B1.3/B1.4

AVIATION MAINTENANCE TECHNICIAN CERTIFICATION SERIES

HELICOPTER AERODYNAMICS
STRUCTURES AND SYSTEMS

12



COMPLIANT WITH EASA European Aviation Safety Agency EASA PART 66/147

EASA 2023-989 COMPLIANT

REVISION LOG

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VERSION	EFFECTIVE DATE	DESCRIPTION OF REVISION(S)
001	2022.03	Module creation and release.
001.1	2022.03	Label correction for Figure 2-1, page 2.2
001.2	2022.10	Inclusion of Measurement Standards for clarification, page iv. Enhanced or modified content within the following Submodules: 12.9(A): Moved content on emergency escape lighting from page 9.14 to 9.5. 12.13: Expanded content on Wiper Systems. 12.14: Expanded content on Emergency Pop-out Floats. 12.19: Added section; Miscellaneous Information Systems.
002	2023.01	Minor type corrections and Figure replacement. Replaced Figures 14-54 on page 14.30, Figure 15-9 on page 15.5, and Figure 18-4 and 18-5 on page 18.5.
003	2024.10	Regulatory update for EASA 2023-989 compliance.

Module was reorganized based upon the EASA 2023-989 subject criteria. Enhancements included in this version 003 are:

12.7.2 *Test Equipment for Avionics* - topic added.
12.10 *Portable Fire Extinguishers* - topic added.
12.12 *Servicing Hydraulic Systems* - topic added.
12.16 *Pneumatic Systems* - topic deleted per 2023-989.
12.18 *Printing and Structural Monitoring* - topics deleted per 2023-989.

HELICOPTER AERODYNAMICS STRUCTURES AND SYSTEMS

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Figure 2-20. Advancing zone flapping movement.

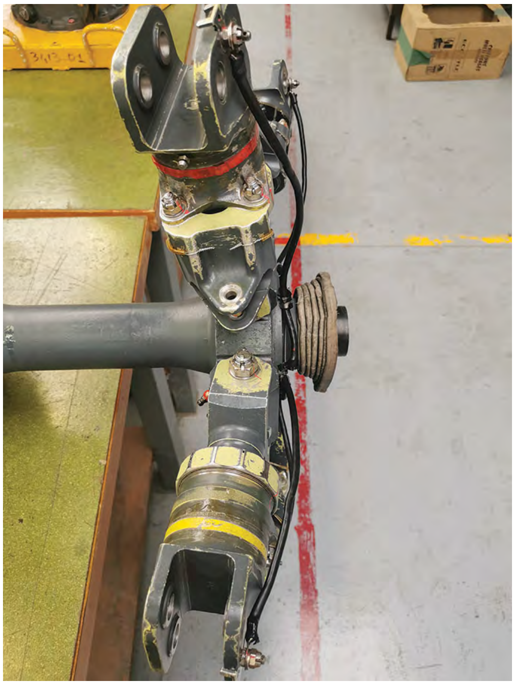

Figure 2-21. Retreating zone flapping movement.

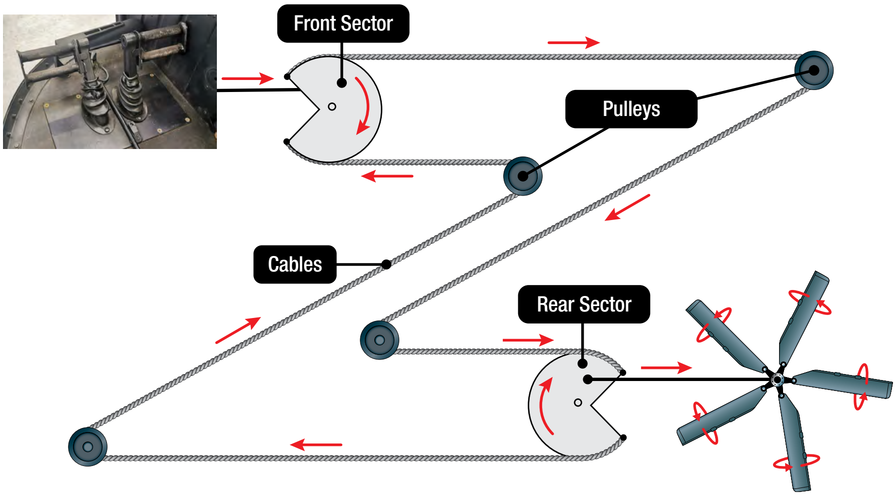

Figure 2-22. Yaw control system.

position of the spider and so changes the blade's angle of attack thus adjusting thrust. [**Figure 2-23**] This cable and pulley system has the additional advantage of being easy to check and repair in the event of damage. Another advantage is the lightness and flexibility of the system required for this task.

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.

On a helicopter with two main rotors, known as a tandem configuration, the main rotors are located at each end of the helicopter and there is no tail rotor. The two main rotors spin in opposite directions, with each one counteracting the torque of the other. The Boeing CH-47 Chinook helicopter has this type of main rotor system. [**Figure 2-24**] Changes in yaw on this helicopter are done with differential cyclic pitch, with the front rotor generating cyclic pitch in the direction the pilot wants the nose to move and the aft rotor generating the opposite cyclic pitch.

On helicopters with two main rotors, known as a coaxial configuration, the main rotors are located one above the other and driven by concentric drive shafts. The two main rotors spin in opposite directions, with each one counteracting the torque of the other. The Russian KA-32 helicopter in **Figure 2-25** has this type of main rotor system. Changes in yaw on this helicopter are made by increasing the collective pitch of one of the main rotors and decreasing the collective pitch of the other, creating a dissymmetry of torque.

On helicopters with two main rotors that are side by side with separate shafts, such as the Kaman helicopter shown in *Submodule 1* [**Figure 1-7**], opposite cyclic pitch on the two rotors is used to produce yaw movement.

THE FENESTRON SOLUTION

While the tail rotor is a highly effective solution, there are real dangers in its use. First, the spinning blades are deadly if someone steps into them. Second is the risk of hitting a tree or other object. If the tail rotor is lost, the helicopter becomes uncontrollable and a crash is inevitable. Aerodynamically, this is also a problem. When the helicopter is in forward flight and a vertical pylon is used to support the tail rotor head, [**Figure 2-26**] drag appears.

Figure 2-23. Cables-rear sector-rod and tail servo-control.

Figure 2-24. Tandem main rotor helicopter.

Figure 2-25. Helicopter with coaxial counter-rotating main rotors.

An alternative solution to the tail rotor, seen in **Figure 2-26**, is a type of anti-torque rotor known as a Fenestron, or fan-in-tail design as seen in **Figure 2-27**. Because the rotating blades in this design are enclosed in a shroud, they present less of a hazard to personnel on ground and they create less drag in flight. Another advantage is to simplify the tail rotor assembly, as inside the shroud, the problem of advancing and retreating blade disappears. This direct benefit allows the removal of the flapping hinge.

Another advantage of the Fenestron is weight. The blades are smaller and lighter than the classic blades, and in case of change the cost is cheaper. As stated before, the tail rotor robs the main rotor of a part of its power. With a Fenestron, the special shape of the tail pylon reduces the tail rotor's power consumption. This occurs during forward flight, as the dissymmetric vertical fin [**Figure 2-28**] creates its own lift to oppose the torque, similar to a wing but in vertical position. However, one negative aspect of a Fenestron is the whistling sound in the cabin due to the airflow into the shroud.

Figure 2-26. Aerospatiale Helicopter Tail Rotor.

Figure 2-27. Fenestron on a Eurocopter Model SA341 Gazelle.

THE BLEED AIR NOTAR SYSTEM

Another method of counteracting the torque of the main rotor is a technique called the no-tail-rotor system, or NOTAR. [**Figure 2-29**]

This system uses a high volume of air at low pressure, which is generated by a fan installed in the tail boom and driven by the helicopter's engine. The fan forces air into the boom, where a portion exits from slots on the right side of the boom and together with the main rotor downwash, creates a phenomenon called the Coanda effect. The air coming from the slots causes a higher velocity, and therefore lower pressure on that side of the boom. The higher pressure resulting on the left side of the boom partially counteracts the torque of the main rotor. [**Figure 2-30**]

The remainder of the air travels back to a controllable rotating nozzle in the helicopter tail. The air exits the nozzle at a high velocity and creates thrust which additionally counteracts the torque of the main rotor. In a hover this force on the left side of the boom counteracts up to 60% of the main rotor torque, with the remainder being controlled by thrust from the nozzle.

The NOTAR anti-torque system eliminates some of the mechanical problems of a tail rotor, including long driveshafts, suspension bearings, mid-gearboxes, and 90° gearboxes. It is safer for the mechanic due to the absence of rotating tail blades, and in flight, the reduction of drag allows for less stress on the structure and reduced fuel consumption. A final advantage, unlike the Fenestron, is that the NOTAR system is quieter.

MAIN ROTOR HEAD: DESIGN AND OPERATION FEATURES

The rotor system on a helicopter consists of a mast, hub, and rotor blades. The mast is a hollow cylindrical metal shaft which extends upwards from and is driven, (and sometimes supported) by the transmission. At the top of the mast is the attachment

Figure 2-28. Fenestron dissymmetric vertical fin.

Figure 2-29. MD-520 helicopter with no tail rotor.

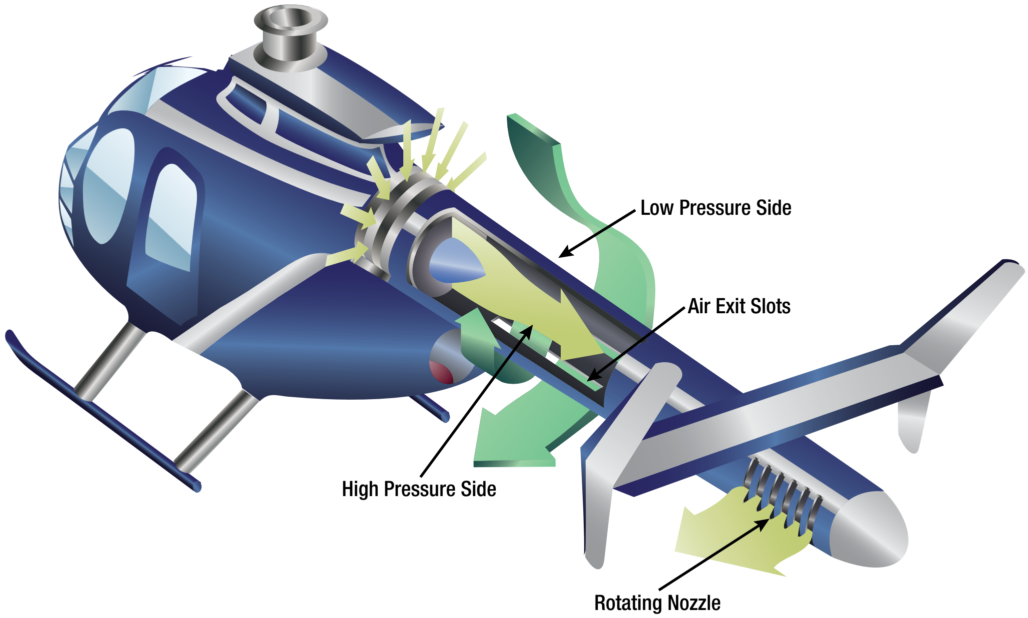

Figure 2-30. Airflow from a variable pitch fan on a NOTAR helicopter.

point for the rotor blades called the hub. The rotor blades are then attached to the hub by a variety of different methods. The blades need three free movements to withstand the various stresses and to control the flight direction. [**Figure 2-31**]

The flapping hinge prevents the helicopter from tilting due to the dissymmetry of lift in the advancing and retreating zone of translational flight. The drag hinge withstands the lead/lag movement due to the Coriolis effect. [**Figure 2-32**] The feathering hinge permits changes to the angle of attack to change the direction of the lift.

Main rotor systems are classified according to how the main rotor blades are attached and move relative to the main rotor hub. There are three basic classifications: fully articulated, semi-rigid and rigid. Some modern rotor systems, such as the bearingless rotor system, use a combination of these types.

FULLY ARTICULATED ROTOR SYSTEMS

Fully articulated systems allow each blade to lead/lag (move back and forth in a plane), to flap (move up and down about an inboard hinge) independently of the other blades, and to feather, or rotate about the pitch axis to change lift. (The term feather should not be confused with the concept of feather as it applies to constant speed propellers.) Each of these blade motions are related to the others. The three hinges are mechanical assemblies with bearings and lubrication. In **Figure 2-33**, the drag hinge and the flapping hinge are lubricated with oil by gravity, and a pipe is connected to the feathering hinge to lubricate it.

As the rotor spins, each blade responds to inputs from the collective and cyclic controls. The center of lift on the whole system moves in response to these inputs to effect pitch, roll, and upward motion.

As the lift on a given blade increases, it tends to flap upwards. The flapping hinge for the blade permits this motion and is balanced by the centrifugal force acting on the blade which tries to keep it in the horizontal plane. Under the flapping hinge, **Figure 2-34**, a mechanical stop is installed to avoid letting the blade rise too high and have uncorrectable loss of lift. At the same time, a lower stop protects the helicopter structure from impact in case the blade's flight would become too low.

Either way, some motion must be allowed. The centrifugal force is nominally constant; however, the flapping force is affected by the severity of in flight maneuvering (rate of climb, forward speed, aircraft gross weight, G forces). As the blade flaps, its center of

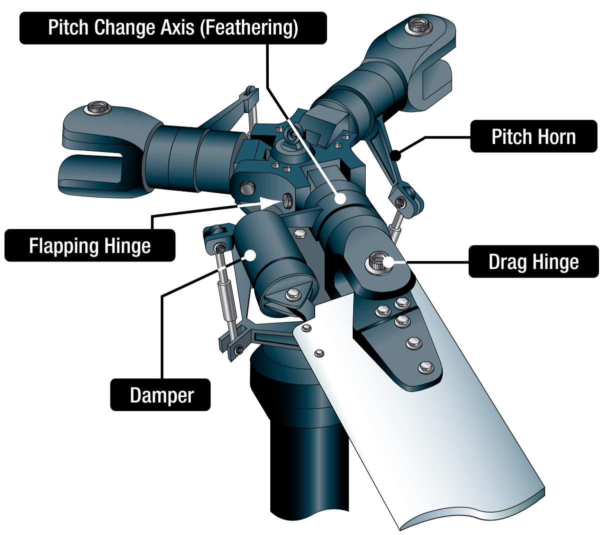

Figure 2-31. Flapping hinge allows up and down blade movement.

Figure 2-33. Fully Articulated Main Rotor System.

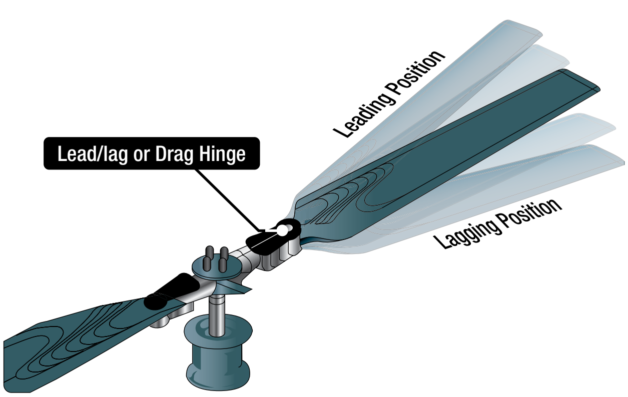

Figure 2-32. Lead-lag hinge allows fore and aft blade movement.

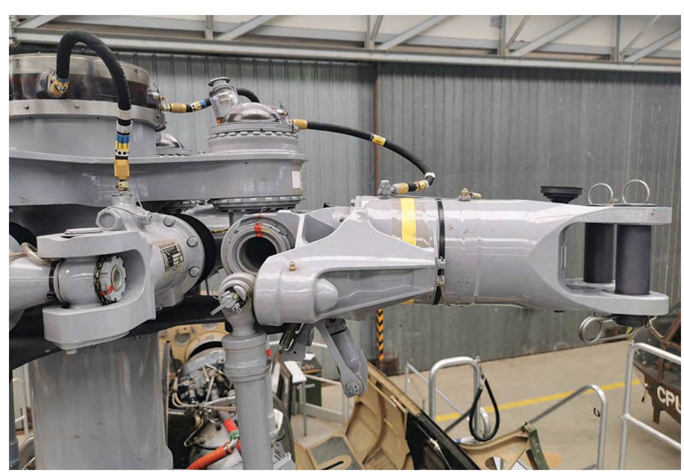

Figure 2-34. Flap stops.

gravity changes. This changes the local inertia of the blade with respect to the rotor system. It speeds up or slows down with respect to the rest of the blades and with the whole rotor system. This is accommodated by the lead/lag or a drag hinge, shown in **Figure 2-32**. The blade trying to speed up or slow down can best be understood by thinking about an ice skater performing a spin. As the skater moves their arms in, they spin faster because the inertia changes, but the total energy remains constant. Conversely, as they extend their arms the spin slows down. This is also known as conservation of angular momentum. An in-plane damper [**Figure 2-35**] controls how quickly the lead/lag motion can occur.

Older hinge designs relied on conventional metal bearings. By basic geometry, this precludes a single hinge from being able to handle both flapping and lead/lag movement and is cause for recurring maintenance. Newer rotor systems use elastomeric bearings, which are arrangements of rubber and steel that can permit motion in two axes. This allows two metal bearings to be replaced by a single bearing. The new hinge design requires less maintenance, is easier to inspect, and its wear is gradual and more visible. The metal-to-metal contact of older bearings and the need for lubrication is thus eliminated.

Figure 2-35. Drag hydraulic damper on SA330 puma.

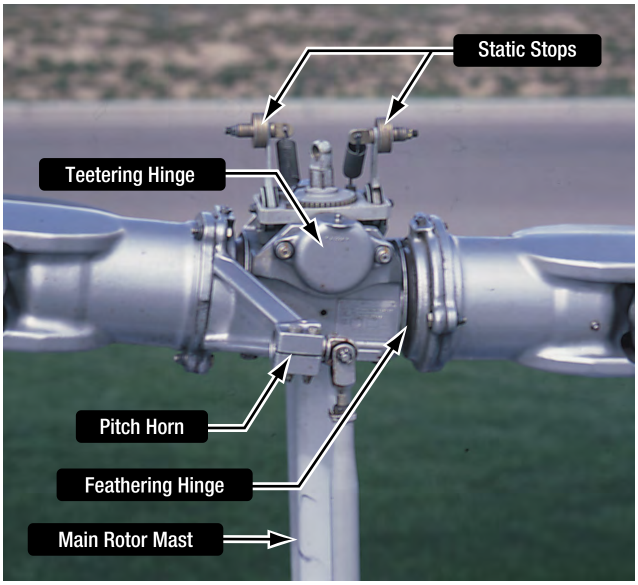

Figure 2-36. Teetering hinge for hub tilt and feathering hinge for pitch change.

SEMI-RIGID ROTOR SYSTEMS

A semi-rigid rotor system is usually composed of two blades that are rigidly mounted to the main rotor hub. The main rotor hub is free to tilt with respect to the main rotor shaft on what is known as a teetering hinge. This allows the blades to flap together as a unit. As one blade flaps up, the other flaps down. Since there is no vertical drag hinge, lead/lag forces are absorbed and mitigated by the blade bending. The semi-rigid rotor is also capable of feathering, which is made possible by a feathering hinge. [**Figure 2-36**]

The underslung rotor system mitigates the lead/lag forces by mounting the blades slightly lower than the usual plane of rotation, so the lead and lag forces are minimized. As the blades flap upward with increased lift, the centers of pressure of the blades are almost in the same plane as the hub. Whatever stresses are remaining bend the blades for compliance.

If the semi-rigid system is an underslung rotor, the Center of Gravity (CG) is below where it is attached to the mast. This underslung mounting is designed to align the blade's center of mass with a common flapping hinge so that both blade's centers of mass vary equally in distance from the center of rotation during flapping. The rotational speed of the system tends to change, but this is restrained by the inertia of the engine and flexibility of the drive system. Only a moderate amount of stiffening at the blade root is necessary to handle this restriction. Simply put, underslinging effectively eliminates geometric imbalance. **Figure 2-37** shows how the centerline of the blades falls below the teetering hinge.

Helicopters with semi-rigid rotors are vulnerable to a condition known as mast bumping which can cause the rotor flap stops to shear the mast. The static stops can be seen in **Figure 2-36**. The mechanical design of the semi-rigid system requires some physical limit to downward flapping of the blades. Mast bumping is the result of excessive rotor flapping. Each rotor system design has a maximum flapping angle. If flapping exceeds the design value, a static stop will contact the mast. It is the violent contact between the static stop and the mast during flight that causes mast damage or separation. This contact must be avoided at all

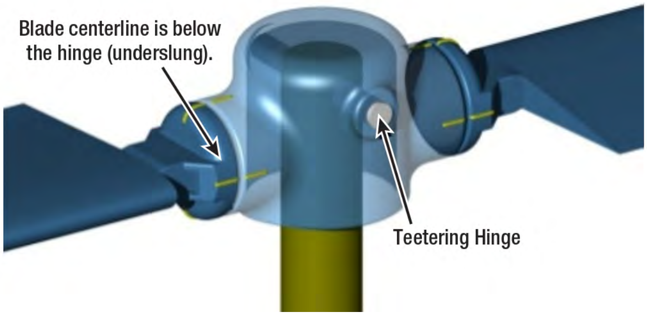

Figure 2-37. Semirigid rotor with underslung design.