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A METHOD FOR REDUCING PARASITE DRAG OF MEDIUM TRANSPORT HELICOPTER

*At present, more and more stringent emission requirements are being imposed on helicopters. Carbon dioxide emissions are a function of fuel consumption, and fuel consumption is directly dependent on the power required for a helicopter cruise flight. The power, required for horizontal flight of a helicopter directly depends on the design of the fuselage and other non-lifting elements, and accordingly, on parasite drag. Therefore, the desire to reduce parasite drag is expected and understandable. Helicopter parasite drag reduction was hailed as one of the key topics of the Seventh Clean Sky Framework Conference. For sixty years of research on this topic, a tremendous amount of experience has been accumulated. In particular, it was found that the main contributors to the total parasite drag of the helicopter were the main rotor hub and swashplate. The **subject matter** of this article is the study of the parasite drag of the hub and swashplate of a medium passager/transport helicopter Mi-8/17. This study aimed to develop methods to reduce the parasite drag of the Mi-8/17 helicopter. Mi-8/17 is the most mass-produced twin-engine helicopter in the world. Currently, more than 4,5 thousand units are in operation around the world. Therefore, the **task** of reducing parasite drag for this helicopter is very relevant. Modern **methods** of computation fluid dynamics (CFD) are used. Modern methods of computational fluid dynamics with an acceptable degree of accuracy make it possible to consider the interference phenomena of the components of the hub, swashplate, and helicopter fuselage, which is not always possible, to obtain correctly during expensive wind tunnel tests. During the work, the following **results** were obtained. An analysis was made of the contribution of each element of the design of the hub and the main rotor swashplate to the total parasite drag. A method for reducing the parasite drag of a helicopter using a mast fairing is proposed. Several variants of the mast fairing were considered, and the most effective one was chosen. The effect, as well as its degree of influence, of the airflow blown by the fan cooling the air-oil radiators, on the general parasite drag of the helicopter was revealed. The results of the studies, given in this article have been implemented in the production.*

Keywords: *helicopter; rotor swashplate; parasite drag; CFD; fairing; numerical simulation; Mi-8/17.*

Introduction

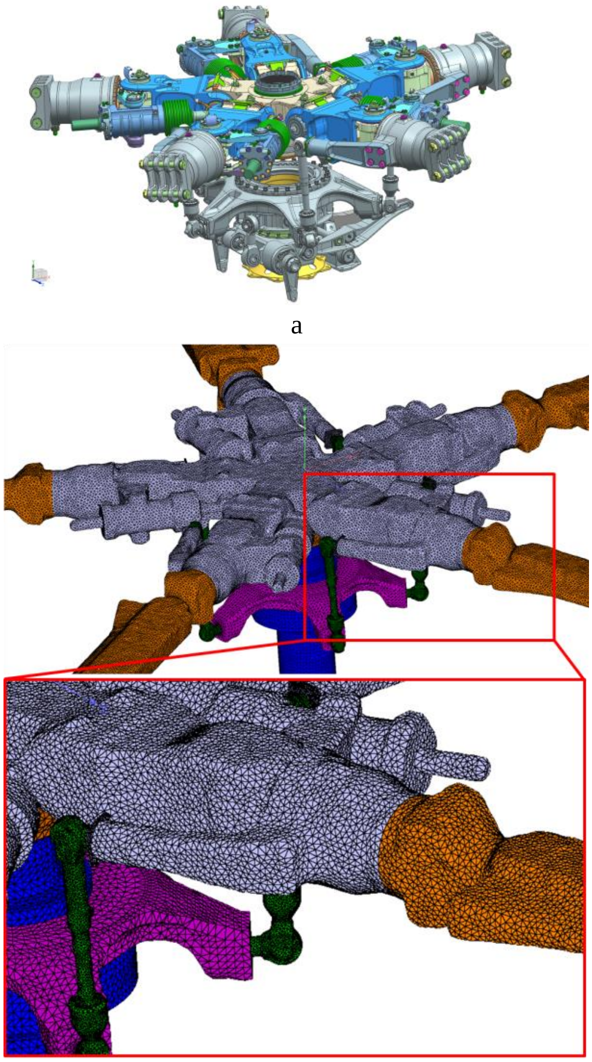
The issue of environmental impact has become especially significant due to the recent increase in helicopter usage. Present day environmental regulations place severe constraints on helicopter exhaust emissions, with expectations of more restrictive future regulations for helicopter efficiency and fuel consumption. As a result, the desire to decrease fuel consumption has prompted research efforts towards optimizing the shape of helicopters to minimize drag. The aerodynamic optimization of helicopter components became a research topic introduced in the work plan of the GRC (Green RotorCraft) project in the frame of Clean Sky program. The Clean Sky JTI (Joint Technology Initiative) was launched in 2008 as a Public-Private Partnership between the European Commission and industry with the mission to develop technologies that increase the environmental performance of air transport [1]. The GRC top objectives are a reduction of CO2 emissions by 25 to 40 %, together with a reduction of the perceived noise on ground by 10 EPNdB, and a full conformity with the European Union Regulation REACH protecting human health and environment from noxious chemical substances [2]. CO2 emissions are function of fuel consumption, and consequently of the power required to fly, which directly depends on the design of the airframe and of the non-lifting rotating components for forward flight [2]. Therefore European Commission 7th Framework Program for collaborative research has defined therefore the reduction of helicopter aerodynamic drag as one of the main goals of its "Clean Sky" JTI [3]. It is well known that helicopters have high aerodynamic drag compared to fixed wing aircraft. High drag compromises the endurance of the helicopter, and presents an additional operational expense. Any attempt to reduce the drag of the helicopter must address the aerodynamic environment of the rotor hub and the surrounding fuselage area. Rotor hub and pylon drag constitute 20-30 % of the total parasite drag of single rotor helicopters [4, 5]. Since parasite drag represents 40-50 % of the total power requirement of a single rotor helicopter, the drag of the rotor hub represents roughly 10 % of the total power required [5]. The unfavorable drag characteristics of rotor hubs are mainly due to their complex design which involves several bulky components. The position of the rotor hub inside the accelerated flow region above, and in its immediate vicinity of the fuselage, are additional factors increasing the drag of the hub [6]. The mast fairing is little more than a faired bluff-body, and pitch links, lag dampers, blade sleeves and other parts located in the rotor hub generate significant amounts of separated flow. Trailed vortices are also formed at the blade roots [6]. The idea of using a hub fairing to streamline the rotor hub dates from the late nineteen-fifties [4]. A great deal of research efforts has been dedicated over the past five decades to rotor hub drag analysis and reduction relying mostly on experimental investigations of reduced scale models [1, 5]. The majority of these investigations indicated that streamlining the main rotor hub and using pylon and mast fairings are efficient means to reduce the overall drag of the helicopter [7, 8]. Computational Fluid Dynamics has the advantage that the drag contributions due to each component can be resolved, [2] and this can assist with an interpretation of the physical significance of the mechanisms at play. Numerical tools have been preferred over wind-tunnel tests, for schedule-and-cost reasons. For example, CFD methods are also able to take into account such a complex phenomenon as the interference of the main and tail rotors of a helicopter, with low costs of computational and time resources [9]. Several published CFD investigations of rotor hub aerodynamics [2, 3] could demonstrate, however, that present day CFD tools are capable to analysis this class of flow problems reliably. In addition, wind-tunnel measurements of interaction drag or direct drag of some subcomponents remain difficult to perform. Thus, in the following, drag evaluations rely exclusively on numerical computations. This work is devoted to the drag analysis of the main rotor's hub and swashplate, as well as a proposal to reduce this drag for a medium transport/passenger helicopter of the Mi-8/17 type.

Object of study

The object of study in this paper is a Mi-8/17 helicopter. Mi-8/17 is among the world's most-produced helicopters [10], used by over 50 countries. As of 2015, it is the third most common operational military aircraft in the world [10]. Currently, more than 4.5 thousand helicopters of this type are in operation around the world. Therefore, the concept of parasite drag reduction in order to improve economic, flight performance and environmental performance is very relevant for this helicopter.

The investigated geometry represents a full-scale model of the helicopter, with five-bladed rotor head, which is illustrated in Fig. 1. The main focus of the present work lies on the evaluation of the aerodynamic forces of the rotor hub and swashplate with its own components. Therefore, the model does not include the full main rotor and the rotor blades are truncated at about one fifth of the rotor radius. It is quite common in wind-tunnel measurements to use truncated rotor blades in fuselage-tail section configuration testing [11].

The models of the main rotor hub and swashplate were simplified to optimize the calculation time, and also due to the insignificance of the influence on the parasite drag of some of their elements [12]. The CAD model of the main rotor hub and swashplate and the numerical surface grid are shown in Fig. 1a, b respectively.



a

b

Fig. 1. Swashplate and main rotor hub of Mi-8/17 helicopter (a – detailed CAD model; b – numerical surface grid)

The numerical grid was generated in such a way as to reproduce all the necessary main features of the geometry of the main rotor's hub and swashplate models (see Fig. 1b).

The main rotor hub and swashplate were conditionally divided into several parts (see Fig. 2) to track the effect of aerodynamic forces on each of the components separately, as it was done previously [13].

Subsequently, a comparison was made between the components in the baseline configuration and the configuration with the proposed swashplate fairings.

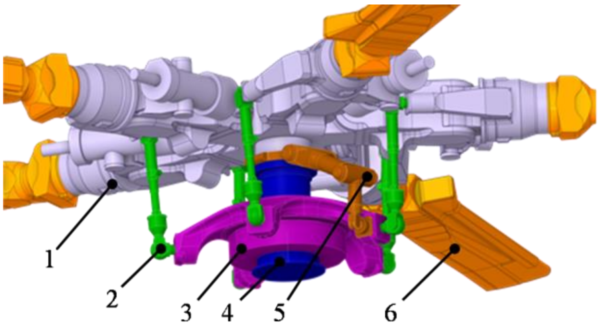


Fig. 2. Computational model of main rotor hub and swashplate: (1 – hub; 2 – pitch link; 3 – swashplate; 4 – shaft; 5 – scissor link; 6 – blade stab)

Numerical Approach

The solution of the problem was carried out by numerical solution of the Navier-Stokes equations averaged by Reynolds (Favre) (RANS – Reynolds Averaged Navier-Stokes) for an incompressible ideal gas with a two-parameter k-ε Realizible turbulence model for closing the system of equation in a non-stationary (transient) formulation. The computational domain has the shape of a parallelepiped with dimensions of 200 m x 70 m x 60 m. It is subdivided into two subdomains - one rotating (with elements of the main rotor hub and swashplate), and one stationary (including the fuselage). Subdomains interact with each other through a sliding interface. The boundary conditions at the inlet are set to a constant velocity, and at the outlet boundary – to zero pressure gradient. The free-slip condition (zero shear stress) is implemented on the side walls boundaries. Engine and fan inlet boundaries are set to a fixed mass flow. The boundary of the air flow outlet from the fan that cools the air-oil radiators of the gearbox is set to a fixed mass flow. The influence of the main rotor is taken into account by setting a previously calculated value of the stationary downwash from the main rotor for the cruising flight mode of the helicopter. In general, the numerical approach is in consistent with the approach, which is used in the previous work [13]. The integral aerodynamic characteristics are of primary interest. Based on the calculation results, the integral values of the aerodynamic forces acting on the model were obtained in the body-fixed axis system. Then, using standard transformations, these forces were recalculated into a wind axis system.

To determine the degree of improvement (or degradation) in the aerodynamic qualities of the designed mast fairing, the baseline configuration (without mast fairing) was calculated previously [13] (all further comparisons were made with this configuration). To determine the degree of influence of the air flow, which is created by the fan that cools the air-oil radiators, the second version of the fairing (Fairing №2) with the fan turned off and on was calculated. All other configurations, including the baseline configuration, were calculated with the fan on (due to its significant effect on aerodynamic characteristics, see Fig. 17 and [13]).

The following mast fairing configurations were considered:

1) Baseline configuration (no mast fairing);
2) Mast fairing №1;
3) Mast fairing №2 (the fan is OFF);
4) Mast fairing №2;
5) Mast fairing №2 + cap.

Numerical Parameters and Flight Conditions

For the calculations, a cruising flight was considered with the preservation of authentic cruising flight parameters of the helicopter. The cruising flight speed of 225 km/h (62.5 m/s) was set in the form of the speed vector components corresponding to it at the inlet boundaries of the computational domain: along the “X” axis 62.4 m/s; along the “Y” axis -3.27 m/s - which corresponds to a flight at a speed of 225 km/h with a true angle of attack of -3° (pitch angle is 0.5°, angle of downwash from the main rotor is -2.5°). Air density – 1.225 kg/m^3, pressure – 101.3 kPa. The air flow rate at the engine inlet is 8.4 kg/s [14], the air flow rate at the fan inlet is 5.7 kg/s [15]. The roughness of the main rotor hub elements is 0.00025 m. The roughness of the fuselage elements is 0.0001 m. The characteristic area used to recalculate the aerodynamic coefficients is 356 m^2. Time discretization is 0.001 s (1.152° of blade azimuth position per 1 time step). The total simulation time of the physical process is 3 s (9 full revolutions of the main rotor).

Results and Discussion

In accordance with assigned task, the aerodynamic forces for the above variants of fairings were calculated.

The calculation of the baseline configuration was carried out earlier, and covered in [13]. A very important result, which was demonstrated, is the component-by-component contribution to the total helicopter’s parasite drag of each of the considered parts [13].

According to the results of the baseline configuration calculations [13], the following distribution was obtained (see Fig. 3.).

As can be seen in Fig. 3, the contribution of the swashplate together with the main rotor hub and its parts is 33 %, which is consistent with the statistical data [1, 12]. The main contribution to the parasite drag of the “main rotor hub – swashplate” subpart is directly divided between the hub (11.7 %) and the blade stabs (13.98 %). This means that the remaining elements (swashplate, pitch links, scissor link, shaft) in total amount to only 7.38 % of the total parasite drag [13]. Such a distribution of parasite drag between the elements is in sufficient agreement with the data given in [1, 12] for the GRC (Green Rotorcraft) helicopter model. If we take into account, that some of the mentioned elements cannot be hidden by the fairing (due to design limitations), then it can be assumed that, potentially, it is possible to reduce the total parasite drag by ~2–4 % by installing a mast fairing.

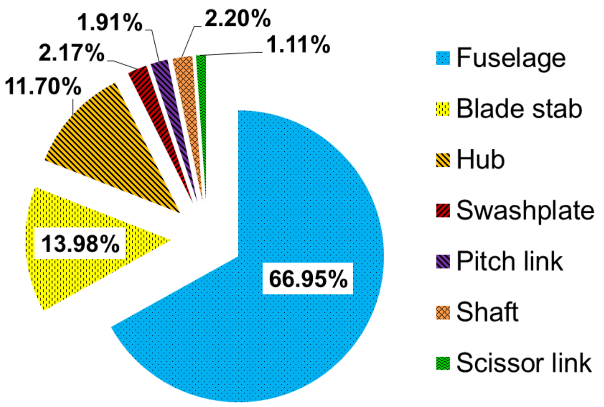


Fig. 3. Parasite drag breakdown of the baseline configuration Mi-8/17 helicopter [13]

Evaluation of changes in drag was carried out according to the main criteria – change in the coefficients of aerodynamic forces relative to the total C_D and C_L of the *baseline* configuration:

$$\frac{C_{D\,comp\ default\ conf} - C_{D\,comp\ N=i\ conf}}{\sum C_{D\,default\ conf}}\cdot 100\%, \qquad (1)$$

$$\frac{C_{L\,comp\ default\ conf} - C_{L\,comp\ N=i\ conf}}{\sum C_{L\,default\ conf}}\cdot 100\%, \qquad (2)$$

where $C_{D\,comp\ default\ conf}$, $C_{L\,comp\ default\ conf}$ – drag and lift coefficients of the baseline configuration's component;

$C_{D\,comp\ N=i\ conf}$, $C_{L\,comp\ N=i\ conf}$ – drag and lift coefficients of the *i*-configuration's component;

$\sum C_{D\,default\ conf}$, $\sum C_{L\,default\ conf}$ – total drag and lift coefficients of the baseline configuration.

Main rotor hub

For all three versions of the mast fairings, an insignificant increase in the drag of the main rotor hub is observed (in all three cases, no more than 0.5 %, see Fig. 4).

Blade stab

There are no obvious changes (see Fig. 5). Configuration "Fairing №2 + cap" shows a slight increase in drag relative to the baseline configuration case (less than 0.5 %).

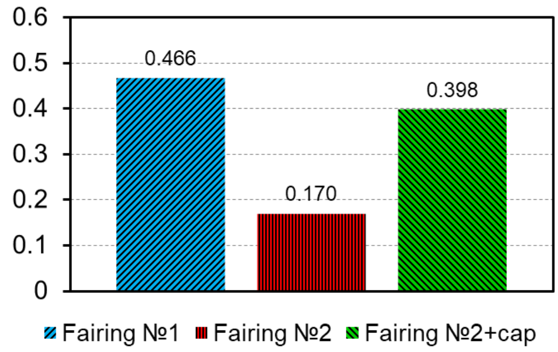


Fig. 4. Drag breakdown for main rotor hub component (relative to the total C_D of the baseline configuration)

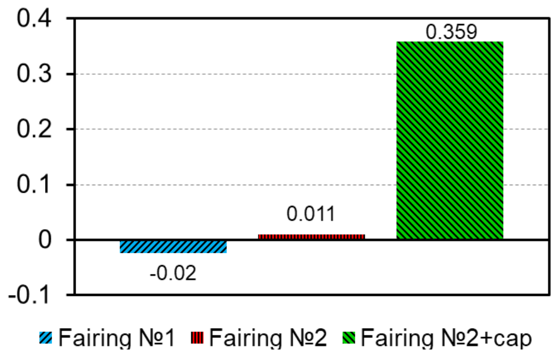


Fig. 5. Drag breakdown for blade stab component (relative to the total C_D of the baseline configuration)

Fuselage

All the three proposed mast fairing configurations demonstrates a slight increase in drag of the "fuselage" subpart, which is most likely related to the slight increase of its midsection compared to the baseline configuration (see Fig. 6). Fairing №1 shows a significant increase in drag by 1.78 %, which is associated with the formation of a separated flow area in the upper part of the mast fairing due to a directed air jet effect from the air-oil radiators outlet (Fig. 16). The use of side slots in mast fairing №2 made it possible to achieve the part of the air flow withdrawal outside the mast fairing through the side slots, which reduced the separation flow area (Fig. 17).

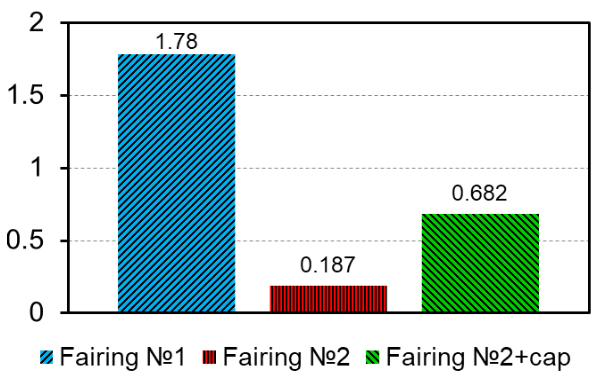


Fig. 6. Drag breakdown for fuselage component (relative to the total C_D of the baseline configuration)

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Swashplate

All three configurations reduce the drag of the main rotor swashplate (see Fig. 7).

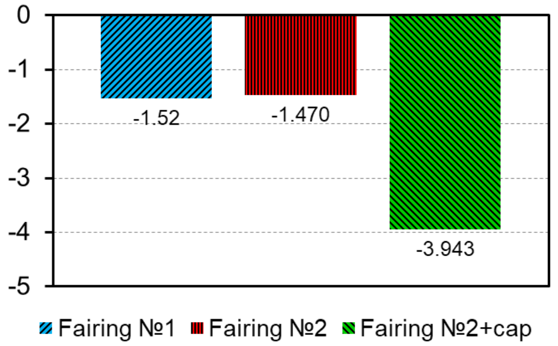


Fig. 7. Drag breakdown for swashplate component (relative to the total C_D of the baseline configuration)

Pitch links

The use of mast fairing almost equally allows to reduce the drag of the parts of the pitch links protruding beyond it by 0.71-0.78 % (see Fig. 8).

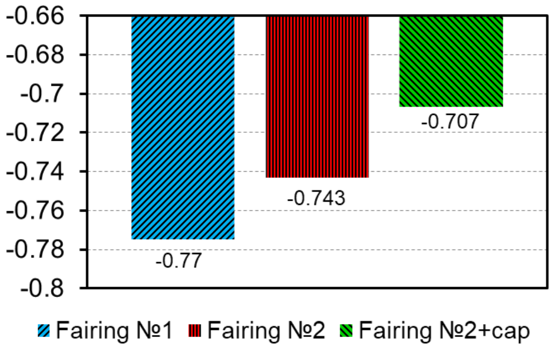


Fig. 8. Drag breakdown for pitch link component (relative to the total C_D of the baseline configuration)

Main rotor shaft

The influence of the mast fairing on the drag of the rotor shaft is insignificant (see Fig. 9), because most part of the main rotor shaft is outside the fairing.

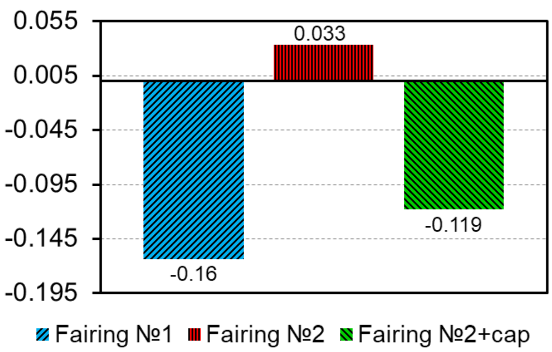


Fig. 9. Drag breakdown for shaft component (relative to the total C_D of the baseline configuration)

Scissor link

The use of the mast fairing allows to significantly reduce the drag of that part of the scissor link that the fairing covers (see Fig. 10).

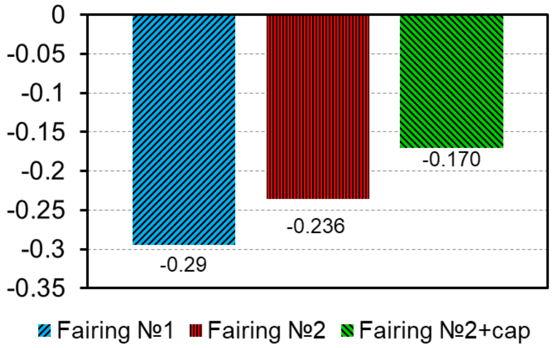


Fig. 10. Drag breakdown for scissor link component (relative to the total C_D of the baseline configuration)

Lift coefficient

Calculation have shown, that minor changes in lift force coefficient of the non-lifting surfaces, do not have a significant effect on the flight performance of the helicopter. Anyway, the lift coefficient changes are shown in Fig. 12.

Total helicopter parasite drag

The use of mast fairing №1 makes it possible to reduce the overall parasite drag of the helicopter by 0.534 %, by reducing the drag of the components of the main rotor hub and swashplate by 2.31 % (see Fig. 11). However, the influence of the airflow generated by the fan cooling the air-oil radiators causes extensive separation of the airflow at the and section of the mast fairing, which causes an increase in fuselage drag of 1.78 % (Fig. 16-19). Analysis of the data obtained as a result of this calculation made it possible to form the appearance of the Fairing №2, which respects the general geometric concept of the Fairing №1, but introduces some structural changes in the form of side slots, that operates as air flow turbulators and remove part of the air, blown by the fan.

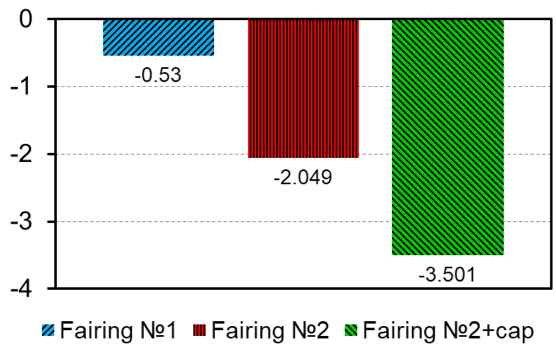
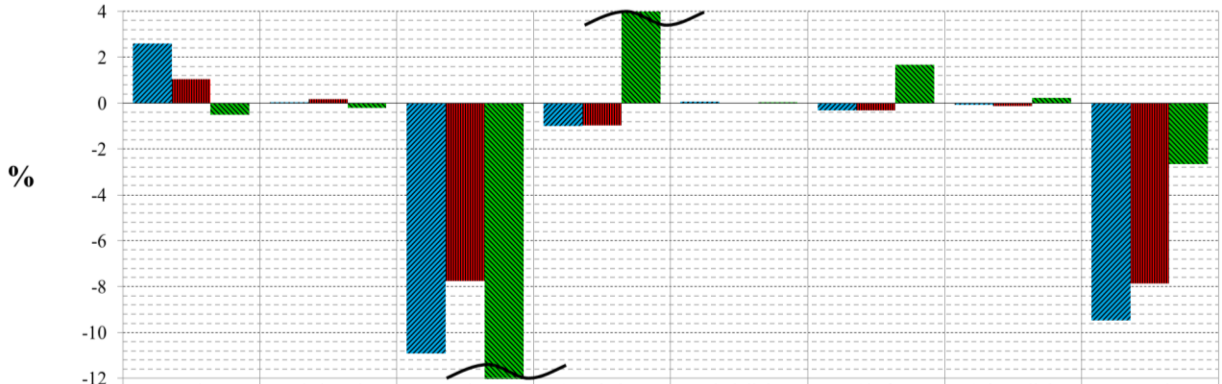


Fig. 11. Total parasite drag breakdown (relative to the total C_D of the baseline configuration)



	Hub	Blade stab	Fuselage	Swashplate	Pitch link	Shaft	Scissor link	Total
Fairing №1	2.616180893	0.053988907	-10.90651163	-0.979444808	0.086997092	-0.296453498	-0.049360599	-9.474603642
Fairing №2	1.062460906	0.189609772	-7.737374178	-0.962867114	0.029284375	-0.308198556	-0.12422135	-7.851306144
Fairing №2+cap	-0.505752516	-0.194383068	-33.7525859	29.830674	0.043611863	1.665477569	0.245183506	-2.667774543

Fig. 12. Lift coefficient breakdown
(relative to the total C_L of the baseline configuration)

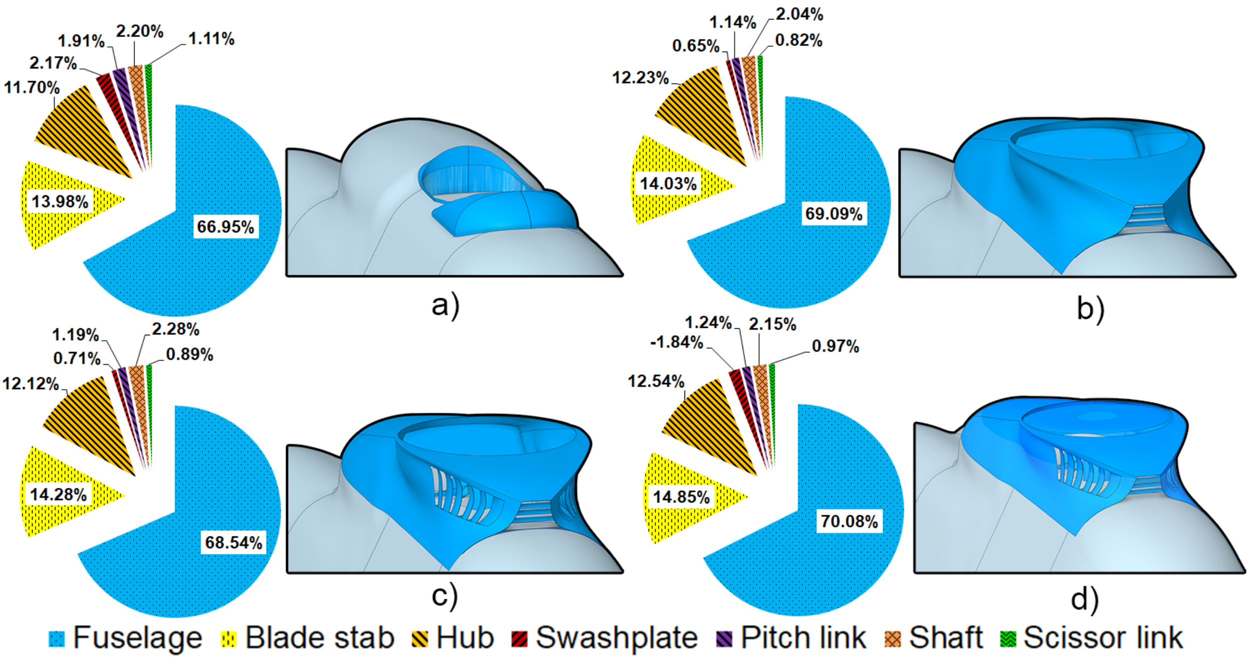
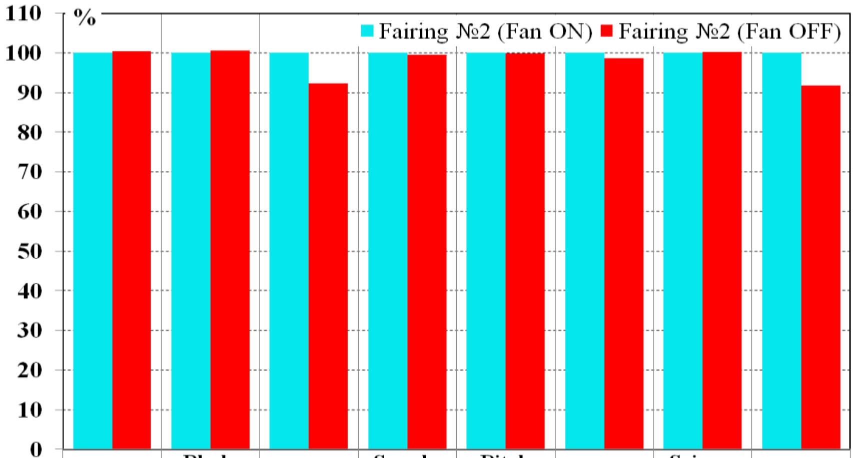


Fig. 13. Drag breakdown of the: a – baseline configuration;
b – Fairing №1; c – Fairing №2; d – Fairing №2 + cap

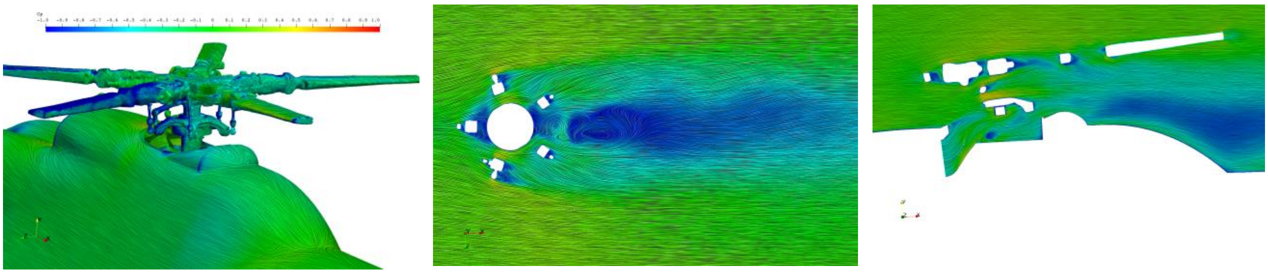
This made it possible to reduce the total drag of the elements of the main rotor hub and the swashplate by 2.24 %, while the resistance of the fuselage increased by only 0.187 %.

These measures made it possible to obtain an overall reduction in parasite drag of the helicopter by 2.05 %. The use of the cap in addition to the Fairing №2 allows to completely isolate some elements of the swashplate and achieve a reduction in the total parasite drag of the helicopter by 3.5 %. A comparative analysis of the distribution of the component-by-component contribution to the total parasite drag of the helicopter is presented in the diagrams (Fig. 4-11) and in Fig. 13. As already mentioned, a rather strong influence of the air flow generated by the fan cooling the air-oil radiators during the calculations was revealed. Comparison of the calculation results for Fairing №2 with the fan on and with the fan off is shown in Fig. 14. As can be seen in Fig. 14, the effect of the air flow from the fan is most noticeable on the fuselage (+7.67 %), and the main rotor shaft (+1.32 %). The total difference between the case with the fan on and fan off is 8.28 %. Such a strong influence is explained mainly by the formation of a separated flow zone from the upper surface of the fairing (see Fig. 15-19).



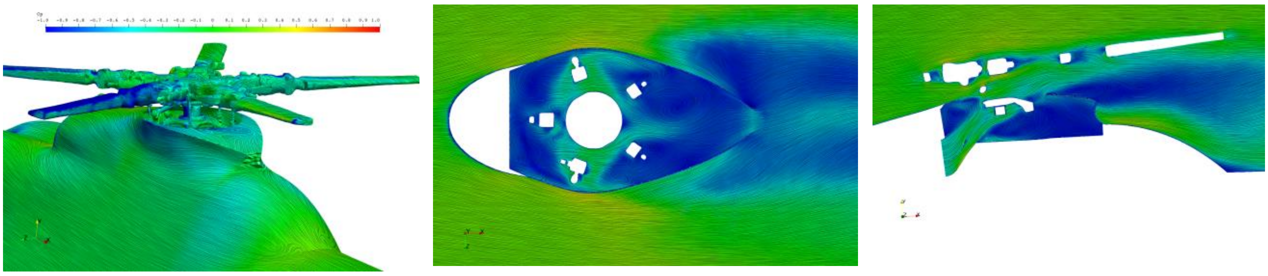
	Hub	Blade stab	Fuselage	Swash-plate	Pitch link	Shaft	Scissor link	Total
	100	100	100	100	100	100	100	100
	100.36	100.67	92.33	99.52	99.98	98.69	100.18	91.72

Fig. 14. Influence of cooling fan on components' drag



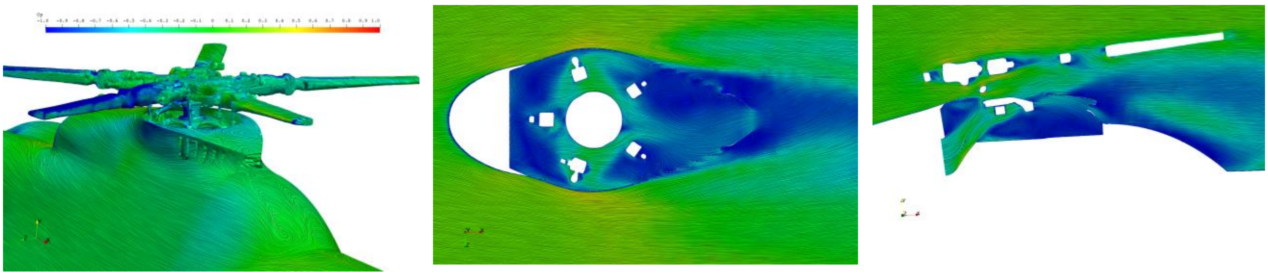
a b c

Fig. 15. Line integral convolution (baseline configuration) [13]
(a – pressure coefficient field; b – velocity field in plane of swashplate;
c – velocity field in plane of radiators outlet)



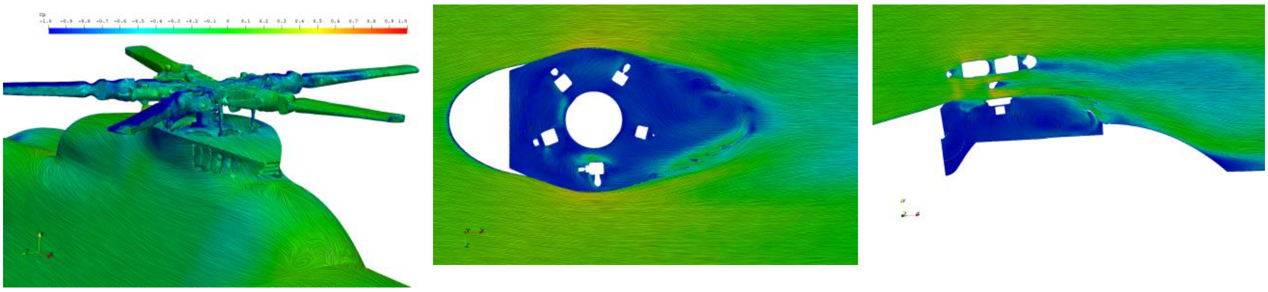
a b c

Fig. 16. Line integral convolution (Mast fairing №1 configuration)
(a – pressure coefficient field; b – velocity field in plane of swashplate;
c – velocity field in plane of radiators outlet)



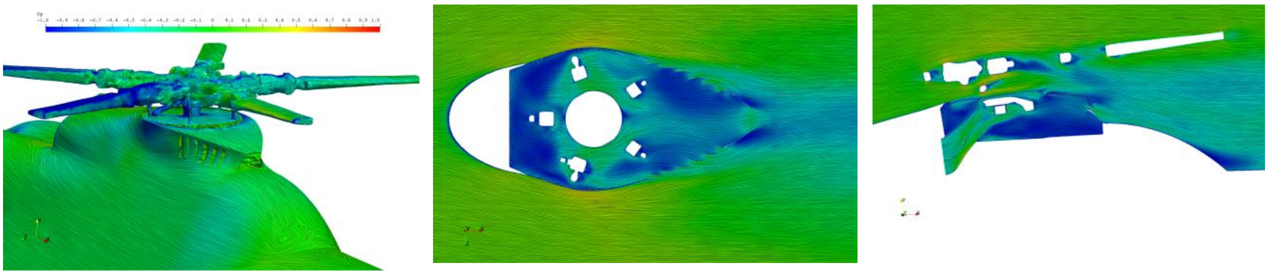
a b c

Fig. 17. Line integral convolution (Mast fairing №2 fan ON)
(a – pressure coefficient field; b – velocity field in plane of swashplate;
c – velocity field in plane of radiators outlet)



a b c

Fig. 18. Line integral convolution (Mast fairing №2 configuration fan OFF)
(a – pressure coefficient field; b – velocity field in plane of swashplate;
c – velocity field in plane of radiators outlet)



a b c

Fig. 19. Line integral convolution (Mast fairing №2 + cap configuration)
(a – pressure coefficient field; b – velocity field in plane of swashplate;
c – velocity field in plane of radiators outlet)

Conclusions

In the course of the study, in order to determine the possible potential for reducing the parasite swashplate drag, the element-wise contribution of the components to the total helicopter parasite drag was analyzed [13] (see Fig. 3). It was found that, potentially, due to the installation of a swashplate fairing, it is possible to reduce the total parasite drag by ~2-4 %. It was found that the air flow generated by the fan to cool the air-oil radiators has a rather strong influence on the flow pattern around the fuselage (the difference in the total parasite drag of the helicopter with the fan on and off is 8.28 %). The degree of its influence on the helicopter and its parts is shown on Fig. 14. In the course of optimization design, an aerodynamic configuration of the mast fairing was developed, which makes it possible to achieve a reduction in the total parasite drag of the helicopter by 2.05 % (without a cap) and by 3.5 % (using cap). A comparative drag diagrams of the components of the main rotor hub and swashplate for three fairing options is shown on Fig. 4-11. The redistribution of the component-by-component contribution of the swashplate elements and the main rotor hub to the total parasite drag of the helicopter for the considered mast fairing configurations is shown on Fig. 13. The velocity and pressure coefficient fields for all of the considered configurations are shown on Fig. 15-19. Calculation have shown, that minor changes in lift force coefficient of the non-lifting surfaces, do not have a significant effect on the flight performance of the helicopter. Anyway, the lift coefficient changes are shown in Fig. 12.

In terms of improving the performance characteristics and economic indicators, it is noted that the use of the mast fairing makes it possible to increase the maximum flight speed by 0.169 % (for the version without a cap) and 0.441 % (for the option with a cap); reduce the value of kilometer fuel consumption by 0.244 % (for the version without a cap) and by 0.602 % (for the version with a cap) and thereby achieve a reduction in the operating cost of the helicopter

Contributions of authors: conceptualization, methodology – **Mykhaylo Kybalnyy**, **Oleksii Prytula**, **Sergii Degtiarenko**; formulation of tasks, analysis **– Mykhaylo Kybalnyy**, **Oleksii Prytula**; mast fairing CAD model creation – **Oleksii Prytula**; development of numerical model, mesh generation, CFD calculation, verification **– Mykhaylo Kybalnyy**; analysis of results, visualization **– Mykhaylo Kybalnyy**, **Oleksii Prytula**; writing – original draft preparation, writing – review and editing **– Mykhaylo Kybalnyy**, **Oleksi Prytula**, **Sergii Degtiarenko**, **Kateryna Izviekova**.

All the authors have read and agreed to the published version of the manuscript.

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МЕТОД ЗНИЖЕННЯ ШКІДЛИВОГО ОПОРУ СЕРЕДНЬОГО ТРАНСПОРТНОГО ВЕРТОЛЬОТУ

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У теперішній час до вертольотів висуваються все більш і більш суворі вимоги щодо викидів вуглецю. Викиди вуглецю перебувають у залежності від витрати палива, а витрата палива – у прямій залежності від потужності, що необхідна для крейсерського польоту вертольоту. Потужність, що необхідна для горизонтального польоту вертольоту прямо залежить від форми фюзеляжу та інших не несучих елементів, і, у свою чергу, від шкідливого опору. Саме тому, бажання зменшити шкідливий опір є бажанням очікуваним та зрозумілим. Зниження шкідливого опору вертольоту було проголошено одним з головних завдань Сьомої Рамкової

Конференції «Clean Sky». Шістдесят років досліджень цієї проблеми дозволили накопичити колосальний досвід. Наприклад, було виявлено, що основними джерелами шкідливого опору вертольоту є втулка несучого гвинта та автомат перекосу. **Предметом** вивчення в статті є дослідження шкідливого опору втулки та автомату перекосу несучого гвинта середнього транспортного/пасажирського вертольоту типу Ми-8/17. **Мета** роботи – розробка методу зменшення шкідливого опору вертольоту типу Ми-8/17. Вертоліт Ми-8/17 є найбільш масовим вертольотом з двома двигунами у світі. У теперішній час, більш ніж 4,5 тисяч одиниць використовується по всьому світу. Саме тому, **завдання** цієї роботи – зменшення шкідливого опору вертольоту цього типу, що є дуже актуальним. Під час дослідження було використано **методи** обчислювальної гідрогазодинаміки. Сучасні методи обчислювальної гідрогазодинаміки дозволяють з прийнятним ступенем точності врахувати явище інтерференції компонентів між собою та фюзеляжем вертольоту, що не завжди коректно вдається під час достатньо дорогих випробувань у аеродинамічних трубах. В рамках виконання цього дослідження були отримані наступні **результати**. Досліджено та проаналізовано покомпонентний вплив кожного з конструктивних елементів втулки несучого гвинта та автомату перекосу на сумарну величину шкідливого опору вертольоту. Було запропоновано метод зменшення шкідливого опору вертольоту за допомогою використання обтікача автомату перекосу. Було запропоновано та розглянуто декілька варіантів обтікачів автомату перекосу, та обрано найбільш ефективний варіант. Було досліджено явище та ступінь впливу струменя повітря від вентилятора, що охолоджує повітряно-масляні радіатори, на величину шкідливого опору вертольоту. Результати досліджень були успішно запроваджені у виробництво.

Ключові слова: вертоліт; автомат перекосу; шкідливий опір; чисельна аерогідродинаміка; обтікач; чисельне моделювання; Ми-8/17.

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