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ESTIMATION OF GAS-DYNAMIC PARAMETERS AT THE EXIT OF THE IMPELLER DURING MODERNIZATION OF MI-2MSB FAN INSTALLATION

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Purpose. *Analysis of methods to increase the efficiency of the cooling system of the AI-450M engine units of the Mi-2MSB helicopter and evaluation of gas-dynamic parameters at the impeller outlet, fan installation MI-2MSB*

Research methods: *finite element method (FEM).*

Results. *It was shown that the use of a centrifugal fan as the main element in the system of air injection, cabin air conditioning and cooling systems and engine units provide the following opportunities and improvements:*

- at constant speeds and without changes in the transmission system to increase the amount of running air by 200...300 %;

- reduce the temperature of heated units to the values recommended by the operation manual;

- to increase the service life of complex-loaded elements of the system of connection of free turbine shafts with the shaft of the main gearbox;

- reduce the risk of accidents due to poor air conditioning in the cockpit and passenger seats.

The analysis of possible types of C.S modernization was carried out, the estimated estimation of gas-dynamic parameters at the exit of the impeller - to the sub-radiator space was carried out. The problem was solved by changing the type of impeller from axial to centrifugal.

Scientific novelty. *The problem of creating an efficient and reliable cooling system for internal systems and units of the Mi-2MSB light multi-purpose aircraft, which has been modernized with the replacement of old GTD-350 engines with newer ones, AI-450 series - urgent, in the absence of similar light helicopters of domestic production. An important component of the safety and reliability of all components of the helicopter is to maintain the correct thermal regime of its components.*

Practical value. *The obtained results are important in the further process of production and modernization of the Mi-2 helicopter of all modifications with the latest engines, as well as for helicopter development projects in Ukraine - SME-2 "Hope", SME-6 "Otaman", SME-8 and others. The ability to increase cooling efficiency, air conditioning and reduce engine load increases the life, reliability of components and improves comfort and performance for pilots and passengers.*

Key words: *fan assembly (FA), centrifugal wheel (CW), finite element method (FEM), cooling system (CS), modernization, air system, aircraft compressor, lubricating radiators.*

Introduction

As a result of the deep modernization of the Soviet Mi-2 helicopter to the Mi-2MSB level, the rather old GTD-350 engine was replaced by the newest AI-450. Due to the use of new materials, technologies for cooling turbine blades and other modern technologies, it was possible to increase the cruising and take-off power by an average of 100…150 hp. At the same time, the gas temperature behind the short-circuit along the entire exhaust increased by 100…200 °C. At the same time, the FA was not changed or modified, the CS, developed for less powerful engines, began to work in more difficult conditions. Productivity began to be insufficient both for cooling the STG-9M starter generators and for blowing the flanges connecting the shafts of the main gearbox and engines (or freewheel clutches, if they are available). Various elements began to experience unwanted heating not foreseen by operational standards.

NPF "Adron" did not finish the work on the development of new screen-exhaust devices for the Mi-2, which were supposed to reduce the load on the D and GR shafts. Instead, the development of helicopters of transport and sanitary modifications, with a capacity of up to 10 people and a flight duration of 5…6 hours, began. In the past, there have already been cases of accidents due to carbon monoxide poisoning, due to defects in the air conditioning system, which will be exposed to a greater load when the passenger capacity is increased.

To cool the units of the power plant, an axial fan is installed on the main gearbox. Air from the fan unit cools

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the following units: oil radiators of the left, right engines and gearbox, starter generators STG-9M, alternator, flanges of free turbine shafts, gearbox and AK-50M1G compressor.

Thus, the research is relevant to improve the cooling characteristics and solve the above-mentioned problems of the helicopter, which is starting to enter into operation more and more often, both in civilian and military versions. As the experience of the Mi-2M and PZL Swidnik Kania shows, reworking the gargrot together with the pneumatic system, when changing the engines and increasing the flight duration, is a necessary stage of improving LTX and EX in the modernization process.

Features of the Mi-2 fan installation before modification

An increase in productivity, and as a consequence, the efficiency of CS work, is possible in the following ways:

- increasing the operating speed of the axial fan;
- increasing the size of the impeller;
- use of a more advanced design of CS;
- use of fundamentally different means of cooling;
- reducing the load on the pneumatic system is not considered, due to the hereditary type of construction of all KB Mil helicopters, namely: the use of fans, which is an almost unique feature in the entire helicopter industry.

The location of units, the peculiarities of the flow of gas-dynamic flows from the engine, savings on heat-resistant and heat-resistant materials do not allow to abandon air cooling.

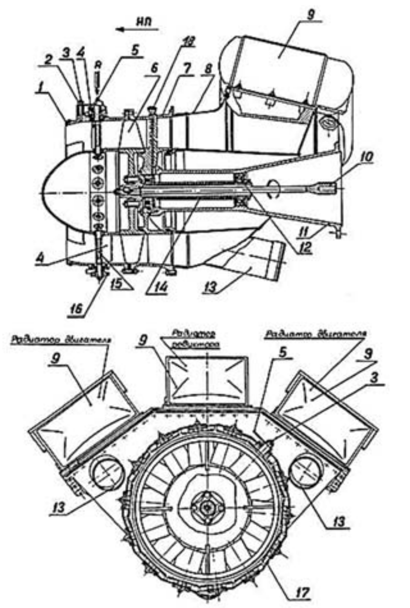

Fig. 1. FA of the Mi-2 helicopter and its modifications:
1 – guiding apparatus; 2 – puck; 3 – nut; 4 – adjustable paddles; 5 – sector; 6 – working wheel; 7 – steering device; 8 – diffuser; 9 – air-oil radiators; 10 – spring shaft; 11 – shaft casing; 12 – ball bearing; 13 – air outlet pipe for cooling units; 14 – fan shaft; 15 – blade axis; 16 – roller; 17 – rope; 18 – buttermilk

The fan unit consists of various elements that work as a complete mechanism. The front winding of the air is performed by a number of adjusting stator vanes (Fig. 1, item 4). Thanks to the cable (Fig. 1, item 17), when one stator blade is turned to a certain angle, all others change their position to the same angle. The working element is the axial wheel (Fig. 1, item 6), which creates an air flow that cools various units of the AI-450M-P engines and the Mi-2MSB helicopter. The torque on the impeller comes through the fan shaft (Fig. 1, item 14) resting on the ball bearing (Fig. 1, item 12). Power comes to the shaft from the VR-2 main gearbox through the spring shaft (Fig. 1, item 10). Lubrication of the ball bearing is carried out with working grease through the oil pan (Fig. 1, item 18). The bearing itself rests on the stator element - the shaft casing (Fig. 1, item 11), through which it transmits further forces to the fastening nodes. Thanks to the diffuser (Fig. 1, item 8), the air flow expands after leaving the channel of the impeller. Further along the direction of movement, it gets to 3 lubricant radiators (two AI-450M-P engine radiators (right and left) and a BP-2 main gearbox radiator) and various nozzles (Fig. 1, item 13) for air intake for the needs of cooling units installed on engines. The main parameters of the fan installation are listed in Table 1.

Table 1 – Basic parameters of the fan installation

Diameter of the impeller, mm	Rotation speed, rpm	Productivity, m^3/s
290	8000	2,8
Pressure, mm. water Art.	Power, hp	Weight (dry), kg
550	25	25

Purpose of the work

After remotorization and replacement of GTD-350 with newer AI-450M-P, which increased power, heat generation also increased. The fan unit was not structurally changed, the cooling system designed for less powerful engines began to work in more difficult conditions. Productivity began to be insufficient both for cooling the STG-9M starter generators and for blowing the flanges connecting the shafts of the main gearbox and engines (or freewheel clutches, if they are available). Since the unit operates at a nominal speed of 8000 per minute, it is possible to use a centrifugal type of fan, which gives us a large increase in the performance of pumping cold heated air to the hot units, which will be calculated later.

Thus, the main goal of this work is the analysis of methods of increasing the efficiency of the cooling system of the AI-450M engine units of the Mi-2MSB helicopter and the assessment of gas-dynamic parameters at the outlet of the impeller. fan installation MI-2MSB

The following software packages and modules were used to create mathematical models, evaluate gas-dynamic parameters at the outlet of the impeller during the modernization of the MI-2MSB fan installation, and evaluate the results of modeling and calculations: Ansys CFX-pre, Ansys CFX-solution, Ansys CFX-post, Vista CCM, BladeGen, TurboGrid, Mesh.

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Modernization of the Mi-2 fan installation and assessment of gas-dynamic parameters at the outlet of the impeller

Changing the operating speed of the fan is a complex and time-consuming process, which requires changing the system of shafts and gears of the transmission of the transmission of rotational forces from GR to VV, recalculating the parameters of the impeller for strength, reliability and performance in conditions of increased revolutions.

Increasing the diametrical dimensions of the impeller is an extensive, not a qualitative way of modernization, which is complicated by structural limitations. In this case, the growth of parameters will be proportional to the increase in size. It does not make sense to consider it, because it requires almost the same modifications of the system as changing the type of impeller to a centrifugal one, while it will give a smaller increase in efficiency.

By fundamentally different cooling methods, we mean liquid-lubricant cooling, which is difficult to implement due to a small supply of lubricant, which is about 25 liters and lubricates the gearbox, drive box and engines, and a set of other factors that significantly affect the feasibility of building hydro and oil linesю

Improvement of CS can be done by methods of increasing the accuracy and quality of nozzles and reworking air ducts with greater use of sealing means and changing the working element. The second way is more productive, so it was chosen as the object of calculations.

The following was chosen as the initial data: fundamentally different, more appropriate to the required parameters of air flow - centrifugal type of fan, standard parameters of the atmosphere (P = 101325 Pa, T = 288.15 K), operating revolutions (8012 rpm). Since the impeller will create additional pressure, we choose “real” gas as the working gas model. To reduce the cost due to versatility, we will calculate the necessary parameters for two engines that are being prepared for operation - AI-450-2 with a power of 650...800 hp. To do this, we will increase the flow several times, compared to the usual one (2.8 m^3/s). Using the correlation method and based on economic considerations, the most effective ratio was adopted - 10 main and 10 splitter blades.

With the help of Vista CCM, BladeGen modules, we determine the performance of the wheel at different revolutions, to be sure of the system's performance in other modes of operation, except for nominal and take-off, the diagram is shown in Fig. 2.

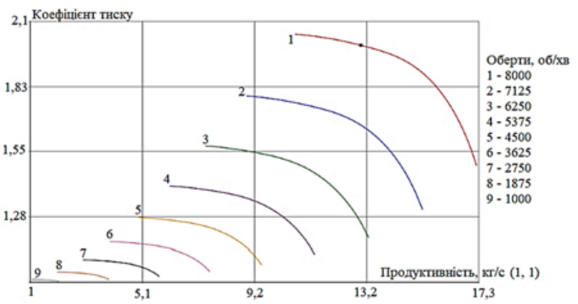

Fig. 2. Productivity at different revolutions of the impeller

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Also, with the help of the Vista CCM module and BladeGen, as a result of 3 approximations at the output, the main parameters of the centrifugal fan were obtained (tabl. 2).

To conduct a gas-dynamic analysis, first of all, it is necessary to create a model of the impeller segment (fig. 3) using the finite element method. For this purpose, the following values were set using the Ansys CFX-pre module: air inlet and outlet planes, data on the inlet flow parameters that we calculated in the previous stages, rotation frequency, and others. In gas conditions, we chose ideal air, since the degree of compression has low values, we can ignore the error value, in wall conditions, boundary layer adhesion was specified, the error of swirling the flow on the blade profile approaches zero.

Table 2 – Basic parameters of a centrifugal fan

Operating revolutions, rpm	Compression ratio	Air mass flow rate, kg/s	Volume air flow rate, m^3/s
8000	2	13	10,08
Inlet temperature, K	Inlet pressure, Pa	Inlet flow angle, gr	Radial distribution
288,15	101325	Up to 35	Permanent
Meridional velocity gradient	Relative velocity ratio	Flux factor	Correlation method
1,15	0,52	Correlation	Kosei-Robinson
Impeller material	Impeller weight, kg	Gas model	Gas
Ti64	11,09	Ideal gas	Air

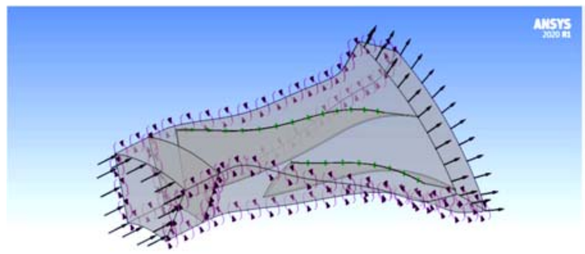

Fig. 3. Calculation area of the impeller segment

The results of the gas dynamic calculation are shown in fig. 6–12, (the number of convergence of a series of numerical values is 0.000001). The comparison in the first approximation indicates a significant increase in productivity compared to the original FA.

Let's take into account possible errors in calculations and designs, the relative performance of the system:

$$p = p_{\text{calc}} - p_{\text{turb}} - p_{\text{depl}} - p_{\text{atm}} - \delta =$$
$$= 1 - 0{,}05 - 0{,}07 - 0{,}03 - 0{,}02 = 0{,}83.$$

It is possible to reduce the drop in values in the following ways:

- increasing the quality of the surface of the working blades (decrease in roughness);
- development of additional elements to improve the quality of flow (stator guide row);

- modification of channel elements (confuser-diffuser system).

More than 100 calculation iterations were performed in the Ansys-Solver module. During the solution process, graphs (Figs. 4, 5) were obtained, which testify to the existing quality and accuracy of the calculation in the first approximation. As can be seen from the force imbalance graph, the process takes on a constant form almost from the middle of the calculation and we have specific numbers of force projections, which creates an onrushing flow on the wheel structure. These forces can then easily be transferred to a mechanical calculation to determine the required geometric dimensions of elements from the condition of minimum mass.

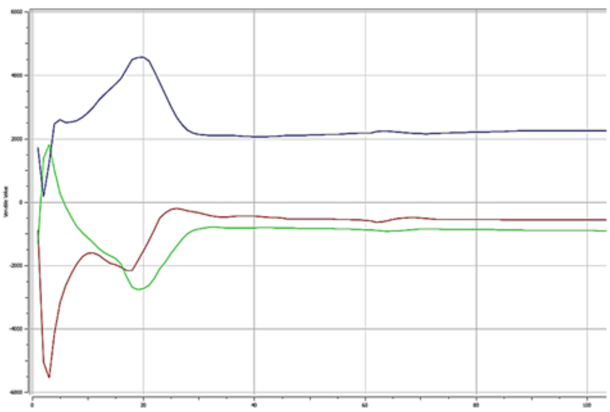

Fig. 4. The chart for determining the magnitude of the projections of the flow forces

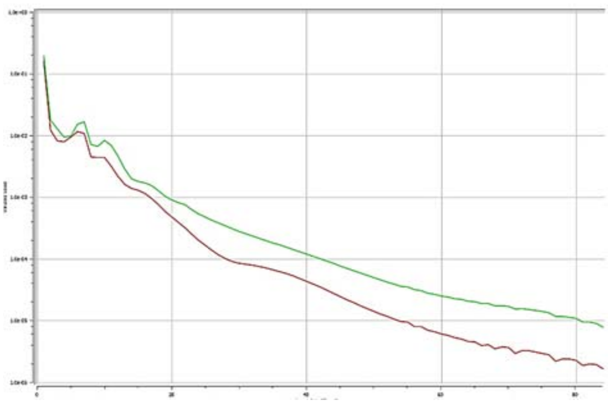

Fig. 5. Graph of convergence of coefficients k-e

The graph of the convergence of the k-e coefficients shows the high accuracy of the calculation, as their value falls below 10^{-5}, and the behavior indicates a clear convergence of the calculation process and a correctly constructed grid of finite elements in the boundary layer area.

Analysis of the results was carried out in the Ansys CFX-post module. As a result of the calculations carried out in the SAE environment at the exit, we obtained the values of the fields of temperatures (Fig. 10), pressure (Figs. 7, 9, 12), air flow (Figs. 6, 11) and other gas-dynamic parameters (Fig. 8) operation of the centrifugal wheel at nominal revolutions. Since we calculated one of 10 identical areas of the wheel, for ease of visualization we duplicate the calculated area around the axis of the wheel.

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The results of the pressure distribution indicate that the pressure does not rise even up to 2 atm. Therefore, the fan will work for air pumping, not for compression, surging phenomena are impossible.

An important parameter of the fan operation is the speed of air outflow from between the blade channels: in this wheel it reaches 363 m/s in the maximum zones (see Fig. 8). Due to this initial acceleration, the new air will blow the oil radiators and engine and helicopter units quite quickly.

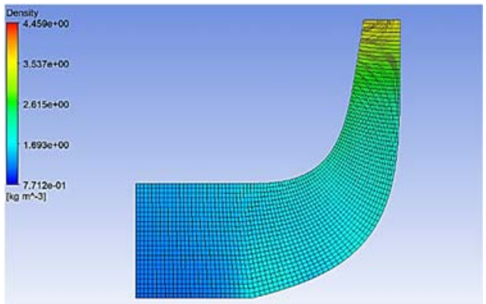

Fig. 6. Distribution of air flow in the cross section of the wheel

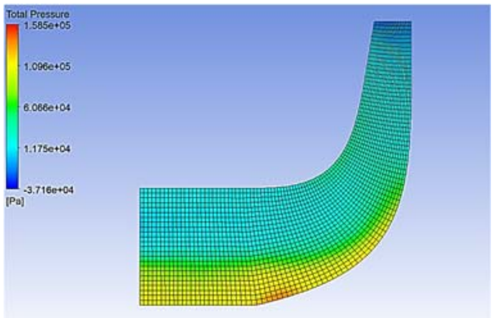

Fig. 7. Distribution of total air pressure in the cross section of the wheel

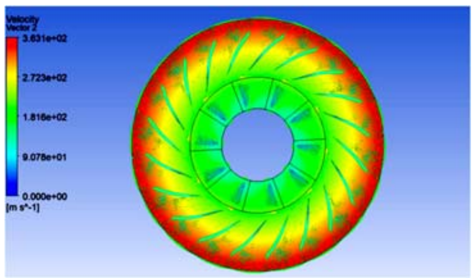

Fig. 8. Distribution of the velocity field along the wheel

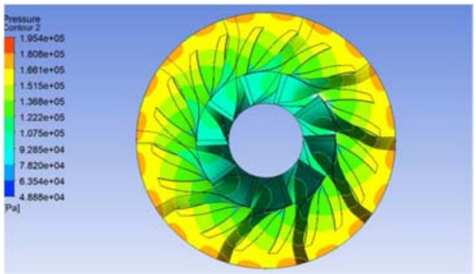

Fig. 9. Pressure distribution in wheel sections

The change in the temperature of the return is normal, a slight increase will be compensated by the design of the channels in the passage of the return (Fig. 10).

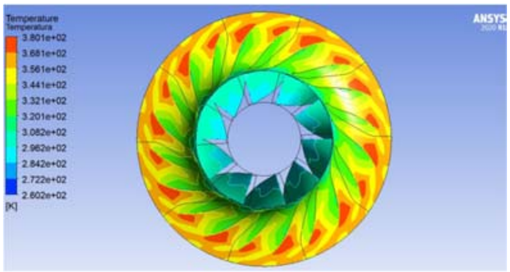

Fig. 10. Temperature field in the working wheel

By hovering over the diagrams, you can tell what effort which creates FA to push through, increases in proportion to the increase in the volume of air along the sections of the blades. The verification calculation confirms the air weight consumption of 12.98 kg/s, which is less than the initial 13 kg/s by 0.15% (Fig. 11).

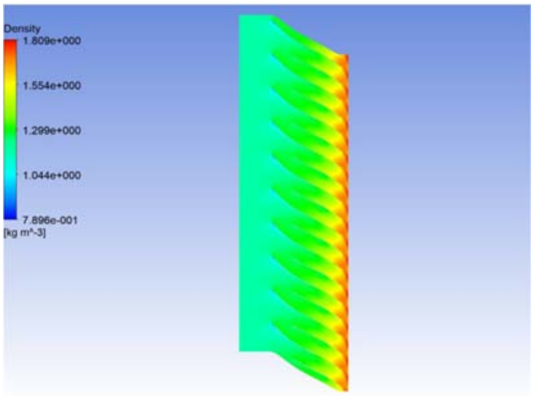

Fig. 11. Air flow sweep

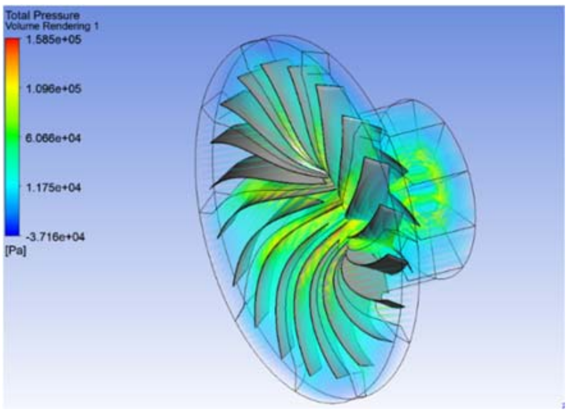

Fig. 12. Distribution of full pressure on the surface of the wheel

It can be seen from the diagrams that turbulent phenomena, and the most dangerous and undesirable Helter vortices in cross-sections, have a value of less than 5%, which is compensated by a sufficient volume of pumped air. At the exit from the wheel, the flow stabilizes and has a constant radial current distribution:

$$dx/dv = 1{,}15\ .$$

Table 3 – Comparison of fan parameters

Parameter	Axial fan	Centrifugal fan
Operating revolutions, rpm	8012	8012
Volumetric productivity, m^3/s	2,8	10,08
Mass consumption, kg/s	3,6	13
Impeller weight, kg	5	11 (Ti-64)
Full Pressure, Pa	5393	11750
Compression ratio	1,25	1,5…1,7
Speed gradient	2,7	1,15
Power, hp	25	50

A small increase in pressure is compensated by an increase in speed and does not significantly affect the temperature field, any gradations are self-compensated by the cavity under the radiator compartment and the branching of the volume.

For correct and more stable operation, the use of a stator row of blades is recommended, which will twist the flow for optimal flow around the blade profile on both sides. The original steering row already had the ability to adjust the angle of installation and rotation of the flow, so its adjustment is reduced to experimental determination of the new recommended range of operation.

From the comparative table, it can be seen that with a rather small increase in power on the scale of a helicopter – 25 horsepower, which is a two-fold increase, we get an increase in the main parameter that characterizes the system – air flow by 3.6 times.

If this value is greater than necessary, due to the design of the system, excess air will be removed through leaky channels of the system of pipes and air ducts.

The centrifugal wheel itself has advantages in greater ease of assembly of the system, technical reviews. The principle of centrifugation and flow channel reduces the impact of ice, dirt, dust and other fine particles on the operation of the installation. Due to the absence of component particles, i.e., the monolithic nature of the impeller, the vibration load decreases and the strength increases.

At the moment, the problems that haunted centrifugal fans in the 20th century, namely the difficulty, and sometimes the impossibility of manufacturing by means of mechanical processing, have been solved. The example of the big three global engine manufacturers: General Electric, Pratt & Whitney and Rolls-Royce shows that this type of fan is manufactured both by traditional mechanical processing (CNC tools) and by advanced additive manufacturing methods with a minimum level of defects and defects (which is inherent machining of axial fan blades).

The obtained results indicate the possibility of obtaining the desired structural, operational and economic improvements. The topic of centrifugal cooling units is the latest and most promising in civil and military aviation, thanks to the latest means of their production, which was not considered in the Mila Design Bureau, due to the complexity of manufacturing at the stages of helicopter development.

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Conclusions

1. The centrifugal fan was chosen as more appropriate for the Mi-2MSB cooling system, because it is better than similar axial, bladeless fans and is more practical to use on board the helicopter than the tangential one in terms of efficiency at the given speeds and design features of the helicopter. 2. According to the analysis of the calculation of the centrifugal wheel, an increase in air flow and its speed at the exit is visible. 3. The type of fan, its dimensions, operating revolutions, the number of working and splitter blades can significantly affect the volume, mass flow of air, blowing speed, temperature after pre-compression and other properties of the flow, which must be taken into account during the design, development and operation of systems , which require cooling during operation. Therefore, the selection of explosive elements, the layout of the system is a very relevant issue and depends on the design of the aircraft and the degree of development of the flow of hot gases from the short-circuit and mechanical heating of the contact surfaces of mechanisms that compress or produce various types of energy. 4. Thanks to the use of a centrifugal fan, it was possible to increase the productivity of the helicopter's pneumatic system, as well as CO from 2.8 m^3/s to 10-13 m^3/s of cold air from the NS.

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ОЦІНКА ГАЗОДИНАМІЧНИХ ПАРАМЕТРІВ НА ВИХОДІ З РОБОЧОГО КОЛЕСА ПРИ МОДЕРНІЗАЦІЇ ВЕНТИЛЯТОРНОЇ УСТАНОВКИ МІ-2МСБ

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Мета роботи. *Аналіз методів підвищення ефективності системи охолодження агрегатів двигуна АІ-450М вертольоту Мі-2МСБ та оцінка газодинамічних параметрів на виході з робочого колеса.* вентиляторної установки МІ-2МСБ

Методи дослідження: *метод кінцевих елементів (МКЕ).*

Отримані результати. *Проведені дослідження показали, що застосування відцентрового вентилятора в якості основного елемента в системі нагнітання повітря, кондиціювання салону та охолодженні систем і агрегатів двигуна надають наступні можливості та покращення:*

- *при незмінних обертах та без змін системи трансмісії збільшити кількість прогонного повітря на 200–300 %;*
- *знизити температуру агрегатів, що зазнають нагріву до значень, рекомендованих керівництвом з експлуатації;*
- *підвищити строк служби складно-навантажених елементів системи з'єднання валів вільної турбіни з валом головного редуктора;*
- *зменшити ризик нещасних випадків, які відбуваються через неякісне кондиціювання кабіни пілотів та пасажирських місць.*

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Був проведений аналіз можливих видів модернізації СО, в роботі проведена розрахункова оцінка газодинамічних параметрів на виході з робочого колеса – до під-радіаторного простору. Проблема була вирішена за рахунок зміни виду робочого колеса з аксіального на відцентровий.

Наукова новизна. *Проблема створення ефективної та надійної системи охолодження внутрішніх систем та агрегатів легкого багатоцільового літака Мі-2МСБ, що зазнав модернізації з заміною застарілих двигунів ГТД-350 на більш нові, серії АІ-450 – нагальна, в умовах відсутності аналогічних вертольотів легкої категорії вітчизняного виробництва. Важливою складовою безпеки та надійності працездатності усіх компонентів вертольоту є підтримання правильного теплового режиму його складових.*

Практична цінність. *Одержані результати мають важливе значення в подальшому процесі виробництва та модернізації вертольоту Мі-2 усіх модифікацій з новітніми двигунами, а також для проектів по розвитку вертольотобудування в Україні – МСБ-2 «Надія», МСБ-6 «Отаман», МСБ-8 та інших. Можливість підвищення ефективності охолодження, кондиціювання та зменшення навантаження на двигун збільшують ресурс, надійність роботи компонентів та покращують комфорт та експлуатаційні характеристики для пілотів та пасажирів.*

Ключові слова: *вузол вентилятора (ВВ), відцентрове колесо (ВК), метод кінцевих елементів (МКЕ), система охолодження (СО), модернізація, повітряна система, авіаційний компресор, мастильні радіатори.*

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