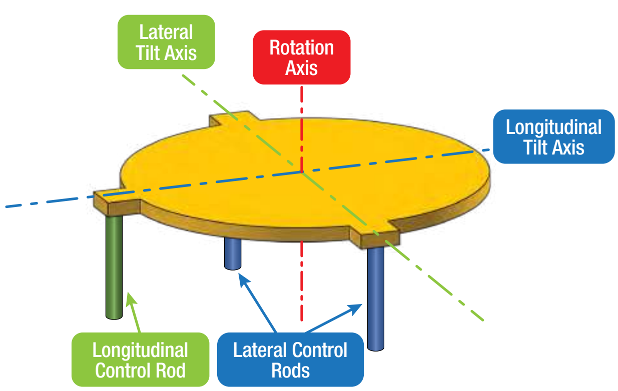

Figure 2-8. Light helicopter axis description.

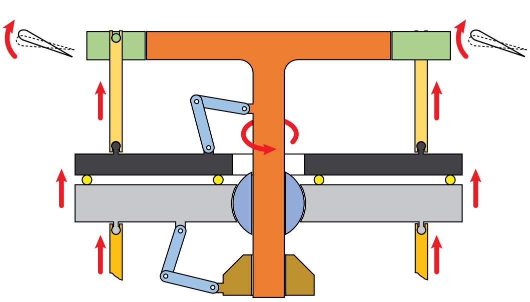

Figure 2-9. Collective movement.

One method to counteract torque is to place a small propeller at the end of the tail boom. Its purpose is to create thrust that acts in the opposite direction of the helicopter's tendency to rotate. The tail rotor force, in newtons, multiplied by the distance from the tail rotor to the main rotor, in meters, creates a torque in newton meters that counteracts the main rotor torque. The main difference is that there is no cyclic control as it is not necessary to modify the direction of the lift but simply to increase or decrease thrust as a collective command. [**Figure 2-11**]

THE TAIL COLLECTIVE HINGE

The tail collective hinge system is the same, regardless of the number of blades on the tail. To modify the thrust of the tail rotor, it is necessary to be able to change the angle of attack of all the blades at the same time. To create the collective movement

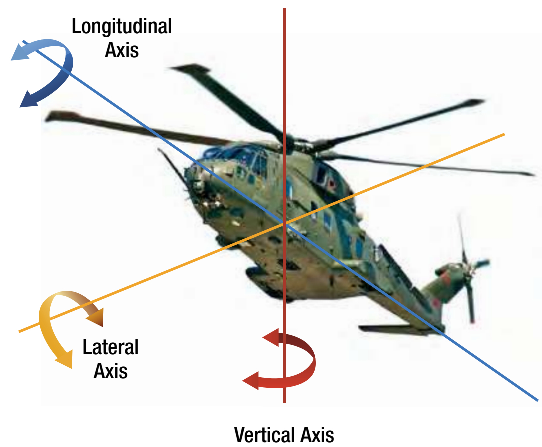

Figure 2-10. Three axes of rotation for a helicopter.

Figure 2-11. Tail rotor description.

on the tail blades, a servo control acts on a platter called a spider. When the spider is in motion, the pitch change rods connected between it and the blades force the latter to move around its feathering hinge.

When the main rotor is turning counterclockwise (viewed from the top), its torque will try to rotate the fuselage clockwise. This makes the nose of the helicopter yaw to the right. When the anti-torque rotor is producing the correct amount of thrust to exactly counteract the torque of the main rotor, the nose of the helicopter will remain steady in the same direction. Making the helicopter yaw to the right is accomplished by pushing on the right anti-torque pedal. [**Figure 2-12**] This action reduces the thrust of the tail rotor (by reducing the blade angle) to less than what is needed to counteract the torque and the helicopter yaws to the right. When the pilot pushes the left anti-torque pedal, increases the blade angle of the tail rotor, the nose of the helicopter will yaw to the left. It is important to understand that the tail rotor does not control the direction in which the helicopter is flying. It only controls the direction in which the fuselage is heading. The direction of flight is controlled by the cyclic pitch system, as previously described.

THE TAIL FLAPPING HINGE

When a helicopter is in motion, the translation speed is added or subtracted from the rotation speed of the blades depending on whether it is an advancing or a retreating blade. This problem is the same on the tail rotor. To solve it, a flapping hinge is added. On the tail rotor, the blades are lighter than the main rotor and the movement is easy to control. When the blade rotates in the advancing zone, the pitch is automatically changed by the change rod which reduces the angle of attack. With this reduction in lift, the reaction of the blade is to return to the average flying plan. [**Figure 2-13**]

When the blade retreats, it tends to move closer to the tail structure. To avoid contact, the pitch change rod increases the pitch. The reaction of the blade with the increased pitch is to move away from the structure. [**Figure 2-14**]

Figure 2-12. Movement of right pedal.

THE TAIL AND PEDAL CONNECTION

Because the tail rotor is too far from the pedals to connect with connecting rods, the usual solution is to route cables through the tail structure. [**Figure 2-15**] At the end of the tail beam, the movement of the cables controls the servo-control of the tail. When the servo-control extends or retracts, it changes the position of the spider and so changes the blade's angle of attack thus adjusting thrust.

DIFFERENT SOLUTIONS

During translational flight, the tail rotor uses 20% of the power supplied by the motor. The remaining 80% is given to the main rotor. Different solutions are used to reduce the power consumption of the tail and restore maximum torque to the main rotor.

Figure 2-13. Advancing zone flapping movement.

Figure 2-14. Retreating zone flapping movement.