МАШИНОСТРОЕНИЕ
2.5.12 – Аэродинамика и процессы теплообмена летательных аппаратов;
2.5.13 – Проектирование конструкция и производство летательных аппаратов;
2.5.14 – Прочность и тепловые режимы летательных аппаратов;
2.5.15 – Тепловые электроракетные двигатели и энергоустановки летательных аппаратов;
2.5.16 – Динамика, баллистика, управление движением летательных аппаратов

УДК 629.735.45.015
DOI: 10.26467/2079-0619-2022-25-3-51-60

Development of the technical solution to prevent a single-rotor helicopter from entering uncontrolled rotation

V.A. Ivchin[1], K.Y. Samsonov[2], A.M. Kasimov[3], A.I. Popov[4]
[1, 2]Joint-stock Company, National Center for Helicopter Engineering named after Mil and Kamov, Moscow, Russia
[3,4]Federal State Budgetary Institution of Science, V.A. Trapeznikov Institute of Control Sciences of Russian Academy of Sciences, Moscow, Russia

Abstract: The phenomenon of a single-rotor helicopter entering an unintended left rotation with the further development of an uncontrolled turn periodically arises while operating this type of helicopter, both in Russia and abroad. This phenomenon can lead to serious aviation incidents and even disasters. Currently, there is no unambiguous justification for the phenomenon of "uncontrolled" U-turn and the causes of occurrence, since the operating conditions of the tail rotor (TR), especially at low-speed modes, depend on many factors. These factors include, firstly, wind direction and speed, T/R "vortex ring", as well as the impact of the main rotor vortex trace. One of the explanations for this phenomenon lies in the special specifics of the yaw trim of a single-rotor helicopter, which is provided by the tail rotor. These papers emphasize that the change in wind speed and direction which affects the helicopter, and the TR is the main cause of the unintentional left turn. Currently, there are no tools and methods for determining the wind effect on the TR in order to develop a warning signal for a pilot about a change in the nature of the TR flow and an alert about the occurrence of uncontrolled rotation. This paper proposes the system for measuring the TR air flow using a special sensor that allows us to measure the inductive air flow velocity of a small value in an aerodynamic way without additional various electronic transformations that are inherent in conventional Pitot tube probes. The use of such a measurement system makes it possible to identify the probability of a dangerous situation, to inform the pilot and help him take the proper actions.

Key words: uncontrolled left rotation, air flow sensor, inductive velocity, vortex ring of the tail rotor, Pitot tube probe.

For citation: Ivchin, V.A., Samsonov, K.Y., Kasimov, A.M. & Popov, A.I. (2022). Development of the technical solution to prevent a single-rotor helicopter from entering uncontrolled rotation. Civil Aviation High Technologies, vol. 25, no. 3, pp. 51–60. DOI: 10.26467/2079-0619-2022-25-3-51-60

Разработка технического решения по предупреждению попадания одновинтового вертолета в неуправляемое вращение

В.А. Ивчин[1], К.Ю. Самсонов[1], А.М. Касимов[2], А.И. Попов[2]
[1]АО «Национальный центр вертолетостроения «Миль и Камов», г. Москва, Россия
[2]Государственное бюджетное учреждение «Институт проблем управления им. В.А. Трапезникова РАН», г. Москва, Россия

Аннотация: Явление попадания одновинтового вертолета в непреднамеренный разворот влево с дальнейшим развитием неуправляемого разворота периодически возникает в процессе эксплуатации такого типа вертолетов как в России, так и за рубежом. Это явление может приводить к серьезным авиационным инцидентам и даже к катастрофам. В настоящее время нет однозначного обоснования явления «неуправляемый разворот» и причин его возникновения, так как условия работы рулевого винта, особенно на режимах малых скоростей, зависят от многих факторов. К этим факторам относятся в первую очередь направление и скорость ветра, «вихревое кольцо» на рулевом винте, а также влияние вихревого следа от несущего винта. Одно из объяснений этого явления – особенности путевой балансировки одновинтового вертолета, которая обеспечивается рулевым винтом. Главной причиной возникновения непреднамеренного разворота влево в исследованиях указывают изменение скорости и направления ветра, действующего на вертолет и рулевой винт в частности. В настоящее время отсутствуют инструментальные средства и методика определения ветрового воздействия на рулевой винт для выработки предупреждения летчику об изменении характера обтекания рулевого винта и о возникновении неуправляемого вращения. В данной работе предлагается система измерения воздушного потока на рулевом винте с помощью специального датчика, позволяющего измерить аэродинамическим способом непосредственно индуктивную скорость воздушного потока малой величины без дополнительных различных электронных преобразований, которые присущи традиционным датчикам типа ПВД. Применение такой системы измерений позволяет определить приближение опасной ситуации, дать информацию летчику и помочь ему предпринять правильные действия.

Ключевые слова: неуправляемое левое вращение, датчик воздушного потока, индуктивная скорость, вихревое кольцо рулевого винта, приемник воздушной скорости.

Для цитирования: Ивчин В.А. Разработка технического решения по предупреждению попадания одновинтового вертолета в неуправляемое вращение / В.А. Ивчин, К.Ю. Самсонов, А.М. Касимов, А.И. Попов // Научный Вестник МГТУ ГА. 2022. Т. 25, № 3. С. 51–60. DOI: 10.26467/2079-0619-2022-25-3-51-60

Introduction

According to [1], 235 aviation accidents occurred in helicopter units and subdivisions of state aviation, as well as in airlines and enterprises of civil aviation over 10 years from 1996 to 2006, 42 (18%) of them due to helicopters entering spontaneous left rotation [2]. 10 air accidents occurred at take-off (4 of them are crashes, 6 are incidents), 27 – at landing (12 crashes, 15 incidents), 5 aviation accidents – at hovering and near-terrain movements (1 crash, 4 incidents). Various publications have shown that trained flight personnel can cope with uncontrolled rotation. For example, the Syzran Air Force Engineering Academy named after Gagarin and some other schools have the similar course. The procedure for helicopter-aircraft piloting varies significantly due to different aerodynamic and physical properties of the aircraft motion principle. There are two characteristic features of helicopter motions in space. The first one is a probability of the lifting rotor (LR) “ring vortex” occurrence [3] and the second one is the occurrence of uncontrolled left rotation during the single-rotor helicopter flight [4, 5]. The stated specifics of a single-rotor helicopter may be the causes which lead to aviation accidents [6, 7]. Let us study the last special feature in order to develop the counteractions after analyzing the problem.

Problem statement, research methods

The relevance of the tail rotor vortex ring (TRVR) mode recognition is confirmed by many studies, computational and experimental speed characteristics of the TRVR are obtained according to various theories – the theorem on the amount of movement, based on a nonlinear vortex model, etc.[1] [8–12].

The general cause of the TRVR occurrence for all flight modes is the lack of information about wind direction and strength as well as the delayed response to the helicopter’s unintended left turn with the excess of the circumferential velocity of TR rotation to the left at the wind velocity more than 3 m/s [11, 13, 14]. Moreover, the lack of the wind speed and direction indicator additionally complicates the rotation situation [10]. The modes of hovering, take-off and landing are the most crucial, they are distinguished by the dynamic and static instability of the helicopter. The number of engineering proposals to detect the prerequisites for entering the TRVR mode or its mitigating is not many [12].

[1] *Loss of tail rotor effectiveness in helicopters* (2017). National Transportation Safety Board. 2017. SA-062 March. Available at: https://ihsf.aero/Repository/NTSB%20Bulletin%20tail%20rotor.pdf (accessed: 21.11.2021).

In the measuring technology, the velocity field in aviation requires a flow rate sensor which immediately determines the velocity, automatically deducting the static pressure. Such a sensor does not require density, height and load corrections, it measures data that are currently in the velocity field, the velocity vector projection on the axis of the instrument. Therefore, it should be installed at the proper location, the aerodynamic field of velocities, which must be determined by means of the analysis, computation and experiment, for example, for a helicopter, in critical situations which are close to the aviation accidents.

Research results

According to [7, 11], the main cause which contributes to the helicopter entering "spontaneous" left rotation mode is the special feature of the TR operation, primarily, related to the impact of the flow induced by the LR at a certain direction of air speed. At the same time, an unsteady flight mode occurs. In the range of sliding angles equal to $30° \leq \beta \leq 90°$, there is a complex interaction between the vortex system of the lifting and tail rotors, while the TR itself is in the zone of strong effect on the LR [6–11, 15].

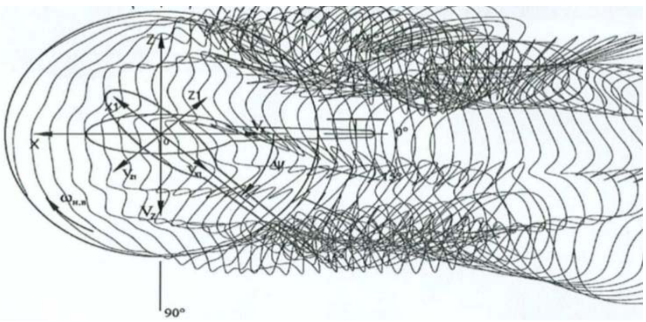

Fig. 1. Effect of the LR vortex trace on the TR at a low speed with sliding – computation and modeling of the flight velocity field [8]

What are the other signs of the occurrence pattern? They are given in papers [8–16].

Unfavorable factors which contribute to the helicopter's spontaneous left rotation are the gusty tail wind from the right of 5–7 m/s or the direction-variable wind, high ambient temperature and the altitude, lack of the wind direction and speed indicator, take-off or landing with sliding, requiring additional deflection of the pedals to maintain the direction of take-off or landing, etc.

These factors affect the velocity field in the TR vicinity, in case these parameters in their own form of velocity can be measured by the proposed probe – Pitot tube. These measured parameters inform about the current situation in the inductive velocity field and are recorded to correct the situation in case of hazard occurrence.

After detecting the signs of the TRVR occurrence according to the publications and their analysis, let us consider which inductive velocities in the TR disk precede.

The dependencies obtained during the flight tests imply a significant increase in the balancing angle of the TR blades installation at the magnitude of longitudinal air flight speed within the range of 5 m/s < V_x < 12 m/s and lateral velocity of 3 m/s < V_z < 12 m/s and static yaw instability occurrence in this mode [8].

It was found from [8, 15] that the LR vortex trace most significantly affects the operation of the TR with the crosswind from the right corresponding to the sliding angle βN = +90° (V_z = 0–15 m/s). Inductive impact of the LR vortex trace leads to the TRVR occurrence at lower speeds ($V_z \approx$ 5 m/s) than in the case of isolated TR operation ($V_z \approx$ 12.5 m/s).

The calculated dependence according to the data of work [9] (designated by points in Figure 2) and experimental data are given in the form of curved lines from various authors [9, 11]. The largest extremum of the relative inductive velocity value $\tilde{\upsilon}$ = 2...2.5 takes place in the range of $\tilde{V}_z \sim -1{,}13$ value.

The data analysis in Figure 2 shows, that the TRVR mode can occur when the relative inductive velocity increases its value up to $\tilde{\upsilon} > 1.5$. A significant transformation of the rotor vortex system occurs at approach flow relative velocities of V_z on the TR, which corresponds to the $-2 < V_z < 0$ ratio. The similar ratio is true for the X-shape TR.

Том 25, № 03, 2022
Vol. 25, No. 03, 2022

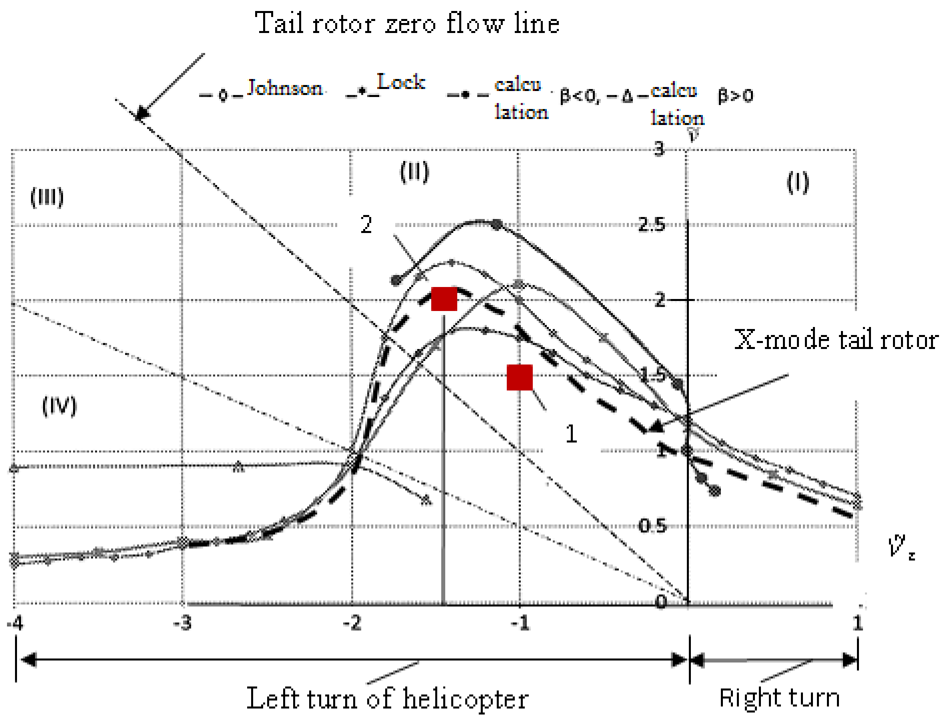

Fig. 2. Experimental and computational dependences of inductive velocities $\tilde{\upsilon} = f(\tilde{V}z)$, operating mode (I), "vortex ring" mode (II), diagram together with [9]

One of the solutions of mitigating the probability of entering the TRVR proposed the change of TR rotation direction [12]. Previously, with the preceding direction of TR rotation (propelling rotor type), TR-generated air flows, coincided in the direction with the direction of LR vortices circulation with the wind from the right-tail wind which deteriorated the efficiency of TR operation (fig. 1).

When varying the direction of the TR rotation (propulsion rotor type), the range of load on the blade has expanded by ~1.5 times from $T/S \leq 500$ kg f/m^2 up to $\geq$ 750…900 kg f/m^2, where T/S is the ratio of T-thrust of the TR to the area S of the TR blades. The load reduction on the TR made it possible to improve the directional control of the single-rotor helicopter design at low speeds when flying to the left and hovering with the wind from the right-tail wind (5–7 m/s) with the capability to use an extended range of heading control.

The authors believe that in the TRVR mode, it is significant to determine values and the area of inductive velocities in the area of the TR disk, characterizing the origin of the TRVR mode itself, i.e., to measure real velocities in addition to theoretical calculations or obtained indirectly from aerodynamic experiments. For this purpose, it is necessary to solve the following issues: determine the area of inductive velocities, based on well-known theoretical works and experimental data, develop a probe to measure the true velocity of a Pitot tube, select the location to install a Pitot tube in the required areas of the velocity field to measure the parameters of the TRVR formation (initiation), employ available techniques of warning the pilot and propose an automation system of recovery from the VR.

The qualitative physical picture differs from the known ones [8, 9, 16] and represents itself as follows.

Two separate masses of medium are involved with the formation of the TRVR: the first vortex mass is inherent to the TR in the hovering mode (fig. 3), the second one, which has come in the form of ram air V_z, does not have VR circulation. These separate masses are composed under the effect of the outer atmosphere force, since in the space between the external boundary of the vortex mass flow and the layers of ram air, areas

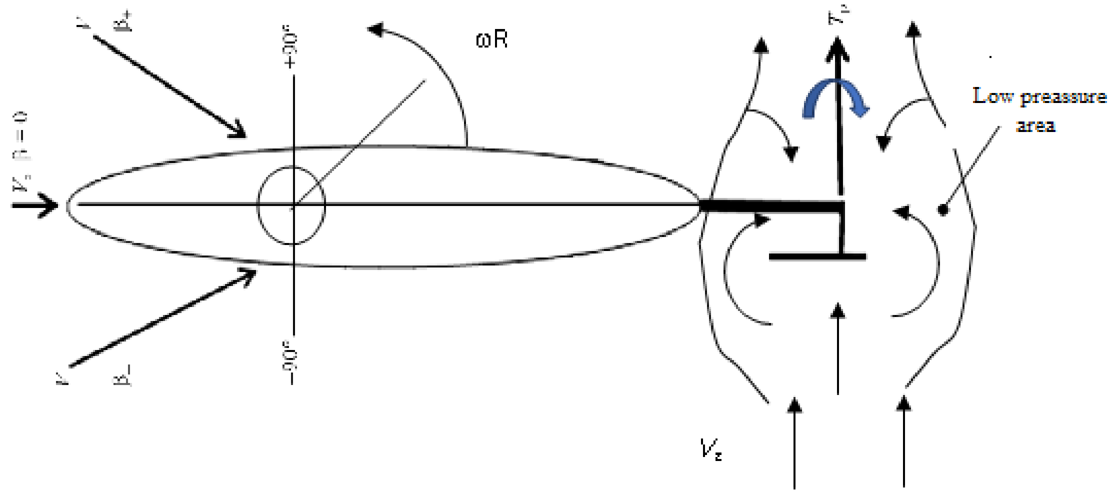

Fig. 3. The layout of the TR in the flow (modified fig. [9])

of reduced pressure with the Coanda effect (fig. 3) emerge, resulting in additional implosion, VR occurrence and intense turbulence, which leads to the increased vibration of the tail beam and deterioration of directional control due to the loss of TR thrust. Subsequently, we can observe the expansion of the vortex system specified by the attached new medium volumes contributing to the total TRVR, in which, the value of inductive velocities increases significantly (by 2.5 times) (fig. 2). Slight decrease or intensity of wind leads to the TRVR shifting relatively to the TR disk and vice-versa, which causes unstable helicopter behavior. This phenomenon forms an uncontrolled flight mode with left rotation due to lack of compensation. One of the techniques for recovery from the TRVR mode is the purposeful actions of the pilot, which allow him to recover from wake vortex-type free masses.

It follows from [16], that currently, our national experts are unable to propose a scientifically and experimentally justified solution to the complex aerodynamic problem of the single-rotor helicopter with the TR uncontrolled left rotation. Therefore, in order to reduce the probability of aviation accidents, it is advisable to increase the requirements for flight training of pilots on mass-produced helicopters and to explore the feasibility of introducing safety factors into computations during the process of designing new helicopters.

Discussion of study results proposals for enhancing helicopter flight safety

The analysis of the TRRV mode, using numerical modeling and mathematical models in works [6, 10–18], showed that:

– the structure of the LR vortex trace at low speeds affects the TR and leads to the TRVR at speed $V_z = 5$ m/s, the sliding angle $\beta_H = 90^0$, to its thrust rollback by 11% [15];

– inductive velocity fields, which are characteristic to the TRVR mode, have been determined (fig. 2, $\tilde{\upsilon} = f(\tilde{V}_z) = 1 \div 2$), but current lines are built without taking into consideration the pressure field between them;

– the following methodological operating conditions of the modes can be adopted in order to prevent the uncontrolled rotation of the single-rotor helicopter: 1) in the “flight” mode with crosswind (≥5 m/s) and the impact of the LR vortex trace on the TR, introduce restrictions for parameters – not more than $\tilde{V}_z = -1$; $\tilde{\upsilon} = 1.5$, that corresponds to the arrangement of t. 1 in Figure 2 with the velocities ratio equal to $\tilde{V}_z/\tilde{\upsilon} \cong 0.75$; 2) in the mode of “hovering” with crosswind (≥ 12 m/s), introduce restrictions for parameters – not more than $\tilde{V}_z = -1.5$; $\tilde{\upsilon} = 2.0$, that corresponds to the arrangement of t. 2 in Figure 2 with the velocities ratio equal to $\tilde{V}_z/\tilde{\upsilon} \cong 0.75$;

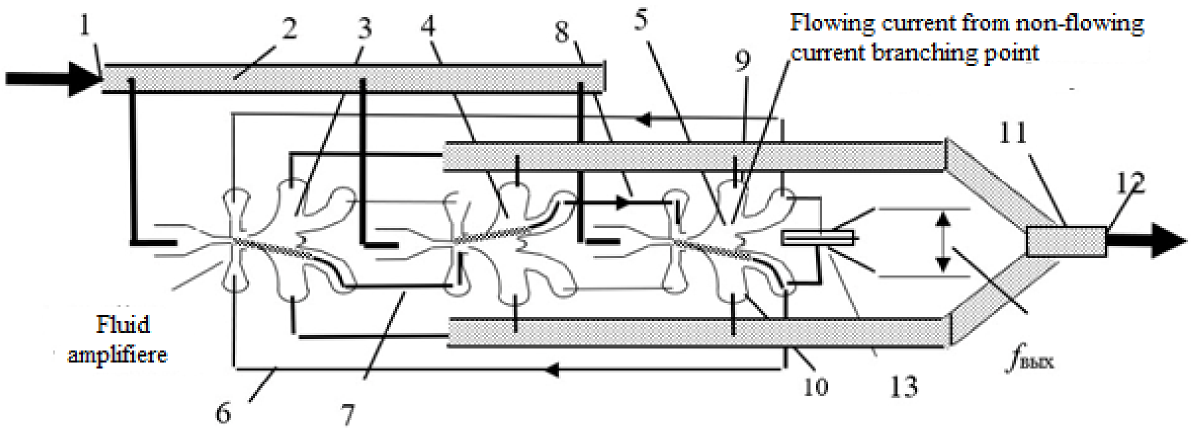

Fig. 4. Schematic diagram of a jet auto generator [18, 19]

– it is necessary to have the velocity field measured by a developed Pitot tube directly in the area of the TR disk in the process of the TRVR generation, since then it moves under the effect of ram air outside the TR disk and returns, causing instability of the TR flow;

– the authors' proposal is to install Pitot tube probes in order to inform the pilot about the probability of TRVR occurrence and to prevent the mode of uncontrolled rotation (fig. 5).

The solution to the specific problems of helicopter safety is to equip it with the cutting-edge autopiloting means, which will adjust critical flight modes depending on a situation. These signals are transmitted to the pilot with the help of audio or light warning devices, which allows the pilot to adjust control, preventing the output of current parameters into a dangerous area. If the pilot does not respond, an aircraft power plant reacts autonomously on an emergency basis with a minimum loss of flight altitude.

The authors have proposed the radical method for predicting, warning and preventing the helicopter mode of "uncontrolled rotation" by integrating a set of Pitot tube probes, that measure the magnitude of the crosswind in conjunction with inductive speeds of the TR disk, into the safety system.

A jet automatic generator, which is placed into a streamlined case with the inlet and outlet, is a sensor – the flowing Pitot tube of true air velocity. Ram air enters inlet 1 and exits outlet 12 (fig. 4).

During the jet automatic generator operation, the alternating dynamic pressure, generated by jet amplifiers 3, 4 and 5 with feedback 6 enters the piezoelectric transducer 13 (fig. 4), which generates an alternating frequency electrical signal transmitted via wires or by Wi-Fi to the cockpit.

The location of the Pitot tube is shown on the TR beam (fig. 5), below or above the beam and on the tailpiece of the beam in the space of the TR disk:

1 – the Pitot tube probe of the wind velocity and the circumferential speed of the beam turn $f_1\ V_z$;

2 – the Pitot tube probe of the inductive velocity of the TR $f_2\ V_{tail\ rotor}$ with reference to [9, fig. 5].

The onset and unauthorized critical increase in uncontrolled rotation of the aircraft flight speed with crosswind V_z can be identified by an audio warning device or annunciator at frequency not more than $f_1 V_z / f_2 V_{and TR} < 0.75$.

Simultaneous measurement of speeds by Pitot tube probes 1 and 2 can assist the pilot (or the power plant) to avoid the TRVR mode with the increase in left rotation speed under the condition of $\tilde{V}_z < -1 \div 1.5$ (fig. 2) at low flight speeds (at $V_z \sim 5$ m/s) at the frequency equal to $f_1 V_z$ ("flight" mode) and while hovering (at $V_z \sim 12$ m/s) at the frequency equal to $f_2 V_{and TR}$ ("hovering" mode). The frequency signal is determined during a flight experiment or

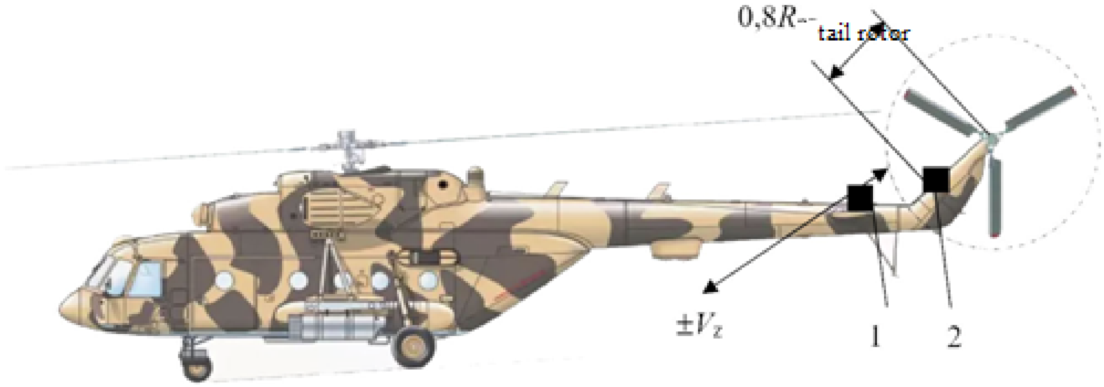

Fig. 5. Mi-171 helicopter with a Pitot tube probe – 1 and a Pitot tube probe – 2, $R_{tail\ rotor}$ – TR radius

a testbench (approximately $f_1 \cong 90$ and $f_2 \cong 120$Hz, data from [18]).

Let us list the properties of the method under consideration implemented in the mock-up model of the Pitot tube: *1* – being measured automatically, static pressure is subtracted from the total pressure; *2* – speed readouts do not depend on medium density ρ, i.e., do not depend on flight altitude; *3* – the property of the output frequency f from the velocity V close to the linear; *4* – the true velocity of ambient air flow, including wind, is measured; *5* – capacity to operate without electric power supply; *6* – no corrections for the value of the dangerous frequency in terms of speed at different altitudes – near terrain or in the mountains, i.e., dangerous frequency readings are the same for different helicopter flight parameters and ambient temperature; *7* – the Pitot tube probe is an application that measures rather than calculates true airspeed directly aerodynamically avoiding complex transformations.

Conclusion

In order to measure, a Pitot tube probe of wind speed and the helicopter beam V_z are installed in the complex, the former, only during beam turn with the TR at a circumferential speed more than > 5 m/s, is an indicator of the TRVR mode occurrence, and it sends an alert notifying that exceeding the frequency value of inductive speed sensors readings is more than 1.5 times – $f_2V_{tail\ rotor}/f_1V_z > 1.3 \div 1.55$ in the "flight" and "hover" modes.

Installation of Pitot tube probes on board a helicopter makes piloting more confident. The installation of Pitot tube probes as a part of onboard equipment will provide radical elimination of the TRRV mode in-flight as well as of uncontrolled rotation.

References

1. **Semenovich, A.N. (**2006). *Mode of spontaneous left rotation*. Vertolet, no. 1, pp. 10–14. (in Russian)

2. **Volodko, A.M.** (1992). *Helicopter in a distinct situation*. Moscow: Transport, 262 p. (in Russian)

3. **Carico, D.M.** (1989). *Helicopter controllability*. California, Naval Postgraduate School. Available at: https://core.ac.uk/download/pdf/36719921.pdf (accessed: 21.11.2021).

4. **Rajendran, S. & Gu, Da-wei.** (2014). *Fault tolerant control of a small helicopter with tail rotor failures in forward flight*. IFAC Proceedings Volumes, vol. 47, issue 3, pp. 8843–8848. DOI: 10.3182/20140824-6-ZA-1003.02047 (accessed: 21.11.2021).

5. **Kelley, H.L., Crowell, C.A., Yenni, K.R. & Lance, M.B.** (1993). *Flight investigation of the effect of tail boom strakes on helicopter directional control.* ATCOM Technical Report 93-A-003, 41 p. Available at:

https://ntrs.nasa.gov/api/citations/19930013465/downloads/19930013465.pdf (accessed: 21.11.2021).

6. **Dequin, A.-M.** (2019). *The myth of losing tail rotor effectiveness*. 45th European Rotorcraft Forum. Poland, Warsaw 17–20 September, vol. 2, pp. 1064–1078.

7. **Ivchin, V.A.** (2020). *The physical nature of an unintentional turn of a single-rotor helicopter at low flight speeds.* Aktualnyye problemy bezopasnosti poletov na sovremennom etape: sbornik statey nauchno-prakticheskoy konferentsii. Moscow: SBPA VS RF, pp. 27–34. (in Russian)

8. **Ignatkin, Yu.M., Makeev, P.V., Shomov, A.I. & Ivchin, V.A.** (2016). *Computational study of aerodynamic characteristics of single-rotor helicopter tail rotor under the influence of vortical wake of main rotor at the hover with crosswind.* Civil Aviation High Technologies, vol. 19, no. 6, pp. 58–67. (in Russian)

9. **Shcheglova, V.M.** (2014). *Computational study of flow parameters in the area of the tail rotor location at low-speed flight modes of a helicopter with sliding*. Uchenye zapiski TsAGI, vol. 45, no. 6, pp. 73–86. (in Russian)

10. **Animitsa, V.A. & Leontiev, V.A.** (2011). *About "spontaneous" rotation of singl rotor helicopters*. Nauchnyy Vestnik MGTU GA, no. 172, pp. 96–102. (in Russian)

11. **Johnson, W.** (1980). *Helicopter Theory.* Princeton University Press, 1089 p.

12. **Nikiforov, V.A.** (2018). *Method of selecting the parameters of the tail rotor of a single-rotor helicopter corresponding to the maximum coefficient of weight return of the helicopter*. Vertolety. Trudy OKB MVZ imeni M.L. Milya. M.: Mashinostroyeniye-Polet, issue 3, pp. 219–247. (in Russian)

13. **Efimov, V.V., Ivchin, V.A., Chernigin, O.E. & Chernigin, K.O.** (2020). *Experimental research of single - rotor helicopter unintentional yaw rotation*. Civil Aviation High Technologies, vol. 23, no. 2, pp. 33–46. DOI: 10.26467/2079-0619-2020-23-2-33-46

14. **Leontiev, V.A., Krymsky, V.S., Ignatkin, Yu.M. & Makeev, P.V.** (2017). *Computational-experimental studies of tail rotor characteristics at helicopter yawing rotation mode.* Trudy MAI, no. 93, p. 4. Available at: https://trudymai.ru/upload/iblock/75b/leontev_krymskiy_ignatkin_makeev_rus.pdf?lang=en&issue=93 (accessed: 21.11.2021). (in Russian)

15. **Ivchin, V.A. & Samsonov, K.Yu.** (2010). *Experimental investigations of the X-shaped tail rotor model aimed at improving aerodynamic characteristics thereof.* Nauchnyy Vestnik MGTU GA, no. 151, pp. 71–78. (in Russian)

16. **Ignatkin, Yu.M., Makeev, P.V., Shomov, A.I. & Ivchin, V.A.** (2018). *Calculation studies of aerodynamic characteristics of the main rotor and tail rotor combination, taking into account aerodynamic interference for the MI-8/17 helicopter when flying at low speeds with sliding*. Vertolety. Trudy OKB MVZ imeni M.L. Milya. M.: Mashinostroyeniye-Polet, issue 3, pp. 203–218. (in Russian)

17. **Artamonov, B.L.** (2019). *Method of calculating the aerodynamic characteristics of an X-shaped tail rotor in axial flow modes based on linear disk vortex theory*. Vertolety. Trudy OKB MVZ imeni M.L. Milya. M.: Mashinostroyeniye-Polet, issue 4, pp. 144–162. (in Russian)

18. **Popov, A.I. & Kasimov, A.M.** (2021). *The study of the receiver of the air speed with frequency output.* Uchenye zapiski TsAGI, vol. 52, no. 3, pp. 67–74. (in Russian)

19. **Kasimov, A.M. & Popov, A.I.** (2018). *Air speed meter*. Patent RU, no. 2672037 C1, November 08, 2018. (in Russian)

Список литературы

1. **Семенович А.Н.** Режим самопроизвольного левого вращения // Вертолет. 2006. № 1. С. 10–14

2. **Володко А.М.** Вертолет в особой ситуации. М.: Транспорт, 1992. 262 с.

3. **Carico D.M.** Helicopter controllability [Электронный ресурс] // California: Naval Postgraduate School, 1989. 208 p. URL: https://core.ac.uk/download/pdf/36719921.pdf (дата обращения: 21.11.2021).

4. **Rajendran S., Gu Da-wei.** Fault tolerant control of a small helicopter with tail rotor

failures in forward flight [Электронный ресурс] // IFAC Proceedings Volumes. 2014. Vol. 47, iss. 3. Pp. 8843–8848. DOI: 10.3182/20140824-6-ZA-1003.02047 (дата обращения: 21.11.2021).

5. **Kelley H.L.** Flight investigation of the effect of tail boom strakes on helicopter directional control / H.L. Kelley, C.A. Crowell, K.R. Yenni, M.B. Lance [Электронный ресурс] // ATCOM Technical Report 93-A-003, 1993. 41 p. URL: https://ntrs.nasa.gov/api/ citations/19930013465/downloads/19930013465.pdf (дата обращения: 21.11.2021).

6. **Dequin A.-M.** The myth of losing tail rotor effectiveness // 45th European Rotorcraft Forum. Poland, Warsaw 17–20 September, 2019. Vol. 2. Pp. 1064–1078.

7. **Ивчин В.А.** Физическая сущность непреднамеренного разворота одновинтового вертолета на режимах малых скоростей полета // Актуальные проблемы безопасности полетов на современном этапе: сборник статей научно-практической конференции. Москва, 10 апреля 2020 г. М.: СБПА ВС РФ, 2020. С. 27–34.

8. **Игнаткин Ю.М.** Расчетные исследования аэродинамических характеристик рулевого винта одновинтового вертолета с учетом индуктивного воздействия вихревого следа несущего винта на режимах висения при боковом ветре / Ю.М. Игнаткин, П.В. Макеев, А.И. Шомов, В.А. Ивчин // Научный Вестник МГТУ ГА. 2016. Т. 19, № 6. С. 58–67.

9. **Щеглова В.М.** Расчетное исследование параметров потока в области расположения рулевого винта на режимах малых скоростей полета вертолета со скольжением // Ученые записки ЦАГИ. 2014. Т. 45, № 6. С. 73–86.

10. **Анимица В.А., Леонтьев В.А.** О «самопроизвольном» вращении одновинтовых вертолетов // Научный Вестник МГТУ ГА. 2011. № 172. С. 96–102.

11. **Джонсон У.** Теория вертолета. В 2 кн. Кн. 1. : пер. с англ. М.: Мир, 1983. 502 с.

12. **Никифоров В.А.** Методика выбора параметров рулевого винта одновинтового вертолета, соответствующих максимальному коэффициенту весовой отдачи вертолета. Вертолеты. Труды ОКБ МВЗ имени М.Л. Миля. М.: Машиностроение-Полет, 2018. Выпуск 3. С. 219–247.

13. **Efimov V.V.** Experimental research of single - rotor helicopter unintentional yaw rotation / V.V. Efimov, V.A. Ivchin, O.E. Chernigin, K.O. Chernigin // Civil Aviation High Technologies. 2020. Vol. 23, no. 2. Pp. 33–46. DOI: 10.26467/2079-0619-2020-23-2-33-46

14. **Леонтьев В.А.** Расчетно-экспериментальные исследования характеристики хвостового винта при режиме рыскания вертолета / В.А. Леонтьев, В.С. Крымский, Ю.М. Игнаткин, П.В. Макеев [Электронный ресурс] // Труды МАИ. 2017. № 93. С. 4. URL: https://trudymai.ru/upload/iblock/75b/leontev_krymskiy_ignatkin_makeev_rus.pdf?lang=ru&issue=93 (дата обращения: 21.11.2021).

15. **Ивчин В.А., Самсонов К.Ю.** Экспериментальные исследования модели Х-образного рулевого винта с целю улучшения его аэродинамических характеристик // Научный Вестник МГТУ ГА. 2010. № 151. С. 71–78.

16. **Игнаткин Ю.М.** Расчетные исследования аэродинамических характеристик комбинации несущего и рулевого винтов с учетом аэродинамической интерференции для вертолета МИ-8/17 при полете с малыми скоростями со скольжением / Ю.М. Игнаткин, П.В. Макеев, А.И. Шомов, В.А. Ивчин. Вертолеты. Труды ОКБ МВЗ имени М.Л. Миля. М.: Машиностроение-Полет, 2018. Выпуск 3. С. 203–218.

17. **Артамонов Б.Л.** Метод расчета аэродинамических характеристик Х-образного рулевого винта на режимах осевого обтекания на основе линейной дисковой вихревой теории. Вертолеты. Труды ОКБ МВЗ имени М.Л. Миля. М.: Машиностроение-Полет, 2019. Выпуск 4. С. 144–162.

18. **Попов А.И., Касимов А.М.** Исследование проточного приемника воздушной скорости с частотным выходом // Ученые записки ЦАГИ. 2021.Т. 52, № 3. С. 67–74.

19. **Касимов А.М., Попов А.И.** Измеритель воздушной скорости. Патент RU № 2672037 C1, 08.11.2018.

Information about the authors

Valery A. Ivchin, Candidate of Technical Sciences, Head of Department, JSC National Center for Helicopter Engineering named after Mil and Kamov, vivchin@mi-helicopter.ru.

Konstantin Y. Samsonov, Leading Flight Test Engineer, JSC National Center for Helicopter Engineering named after Mil and Kamov, samsonov.k@inbox.ru.

Asim M. Kasimov, Doctor of Technical Sciences, Senior Scientific Officer, Principal Researcher, Trapeznikov Institute of Control Sciences of Russian Academy of Sciences, kasimov@ipu.ru.

Alexander I. Popov, Senior Researcher, Institute of Management Problems named after V.A. Trapeznikov of the Russian Academy of Sciences, daten@ipu.ru.

Сведения об авторах

Ивчин Валерий Андреевич, кандидат технических наук, начальник отдела, АО «НЦВ Миль и Камов», vivchin@mi-helicopter.ru.

Самсонов Константин Юрьевич, ведущий инженер по летным испытаниям, АО «НЦВ Миль и Камов», samsonov.k@inbox.ru.

Касимов Асим Мустафаевич, доктор технических наук, старший научный сотрудник, главный научный сотрудник, ИПУ РАН им. В.А. Трапезникова, kasimov@ipu.ru.

Попов Александр Иванович, старший научный сотрудник, ИПУ РАН им. В.А. Трапезникова, daten@ipu.ru.

Поступила в редакцию	26.03.2022	Received	26.03.2022
Принята в печать	24.05.2022	Accepted for publication	24.05.2022