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NOISE REDUCTION METHODS OF MODERN SINGLE ROTOR HELICOPTERS

It has been an enormous development since the first practically useable helicopter, VS-300 made by Igor Sikorsky, took off in 1939. At that time their flight performance was very limited but their ability to take off and land vertically and to hover was attractive both for civilians and the militaries. The designers' first aim was to improve this poor flight performance. Although modern helicopters have some limitations, too, but they are very useful in many fields and have become important weapons in the militaries.

Nowadays, a new challenge has appeared for helicopter manufacturers and this challenge is the reduction of emitted noise. It has been well-known for decades that helicopters are noisy devices but growing public sensitivity to helicopter noise and the claim to approach the battlefield as quietly as possible for attack helicopters forced them to be innovative in reducing the measured and perceived external noise levels of their products.

These new noise emission requirements, helicopter manufacturers facing with, have appeared in stricter local and international noise certification standards. Previously, helicopter noise was measured in a simple flyover of a single microphone at 500 feet AGL, regardless of aircraft gross weight. Recently the measurement protocol has also changed and it depends on the gross weight of the helicopter. At present, helicopters over 6,000 pounds gross weight have to pass a series of tests under specific operational and meteorological conditions in take off, flyover and landing mode and the measurement are taken over an array of three microphones. This approach produces an objective measure of aircraft noise. Other variables, such as spatial frequency distribution and frequency of events, are factored into the calculations to provide a subjective value for noise known as Effective Perceived Noise Level (EPNL) and it is measured in EPNdb.

Generally speaking, helicopter noise standards of the main aviation authorities, such as Federal Aviation Authority (FAA, United States), Joint Airworthiness Authority (JAA, Europe) and International Civil Aviation Organization (ICAO, a branch of the United Nations) are identical but the new standards expectedly will be stricter and stricter.

THE MAIN COMPONENTS OF ROTORCRAFT NOISE

Each helicopter has a unique noise signature, but we can say that irrespective of the type of MTR helicopters the main sources of rotorcraft noise are the following [4]:

- The main rotor;
  - High rotor blade tip speed (during high speed flight);
  - Blade-vortex interaction, BVI (during slow speed flight or turn);
- The anti-torque system;
  - The noise of tail rotor;
  - The sound produced by tail rotor blades cutting the main rotor vortices;
- Engine(s) and gearboxes.

In this work I deal with the first two noise emission sources (main rotor and anti-torque system) which have strong connection with the aerodynamics of rotorcraft. To decrease these noises the major manufacturers use a variety of technologies and design solutions including compromises, too.

Lower tip speed

We have known for decades that the high tip speed makes a lot of noise. At high forward speeds the advancing rotor blade tips ($\psi = 90^0$, Figure 1. [2]) approach the speed of sound, so the compressibility of air appears with its negative phenomenon (shock waves, vibration and strong impulse noise).

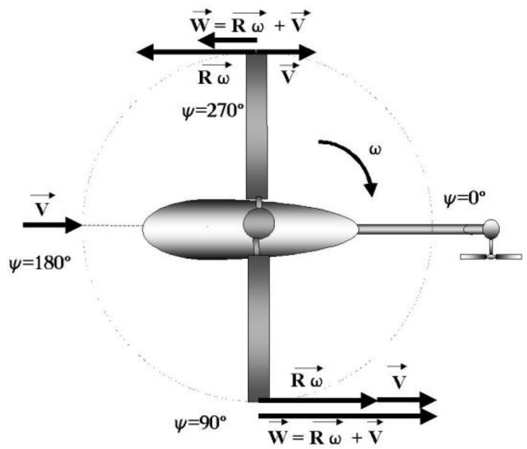

Fig. 1. Resulted tip speeds at $\psi = 90^{\circ}$ and $\psi = 270°$

The development of Bell UH-1 series is a good example for this. Bell UH-1A had a modest rotor tip speed with reasonable noise level. UH-1B got a stronger Lycoming T-53 turbine and the rotor diameter was increased with unchanged rotor RPM. That increment resulted in an advancing tip Mach number of 0,9. Thus the observers on the ground could hear the impulse noise as the helicopter approached from miles away.

If the high tip speed makes the helicopter noisy, then it follows that reduced tip speed results in a quieter helicopter. One solution can be the reduction of rotor RPM. But unfortunately, it is not so simple. At a reduced rotor RPM the size of helicopter envelope will decrease, which means that its maximum rotor thrust, forward speed, payload and flying altitude will also decrease.

Reducing the rotor RPM, but increasing the number of rotor blades the decrement in performance is not as significant as in the first case however assuming unchanged rotor thrust we can expect some disadvantages:

- Reduced allowable payload resulted by the weight of the extra rotor blades;
- Higher required power resulted by the profile drag of extra rotor blades;
- Higher main rotor drive torque, which means higher required power for the tail rotor;
- Reduced maximum forward speed resulted by retreating rotor blade stall.

Despite these disadvantages the use of four or more rotor blades combining lower rotor blade tip speed and blade loading is a feature of nearly all quiet helicopters. We can say that present day new technologies, more sophisticated airfoils, rotor blade shapes, lighter new composite materials balance the above mentioned disadvantages.

An other possibility is the variable rotor RPM. Using rotor RPM governor with two or more settings we can get different rotor RPM-s in accordance with settings, which can be adjusted manually or automatically. For example, using two settings the lower setting would be for flight when the helicopter is near inhabited areas, primarily during take off and landing and other low-altitude operations. The higher setting is for flight situations where noise is less important, such as high altitude cruise or air-to-air combat for military helicopters. Unfortunately, this solution does not totally fit for the operational characteristic of helicopters because the higher performance, rotor thrust (available in case of higher rotor RPM) would be necessary only during take off and landing. Nevertheless, many manufacturers (Eurocopter, MD, Bell) use this device, but we can say that the purposes they want to reach are very different, and, in most cases it is not the noise reduction.

Swept rotor blade tips and thinner tip airfoils

We know that the negative effects of compressibility (for example, impulse noise) related to the difference of Mach number of the rotor blade tip and its critical Mach number. The nearer the rotor blade tip Mach number approaches its critical Mach number the stronger its noise will be. A way of getting performance advantages of high rotor tip speeds without the noise penalty is to sweep the rotor blade tips. This solution reduces the effective Mach number in the swept region. Generally the outside 7-14% part of blade is swept back by 15-25°, which decreases the effective Much number in this region by 6-10%.

Another way to minimise compressibility problems is to raise the critical Mach number of rotor blade tip by using thinner airfoils here. This is not a too difficult problem nowadays when most rotor blades are made of composites. The disadvantages of both methods are that they reduce the angle of attack of stall at the retreating rotor blades, and the sweep can cause unwanted aeroelastic couplings.

At present, probably the most sophisticated version of swept rotor blades is the BERP (British Experimental Rotor Program) rotor blade [5]. This strange paddle-shaped rotor blade tip was the product of the ten-year (1976-86) joint project of Westland Helicopters and British Royal Aeronautical Establishment. This shape came from the special sweep they used. They swept the leading edge first forward and then aft (air does not care about the sign of sweep).

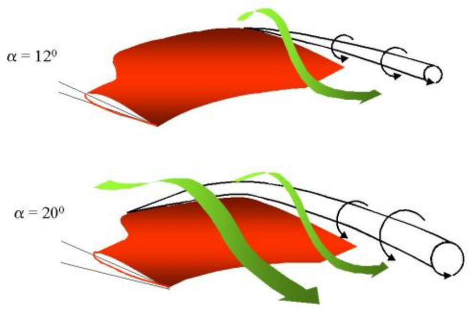

Fig. 2. Tip vortices around the BERP tip

This method could maintain both the tip's aerodynamic center and its center of gravity near the structural axis avoiding the above-mentioned unwanted aeroelastic couplings. In addition this sweep resulted in considerable increment in chord of rotor blade tip, thus it became relatively thinner, further reducing compressibility effects. But the most surprising was that despite its smaller thickness ratio, BERP tip delayed the retreating tip stall reaching about 20° local angle of attack compared to 12-15° for conventional tips. This phenomenon was caused by the vortex (Figure 2.), which is generated at the notch of the tip. Proving its abilities a modified Westland Lynx helicopter with this BERP blades achieved a new helicopter speed record of 216.3 knots (400.8 km/h). Now these kinds of rotor blades are used on the Westland Lynx III battle helicopter and EH-101 transport helicopter.

Blade-vortex interaction

Blade vortex interaction (BVI) is what we can hear when the helicopter flies slowly or banks. It is a sharp slap when a rotor blade strikes or just comes too close to the tip vortex left by previous blade [1]. Much effort has gone to understand and reduce this phenomenon with relatively few results. At present the most effective method to diminish this noise is to avoid the combinations of forward speed and rates of ascent or descent at which the helicopter is noisiest. These combinations are found in some flight manuals.

Nowadays some manufacturers are conducting research on active rotor blade control, which can be the most promising device against the BVI. They try to use smart materials, which would change the twist (in this way the angle of incidence) of rotor blades using only electrical impulses. This electrical actuation can change the flight path of the individual rotor blades allowing them to avoid vortex interactions and, in addition, this technology would make it possible to eliminate the mechanical control system.

Fenestron (fan-in-fin, fantail)

Driving the main rotor, by applying power at the rotor shaft, automatically tries to rotate the helicopter’s fuselage in the opposite direction of the rotor blades. By far the commonest arrangement is the “main and tail rotor” (MTR) helicopter, in which the main rotor drive torque is counteracted by the tail rotor thrust. Despite the general use of tail rotor it has many disadvantages. For example, vibration, high power requirement, vulnerability, safety problems, and last but not least, high noise emission. Due to the tail rotor's higher RPM the frequency of its noise is much higher than the frequency of main rotor noise. In addition, further noise emission source appears if the tail rotor cuts through tip vortices left by the main rotor. Probably that was the reason why the leading helicopter manufacturers sought new ways to counteract torque. Nowadays two systems replace the conventional tail rotor: fenestron and NOTAR.

Fig. 3. Fenestron of EC-120 and EC-135 helicopters.

The “fenestron” was pioneered by Aerospatiale before it became part of Eurocopter. Later Eurocopter has referred to it as a “fan-in-fin” and Boeing Sikorsky as a “fantail”. Because the blades have very small clearances with the side of the duct, there are essentially no tip vortices and the noise from the blades is at least partially blocked by the duct, thus it should be inherently quieter than a tail rotor. Despite this facts the first versions of fenestron were not totally successful. Although the emitted noise was lower, but on a single dominant high frequency, which made them like a siren. Later Eurocopter on EC-135 (Figure 3.) and subsequent Eurocopter designs made the blade spacing uneven, slanted the supports and reduced the tip speed by 10%. This made a more distributed noise, which is easier on the ears than the shrill sound of the original designs.

NOTAR helicopters

As I mentioned in the previous chapter the tail rotor with its disadvantages is a necessary evil. Helicopter designers have been working on replacing the tail rotor since the first helicopters left the ground.

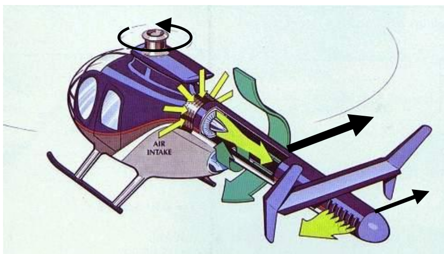

Fig. 4. Scheme of NOTAR system

Although fenestron solved some problems of tail rotors but in the late 1970s then Hughes Helicopters started a new project, which was totally different from the previous methods.

After long tests and some difficulties its successor, McDonnell Douglas could introduce the MD 520N helicopters in 1991. NOTAR means “no tail rotor” and it uses a fan-driven air circulation within the tail boom to counteract the main rotor drive torque (Figure 4.) and to provide the yaw (directional) control of helicopter. Of course, the fan mounted in tail boom is not soundless, but especially at subsequent more sophisticated versions, MD 600N and MD 902 the noise decrement is significant. These NOTAR-equipped helicopters with five and six-bladed main rotor are well below even the most restrictive ICAO noise standards.

SUMMMARY

Summarising these efforts, we can say that none of them offers fundamental breakthrough. Present day quiet helicopters usually use the variety of above-mentioned solutions and many times designers are forced to pay performance for noise reduction. We can be sure that any manufacturers will not be able to produce an absolutely quiet helicopter, but we can also be sure that manufacturers will do everything possible competing for the favours of their buyers.

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