Numerical study of aerodynamic drag of modern attack helicopters

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Abstract.
This paper is devoted to the study of the aerodynamic drag of modern attack helicopters using numerical methods. The parasitic drag of the fuselages of modern attack helicopters was calculated and analyzed. The contribution of the main fuselage components to the total aerodynamic drag of the helicopter was analyzed.

Keywords:
- helicopter
- CFD
- drag analysis
- numerical study
- aerodynamic
Introduction

Speed is one of the key parameters in the flight performance of attack helicopters:
- Maneuverability in combat conditions - high speed allows attack helicopters to effectively maneuver in combat situations, evade threats and quickly respond to changing situations.
- Anti-Air Threat Avoidance - Moving quickly allows to evade threats from enemy anti-air weapons such as anti-aircraft missiles and fighter aircraft.
- Rapid entry into the combat zone - attack helicopters must quickly reach the combat zone to support ground forces or to perform other combat missions.
- Attack Efficiency - Greater speed increases the effectiveness of air attacks, allowing helicopters to quickly approach the target, carry out a strike and move away from the danger zone.
- Survivability - the ability to quickly escape from dangerous zones and dodge threats increases the survivability of helicopters.

Overall, high speed is an important factor for ensuring the successful completion of combat missions and increasing the survivability of attack helicopters in hostile environments.

During Russia’s armed aggression against Ukraine, both conflicting parties used combat helicopters [1]. On the Russian side, these were helicopters such as the Ka-52 “Alligator”, Mi-28 “Havok” and Mi-24/35 “Hind”. Ukraine mainly used the Mi-24. Attack missions were primarily carried out in pairs using a combination of guided/unguided missiles and artillery against enemy concentrations, lightly armored vehicles and, much less frequently, guided missiles against tanks and other armored targets [1, 2]. In the early stages of the conflict, helicopters were primarily used for “hunter-killer” missions, penetrating up to 50 km deep into enemy territory [2]. Russian helicopters flew at fairly high altitudes of 50-150 m, ignoring the requirements of maneuvering (constant changes in altitude and course), sometimes even hovering in place to sight and track targets. All this led to significant losses of helicopters [1]. Since
March 2022, the tactics of Russian attack helicopters have undergone changes:

- Flights of large groups of helicopters (as was the case in the early stages of the war) were excluded to prevent unmasking.
- Helicopters began to fly at extremely low altitudes (5-50 m) and maximum flight speeds, using the terrain and vegetation for cover.
- Flights began to be carried out mainly at night to strike targets of critical importance.

All these measures allowed to increase survivability, and thereby reduce losses among attack helicopters [1]. It is worth noting that flights at low altitudes (contour flying or “Nap-of-the-earth”) at maximum speeds are part of the current NATO standards regarding the tactics of using attack helicopters [3,4]. This is also reflected in helicopter pilot training programs, for example in Poland Air Forces [5].

In this type of attack helicopter tactics, speed and maneuverability are the decisive parameters [4].

The parasitic drag of a helicopter is one of the key factors that influence the flight performance of the helicopter as a whole, and also acts as a limiting factor that often determines the maximum flight speed of the helicopter.

Fuel consumption at cruising and extreme flight modes significantly depends on the magnitude of parasitic drag, which also determines the effective range of the helicopter.

The required power of the power plant as well as the available power for the tail rotor also largely depends on the amount of parasitic drag, which, in turn, determines the limits of its maneuverability.

A number of scientific works, both past and present, are devoted to reducing the parasitic drag of a helicopter. For example, work [6] is devoted to finding a way to reduce parasitic drag of a small multi-purpose helicopter, including through the use of a main rotor hub fairing. Work [7] is devoted to reducing the parasitic drag of a helicopter through the use of vortex generators. In [8], the possibility of reducing parasitic drag by modifying the shape of the fuselage is considered. Work [9] shows how, by optimizing the engine
outlets, it is possible to reduce the parasitic drag of the entire helicopter. In [10], the authors examine the contribution of the main rotor hub and swashplate components to the total parasitic drag of an average transport helicopter, and in [11] they propose a non-standard method for reducing it.

This work is devoted to determining the parasitic drag characteristics of modern attack helicopters using numerical methods, as well as the contribution of the main parts of the fuselage to the total parasitic drag.

**Numerical approach**

The solution to the problem was carried out by numerically solving the Reynolds Averaged Navier-Stokes equations (RANS) for a compressible gas (ideal gas) with a two-parameter $k-\varepsilon$ Realizable turbulence model [12] to close the system of equations in a steady-state formulation.

As parameters of the free stream, the parameters were chosen that are most typical for the cruising flight of the helicopters selected for analysis: inlet velocity $- 69.4$ [m/s]; air pressure $- 101.3$ [kPa]; air temperature $- 15$ [$^\circ$C].

As for pure, non-reacting gas, the dynamic viscosity is only dependent on temperature [13], than the dependence of viscosity on temperature was taken in the form of Sutherland's law [14].

The boundary conditions at the inlet boundary corresponded to the velocity-inlet, and at the outlet boundary to the static pressure. The model surface was assumed to be adiabatic. The no-slip condition was implemented on it.

The size of the computational domain and the spatial position of the helicopter fuselage model (using the example of a Ka-52 helicopter) are shown in Fig. 1.

The total number of elements of the computational grid, depending on the fuselage model under consideration, was about 4-6 million cells.

The computational models of the helicopters studied in this paper are based on publicly available images and do not claim to be reliable.

The main interest in this work, as already noted, is the integral aerodynamic characteristics. Based on the
calculation results, the integral values of the forces that act on the model in a Body-Fixed Coordinate System were obtained. Then, using standard transformations, these forces were recalculated into a Wind-Axis Coordinate System and into dimensionless coefficients.

Comparative calculations were carried out in the range of attack angles from $-90^\circ$ to $+20^\circ$ (with 10° steps in the $-90^\circ$...$-30^\circ$ section; with 5° steps in the $-30^\circ$...$-20^\circ$ section; with 2° steps in the $-20^\circ$...$+20^\circ$) at zero slip angle, as for the most typical modes for cruising flight and combat maneuvering.

Each of the models was divided into its main components to be able to determine the contribution of one or another component to the total parasitic drag (see Fig. 1). However, the need to take into account the mutual influence of individual elements of the fuselage, such as the main rotor hub, gun, landing gear and the fuselage itself, requires
calculations of the corresponding layouts [15]. In this work, the task was to determine the aerodynamic characteristics of the body with all the above-mentioned layout elements. All fuselages were considered without a wing and a horizontal stabilizer to create equal conditions for conducting a numerical experiment [16].

**Calculation results**

In accordance with the task, the aerodynamic forces acting on the fuselage depending on the angle of attack for the helicopters under study were calculated, which were then converted into dimensionless coefficients. The main interest among which is the drag coefficient:

\[ C_D = \frac{D}{0.5 \rho V^2 A}, \]  

where, \( D \) - drag force, [N];  
\( \rho \) - air density, [kg/m\(^3\)];  
\( V \) - free-stream velocity, [m/s];  
\( A \) - reference area, [m\(^2\)]

The values of the midsection area and the area swept by the main rotor for the helicopters under study are given in Table 1.

Cumulative diagrams depicting the component contribution to the total parasitic drag depending on the angle of attack of the fuselage are presented in Fig. 8.

The distribution of the pressure coefficient over the fuselage surface (at \( \alpha = 0^\circ \)) for each of the helicopters under consideration is presented in Fig. 10-18.

**Table 1**

<table>
<thead>
<tr>
<th>Helicopter</th>
<th>AH-12</th>
<th>AH-64</th>
<th>EC-665</th>
<th>AH-129</th>
<th>Mi-2-10</th>
<th>Mi-2-28N</th>
<th>Mi-1-35</th>
<th>Mi-2-24P</th>
<th>Mi-2-32K</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A_{\text{MID}} ), [m(^2)]</td>
<td>4,949</td>
<td>6,174</td>
<td>5,078</td>
<td>4,546</td>
<td>4,628</td>
<td>8,312</td>
<td>8,621</td>
<td>7,068</td>
<td>6,813</td>
</tr>
<tr>
<td>( A_s ), [m(^2)]</td>
<td>168.6</td>
<td>168.6</td>
<td>132.7</td>
<td>111.2</td>
<td>113</td>
<td>235</td>
<td>235</td>
<td>235</td>
<td>165.4</td>
</tr>
</tbody>
</table>

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Figure 2
Comparative diagram $C_{D0}$ for the helicopters under study

$\sum C_{D0}$ (lower is better)

- AW-129: 1.567
- WZ-10: 1.579
- Mi-24P: 1.627
- EC-665: 1.827
- AH-1Z: 1.900
- Ka-52: 2.211
- AH-64: 2.446
- Mi-35: 2.987
- Mi-28N: 3.171

Figure 3
Comparative diagram $C_{D0}$ for “landing gear” component for the helicopters under study

- Ka-52: 4.2
- Mi-28N: 11.5
- AH-64: 12.8
- AH-1Z: 13.6
- Mi-35: 19.2
- EC-665: 22.1
- AW-129: 23.2
- WZ-10: 23.7
Comparative diagram $C_{D0}$ for “gun pod” component for the helicopters under study

Comparative diagram $C_{D0}$ for “hull” component for the helicopters under study
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**Figure 6**
Comparative diagram $C_{D0}$ for “DPS” component for the helicopters under study

**Figure 7**
Comparative diagram $C_{D0}$ for “ESD” component for the helicopters under study
Figure 2–7 depicts the comparative diagrams of $C_{DD}$.
\( C_D(\alpha=0^\circ) \) of all main components of the helicopters under study.

Figure 19 shows the turbulent intensity field in the vicinity of the helicopters under study.

**Figure 8**
Cumulative diagram of the contribution of each component to the total parasitic drag of the helicopter:

- a – AH-1Z;
- b – AH-64;
- c – EC-665;
- d – AW-129;
- e – WZ-10;
- f – Mi-28N;
- g – Mi-35;
- h – Mi-24P;
- i – Ka-52
Fig. 9 shows that most of the helicopters under study are “localized” at the same level on the plot. Only two helicopters stand out unfavorably – these are the Mi-28 and Mi-35. This is not surprising, since both of these helicopters have the highest mid-section values of all the helicopters studied in this paper.

It was also noted that the main rotor mast makes a very large contribution to the total parasitic drag of the Ka-52 helicopter (about 40%), which is not surprising in view of its complex coaxial configuration.
Figure 10
Surface Line Integral Convolution (LIC) colored by the pressure coefficient for the AH-1 helicopter

Figure 11
Surface Line Integral Convolution (LIC) colored by the pressure coefficient for the AH-64 helicopter
Figure 12
Surface Line Integral Convolution (LIC) colored by the pressure coefficient for the EC-665 helicopter

Figure 13
Surface Line Integral Convolution (LIC) colored by the pressure coefficient for the AW-129 helicopter
Figure 14
Surface Line Integral Convolution (LIC) colored by the pressure coefficient for the WZ-10 helicopter

Figure 15
Surface Line Integral Convolution (LIC) colored by the pressure coefficient for the Mi-28 helicopter
Figure 16
Surface Line Integral Convolution (LIC) colored by the pressure coefficient for the Mi-35 helicopter

Figure 17
Surface Line Integral Convolution (LIC) colored by the pressure coefficient for the Mi-24P helicopter
Figure 18
Surface Line Integral Convolution (LIC) colored by the pressure coefficient for the Ka-52 helicopter

a) b) c) d)
However, despite the aerodynamic drag introduced by it, in general, the drag of the Ka-52 helicopter is within the limits of other helicopters considered and even less than...
some of them.

Despite the rather successful shapes from an aerodynamic point of view, some of the helicopters under consideration have increased parasitic drag due to poorly streamlined structural elements that create unstable large vortex formations (Fig. 10-19), but, in any case, must be placed on the fuselage and cannot be hidden behind fairings (gyro-turrets, guns, antennas, landing gear, etc.). However, one can notice a number of design solutions (see Fig. 10-18) aimed at reducing the parasitic interference of the fuselage with them (the use of sponsons, fairings, structural niches in the fuselage).

CONCLUSIONS

In this work, a study of the parasitic aerodynamic drag of modern attack helicopters from several countries of the world was carried out. This study is quite relevant in light of recent military conflicts, which have revealed a number of key flight characteristics, the improvement of which increases the survivability of a helicopter - speed and maneuverability [2]. Flights at low altitude at maximum speed, contour flying, as well as increased maneuverability can significantly increase the chances of survival of a helicopter [1, 2], in some cases even more than armor [1, 2]. All these characteristics directly depend on the available and required power of the power plant, and therefore on the magnitude of the parasitic drag of the helicopter [7, 8].

The results of the study may be useful in the design of a new perspective attack helicopter, which will take into account the distribution of parasitic drag across components, as well as locations on the fuselage where their placement is highly undesirable.

The work also shows that the Mi-24P helicopter, which is quite outdated by modern standards, has a fairly low parasitic drag value, while being one of the fastest helicopters in the world [17]. Modernization of the rotor system, the use of new blades with improved aerodynamic characteristics, a new X-shaped tail rotor and a higher power-to-weight ratio, coupled with modernization of on-board equipment can keep this helicopter relevant as the main attack helicopter of many countries for many years to come, especially considering the
fact that many states (especially the countries of the former Warsaw Pact) still have an impressive fleet of this type of helicopters in service [18].

The work also noted that, despite the huge contribution of the main rotor mast to the total parasitic drag of the fuselage, a coaxial helicopter (the previously reviewed Ka-52) has a total parasitic drag at the level (and in some cases less) of modern attack helicopters of the conventional design. Which, taking into account the absence of a tail rotor, gives it a serious advantage in speed and maneuverability (due to the presence of power reserves of the power plant).

References:

[5] Program szkolenia lotniczego na śmigłowcach w lotnictwie Sił Zbrojnych Rzeczypospolitej Polskiej (PSzL, or Polish Aviation (Helicopters) Training Program), 2012


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