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METHODS OF AVOIDING THE YAW OF HELICOPTERS

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Abstract: *The purpose of this paper is a comparative analysis of the various types of helicopter rotor configurations used to avoid the yaw phenomenon of these types of aircrafts. An helicopter is a motorized aircraft whose support and movement are provided by one or more propellers rotating about vertical axes and which can land in an extremely small space or be held in the air at one point, fixed. The rotor blades rotate about a vertical axis. The rotor must develop a traction force with good efficiency to support the weight of the helicopter [1]. Helicopters can use different rotor configurations (such as a single main rotor with a tail one, tandem rotors, coaxial, side-by-side rotors), on which their aerodynamic complexity depends [2].*
Keywords: *Helicopter, rotor, moment, rotation, configuration*

1. INTRODUCTION

The placement of the rotor or rotors on a helicopter is its most distinctive external element and an important factor in its behavior, especially in the maneuverability and stability of the device. Usually, power is delivered to the rotor through a shaft, to which a torque is transmitted, this torque balancing is the one that confers the configuration of the helicopter [1]. To analyze the performance of the helicopter, an empirical aerodynamic model is used. It includes a main rotor model, a fuselage model, a tail rotor model and a propulsive drive method. These main component can be seen in the figure 1. The fuselage is treated as a rigid body with aerodynamic forces and moments. The propulsion of the tail rotor is determined by the main torque of the rotor divided at a distance from the center of the tail rotor hub to the main rotor shaft. Given the traction and feed rate, the power of the tail rotor is determined by gliding the aircraft and flying forward. Given three initial step controls (collective and cyclic) and two rotor shaft attitude angles (longitudinal and lateral tilt axis angles), the periodic rotor response can be obtained for a previously prescribed speed [2].

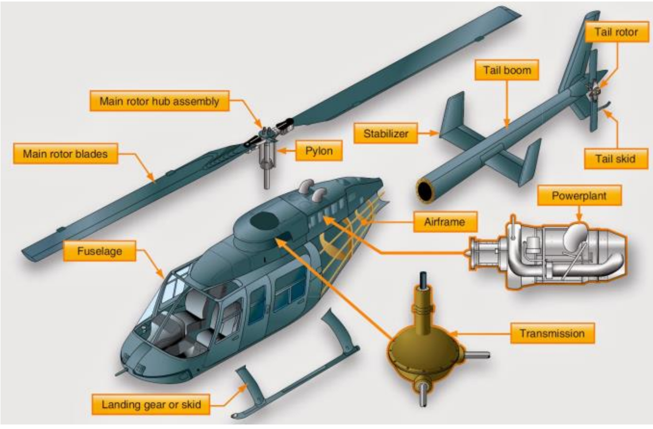

Figure 1: Main components of an helicopter [3]

The forces and moments of the main rotor hub are balanced by the forces and moments acting on the tail rotor. The forces and moments on the fuselage are determined by the angle of flight condition and attitude. The traction force and power of the tail rotor are due to the torque of the rotor and the fighting state. These forces and moments are the equilibrium equations of the helicopter, which are solved to update the pitch controls and the rotor attitude angles [2].
To reduce the rotation, two constructive methods are used:
• Configuration with a single main rotor and a tail rotor
• Configurations with two counter-rotating rotors [1]

2. HISTORIC

One of the ideas born in the mind of the genius Leonardo da Vinci, discovered among his sketches, was a helicopter-like device, so it is assumed that Leonardo was the first man to design such a machine.
Subsequently, a large number of inventors tried to make a functional helicopter, but they usually ran into the same problem: finding an engine that could spin a propeller fast enough to create "lift" or vertical force that would lift the appliance off the ground.
In 1906, a helicopter designed by Paul Cornu managed to rise from the ground. In 1923, the Spaniard Juan de la Cierva managed to fly an "autogyro", but a practical aircraft was created only in the 1930s through the work of Igor Sikorsky, whose name became synonymous with helicopters.
The configuration of the helicopter refers mainly to the number and position of the load-bearing rotors, to the means of balancing the reactive torque of the main rotor and to control the turn, as well as to the arrangement of the fuselage. This basic analysis of the rotor is applicable to all helicopter types. The configuration of the helicopter has an important influence in its behavior, especially on the characteristics of maneuverability and stability [1].

Configuration With Main Rotor And A Tail Rotor

-use a small auxiliary rotor to achieve torque balance and rotation control
-this auxiliary rotor is placed behind the main rotor disk
-the tail rotor is normally vertical, with the axis horizontal and parallel to the lateral axis of the helicopter [4]
-the torque balance is achieved by the traction of the tail rotor, which acts as an arm to the main shaft
-the main rotor produces lift, propulsion force and control of roll, pitch and vertical translation [1].

Configuration With Two Twin Main Rotors

- use two counter-rotating rotors, of the same dimensions and loads, so that their reaction torques are equal and opposite.
- there will be no turning moment acting on the helicopter and due to the two main rotors
- this configuration automatically balances the torques of the main rotors, without the need for an auxiliary rotor, which consumes power
- all losses through the aerodynamic interface between the two rotors amount to approximately the same value as the power consumed by the tail rotor
- the most common location of the twin rotors is in the tandem configuration, with the front and rear fuselage placement of the two main rotors, usually with a significant overlap of the rotor discs and the rear rotor above the front rotor [1] .

Single main rotor configuration

It is currently the most common configuration. It consists largely of an aerodynamic fuselage, a main rotor and a tail rotor. The latter is used to balance the reaction torque of the main rotor and to control the turn. It is placed on the tip of the tail of the helicopter and has traction oriented in the direction in which the blades of the main rotor pass over the fuselage, through the rear part of it. .
The pitch and roll control is performed by tilting the traction of the main rotor and implicitly its disc, using the cyclic step.
This configuration has the advantage of simplicity, requiring only one set of controls for the main rotor and a single and compact main transmission. The tail rotor gives good cornering control, but it absorbs power in balancing the main rotor torque, which increases the power required of the helicopter by a few percent.
This type of configuration has a fairly small range of centering variation, although this range increases if the rotor has no joints (rigid or semi-rigid hub rotor). The tail rotor poses some danger to ground personnel, unless in which it is placed quite high above the tail, it can also touch the ground on landing [1].
The tail rotor works in rather heavy aerodynamic conditions due to the main rotor and fuselage, which reduces the aerodynamic efficiency and increases the dynamic stresses and vibrations of the tail rotor. The configuration with a main rotor and a tail rotor is the simplest and easiest solution. for small and medium-sized helicopters [1].
Various anti-torque solutions have been devised to replace the tail rotor. A successful alternative must provide maneuverability and stability in rotational motion, self-rotating maneuverability, average weight and satisfactory power consumption [1].
The most popular alternative to the tail rotor seems to be the intubated fan, the "fenestron" type. It eliminates the main shortcomings of the tail rotor, namely the danger to ground personnel, noise and vibration. In addition, it requires only joints, because it is no longer subjected to a current in the plane of the rotor. Another anti-torque solution is presented by the NOTAR model which uses an axial compressor placed in the fuselage, delivering compressed air laterally, through the tail of the device [1].

Figure 2: Sikorsky Aircraft S-58 (helicopter with a main rotor and a tail rotor) [5]

Two (or more) main counter-rotating rotors

In this configuration, the torque balance is inherent and, as a result, no special anti-torque device is required. The main advantage is the energy saving consumed by the anti-torque rotor (approx. 5%). Unfortunately, the aerodynamic losses caused by the interference between the main rotors, as well as between them and the fuselage, reduce the overall efficiency by about the same order of magnitude (approx. 5%), which makes the solution comparable to the configuration with a single main rotor, at least in terms of global efficiency [1].
With two main rotors, the mechanical complexity increases due to the doubling of the control system and transmissions. However, for large helicopters the increase in weights and maintenance costs is offset by reducing the size of the rotors and transmission to the same total weight [1].
The substantial advantage of a multi-rotor system is the elimination of the tail rotor, which usually consumes 5% to 10% of the power of the main rotor. On the other hand, mechanical complexity and associated parasitic traction are considered to be major disadvantages, which have made this configuration relatively unpopular so far. However, the absence of a tail rotor reduces the number of helicopter accidents associated with the tail rotor and allows a more compact configuration than conventional helicopters. Therefore, due to its compact size and lifting capacity, the multi-rotor system seems to be a viable alternative in helicopter design [6].
The configuration with two main rotors is classified into:
-two tandem rotors
-two- coaxial rotors
-two- left-right rotors
-the syncopter

2.1. Two tandem rotors

This configuration has two main rotors, one in front and the other in the back. The discs of the two rotors are generally superimposed by 30% to 50% (the distance between the main shafts is 1.7R to 1.5R). to minimize the aerodynamic interference created by the operation of the rear rotor in the wake of the front rotor, the front rotor is raised on a pillar, usually by 0.3R to 0.5R, above the front rotor [7] [1].
The pitch control is achieved by the difference between the traction values of the two rotors, for which the collective step of the two rotors is operated differently.
The roll control is obtained by the lateral inclination in the same direction of both rotors, with the help of the cyclic step of both.
The turn control is performed by tilting the two rotors in the opposite direction, using a differential cyclic step [1].
Undoubtedly, the configuration presupposes the existence of a long fuselage, of constant section, due to the need to locate the two rotors and for reasons of centering. This also brings an advantage, namely a wide range of longitudinal centering, due to the possibility of balancing the existence the two tractions of the rotors, with a large distance between them [8].
The operation of the rear rotor in the wake of the front one is a significant source of dynamic loads, vibrations and noise, including a cause of higher power losses. The weight of the rear pillar is also a disadvantage [1].
The high inertia in pitch and rotation movements, the unstable aerodynamic moments of the fuselage and the poor effectiveness of the rotation controls negatively affect the maneuverability and stability qualities of helicopters with this configuration. In general, the tandem rotor configuration is suitable for medium and medium heavy [1].
To minimize the aerodynamic interference created by the operation of the rear rotor following the front, the rear rotor is raised on a high voltage pole (0.3r to 0.5r above the front rotor) [9]. In a tandem rotor helicopter, the turning moment is obtained by the lateral inclination of the pressure of the two main rotors and, finally, the vertical force is obtained by changing the collective step of the main rotor [10].

Figure 3: Boeing / Vertol CH-47 Chinook (tandem configuration) [11]

2.2. Two left-right rotors

This configuration has two main counter-rotating rotors, located to the left or right of the fuselage [12]. The rotors are mounted on the tip of short wings or on the top of some pillars and generally do not overlap (so that the distance between the main shafts is greater than 2R); the control is the same as in the tandem configuration, but, taking into account the placement of the rotors, things stand as if the pitch axis had become the roller axis, and reverse. The roller control is provided by the different collective step at the two rotors, and the pitch command at the cyclic step, common to the two rotors [1].
The structure that must support the rotors is an additional and undesirable source of forward resistance and passive weight, unless the helicopter has a sufficiently high forward speed to benefit from the fixed wing lift [1].

Figure 4: Focke-Wulf Fw 61 (left-right rotors) [12]

2.3. Two coaxial rotors

This configuration possesses two main counter-rotating coaxial rotors. Of course, it requires the existence of a vertical space that allows the reverse beating of the two rotors (at least in the lateral direction), requires a substantial shift of the two rotors [13]. The size of the main shaft and the two cyclic plates, leads to a significant increase in passive resistance [1].
The rotation control is obtained by the torque difference (respectively, of collective pitch) between the two rotors. The other controls are obtained exactly as in the helicopter with a single main rotor, by means of the cyclic pitch, modified in the same direction at both rotors [1].
The coaxial configuration complicates the upper rotor controls and the transmission, but eliminates the long transmission shafts that occur in other configurations with twin rotors, small diameter and does not require tail rotor [14].
Coordination of coaxial rotors is one of the technological solutions to increase the loading capacity of helicopters. Because two rotors produce net force instead of a single rotor in the conventional design, the diameter of the rotors can be reduced to carry the same weight. The most attractive feature of a coaxial design is the resulting compactness and safety of the vehicle. Second, the reverse torque generated by the two rotors would be canceled due to opposite directions of rotation, and the tail rotor and tail arm could be eliminated, resulting in a smaller and lighter vehicle [15].
For coaxial rotors, the force of the upper rotor is higher than that of the lower rotor and the peak fluctuation of the upper rotor is slightly higher than that of the lower rotor [16].
The lower rotor is located at the exit of the upper rotor and the upper rotor generates a high flow rate in place of the lower rotor, adding the lower rotor itself down, so that the resulting collective drainage speed at the place of the lower rotor plane is much higher than that of the individual rotor. On the other hand, the discrepancy between the drip speeds may explain the difference between the thrust values between the two coaxial rotors. The higher drip speed decreases the effective angle of attack of the lower rotor, resulting in a lower thrust coefficient [16].

Figure 5: Sikorsky Unveils S-97 (two coaxial rotors) [13]

2.4. The syncopter

The syncopter is a helicopter with two main counter-rotating rotors, having an arthemical lateral displacement of the shafts [1]. The device has almost a coaxial configuration, but it is simpler than this, from a mechanical point of view, due to the existence of two distinct main shafts [1].

Figure 6: The syncopter [17]

3. OTHER SOLUTIONS

In most helicopter configurations, power is supplied to the rotor by a mechanical transmission, i.e. through a shaft to which a torque is applied. Such configurations require a transmission and a means of balancing the reactive torque of the main rotor power is supplied by the reaction of a jet, using either cold air or hot air ejected to the trailing edge of the blades, at or along their blades. For example, have been built helicopters in which the engine jet is ejected through a tapered body placed on top of the blades or by linear ejectors placed along the vanishing edge of the blades; they used compressed air obtained in the fuselage and no anti-torque device is needed, which leads to a considerable reduction in the weight of the aircraft. However, the helicopter must have a mechanism for turning control. Aerodynamic surfaces such as those used on planes for turning control are not very efficient at low forward speeds, depending on the forces that it can generate the speed of the main rotor shaft [1].

Based on the information presented above, the following table was made in which the advantages, respectively the disadvantages of each configuration are highlighted, these being analyzed from a functional and constructive point of view.

Table1: Advantages and disadvantages of different rotors configurations

Configuration	One main rotor and one tail rotor	Two tandem rotors	Two coaxial rotors	Two left right rotors

Advantages	Simplicity of handling the device Requires a single set of controls and a single transmission for the main rotor The tail rotor provides good turn control Is the simplest and easiest solution for small and medium helicopters can carry up to 5 tons reaches speeds of 336 km / h	Does not require tail rotor Does not require a special anti-torque device Fewer helicopter accidents Wide longitudinal centering range Construction suitable for medium and heavy helicopters Carries up to 11 tons of equipment Reaches 417km / h	Does not require tail rotor Does not require a special anti-torque device Fewer helicopter accidents Remove long drive shafts Is compact and has a small diameter Higher load capacity Reverse torsion moments are canceled Small and light vehicle Safety vehicle Reaches 565km / h	Does not require a special anti-torque device Does not require tail rotor Fewer helicopter accidents More compact configuration Higher lifting capacity
Disadvantages	The helicopter requires more power The tail rotor can be a danger to those on the ground The auxiliary rotor can touch the ground on landing, causing material damage High power consumption The auxiliary rotor works in heavy aerodynamic conditions in the main one Reduces aerodynamic efficiency Increases the dynamic stresses and vibrations of the tail rotor	Mechanical complexity (two sets of controls and two transmissions) Implies the existence of a long fuselage Unwanted source of dynamic loads, vibrations and noise High power loss Unwanted weight of the rear pillar High inertia in the rotation and pitch movement Poor efficiency of the rotation control Low maneuverability and stability	Mechanical complexity (two sets of controls and two transmissions) The controls of the upper rotor and the transmission are complicated The existence of a larger vertical space Significant increase in passive resistance	Mechanical complexity (two sets of controls and two transmissions) Structure with undesired source of resistance to advance Additional passive weight source

4. CONCLUSIONS

Following the analysis of the table, the configuration with two coaxial rotors seems to be the most suitable for construction and use. Helicopters with this structure, although complicating the transmission and control of the upper rotor (hence mechanical complexity), are primarily compact and thus reduce materials needed for their construction, but also reach quite high speeds. By design, the configuration with axial rotors does not require tail rotor because the balancing of torques is inherent by rotating in the opposite direction of the main ones. The most important aspect to consider in this configuration is the safety of the vehicle and the low number of accidents in which it is involved.

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