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ӘУЕ КӨЛІГІ ЖӘНЕ ТЕХНОЛОГИЯЛАР
ВОЗДУШНЫЙ ТРАНСПОРТ И ТЕХНОЛОГИИ
AIR TRANSPORT AND TECHNOLOGY

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IRSTI 629.7.05
https://doi.org/10.53364/24138614_2024_35_4_1

[1]Islam Isgandarov, [1]Sakhavat Amirbayli*
[1]National Aviation Academy, Azerbaijan, Baku

E-mail: Sakhavat.Zahid92@gmail.com

STRUCTURAL MODEL AND REPORTING METHODOLOGY OF THE PERSPECTIVE ANTI-ICING SYSTEM FOR CIVIL AVIATION AIRCRAFT

Abstract: *In this article, analyzes the operational and technical characteristics of anti-icing systems used in modern civil aircraft, as a promising anti-icing system, a structural model of a system equipped with a microwave generator that can be installed on the wing of an aircraft, as well as on other aircraft surfaces that may be subject to icing, has been proposed. An application scheme for such a system for carbon-fiber and aluminum-based front edges has been developed, and the microwave generator to be used in the system will be used in the form of a block with low energy consumption and minimal traction on the icy parts of a particular type of aircraft.*

Keywords: *Anti-icing system, Leading edges ,Carbon fiber,De-icing, Anti-icing, Unmanned aerial vehicle,Composite,Dielectric ,Aerodynamic surface,Thermal anti-icing system, Pneumatic anti-icing system, Laminar flow, Turbulent flow, Microwave energy.*

Introduction. Aircraft icing in flight is recognized as a serious safety problem worldwide. Under certain flight conditions, water droplets can cool and freeze within clouds, causing damage to the leading edge of the aircraft fuselage, wings, controls, and engine air intakes. The ice sheet changes the shape of the aerodynamic surfaces and the resulting aerodynamic performance of the aircraft can be dangerous to the flight. As we know, the aircraft eliminates ice accumulation during flight by activating anti-icing systems. Most systems currently in use can be divided into two main types: thermal and pneumatic. There are real limits to the application of other types such as vibration, chemical, shape memory alloys and super hydrophobic and are still under development. Thermal anti-icing systems melt ice build up on the wing's protected surface or prevent ice from forming by applying heat. This is done either by the use of electric heaters or by transferring hot air from a jet engine. Typical applications of off-wing anti-icing systems are on the leading edges, as well as the engine and propeller blades, where ice accumulation can be detrimental. Therefore, each anti-icing system has its own impact on weight, energy, as well as consumption and costs, for this reason we will try to classify all possible technical solutions, of course, this leads to ratings with no general reliability. In this article, operational and technical features of anti-icing systems applied in modern civil aviation aircrafts are analyzed, and a structural model of a system that can be installed on the aircraft wing and also on other aircraft surfaces that may be exposed to icing by being equipped with a microwave generator as a prospective anti-icing system is proposed. The application scheme of such a system for carbon-fiber and aluminum-based front edges has been worked out, and the placement of the microwave generator to be used in the system in the form of a block is justified by consuming less energy and having a minimum weight in the parts of a specific type of aircraft subject to icing [1].

Development of the scheme of perspective anti-icing systems. Since the early days of aviation, the growth of ice on the surface of airplanes during flight has been able to cause from minor danger to major disasters. Despite great developments, aircraft anti-icing systems have become more effective over the years due to increased understanding, but unfortunately, accidents due to this reason still occur during icing. As it is known, the ice formed on the aerodynamic surfaces of the plane disrupts the laminar flow of air, as a result, the lifting force decreases, the resistance increases, and it weakens the stability by complicating the work of the control bodies. Maintaining altitude, increasing angle of attack, and expending power to compensate for additional drag allow ice to accumulate on the underside of the fuselage and wing. Ice accumulates not only on the wings, fenders and windshields, but also on the front surfaces of the aircraft, including antennas, vents and inlets. Vibrating the antennae so severely eventually causes them to break. Most of the systems in use today are classified according to two main types: thermal and pneumatic. Other types, vibration, chemical, shape memory alloys and superhydrophobic are limited in real application and are still under development. Thermal systems melt ice on the wing's protected surface and prevent ice from forming through heat. This occurs through electric heaters or hot air from the engine. Pneumatic de-icing systems usually consist of a rubber inflatable cargo area located on the leading edges of the wing. In this research topic, we will talk about the application of microwave anti-icing system for carbon-fiber reinforced plastic front edges. Thus, the microwave anti-icing system for carbon-fiber-based front edges is capable of performing both anti-icing and de-icing functions through a microwave generator placed on those front edges, which has a high absorption rate of microwaves. Thanks to such a high ratio, the efficiency of the system is extremely high with negligible losses. Typical power consumption for a regional aircraft is approximately (20kW). The system is always reliable due to its vital importance, but can result in difficulty caused by the heavy weight as protection of adjacent structures and systems is required. A schematic diagram of the microwave anti-icing system for composite leading edges is shown in figure 1.

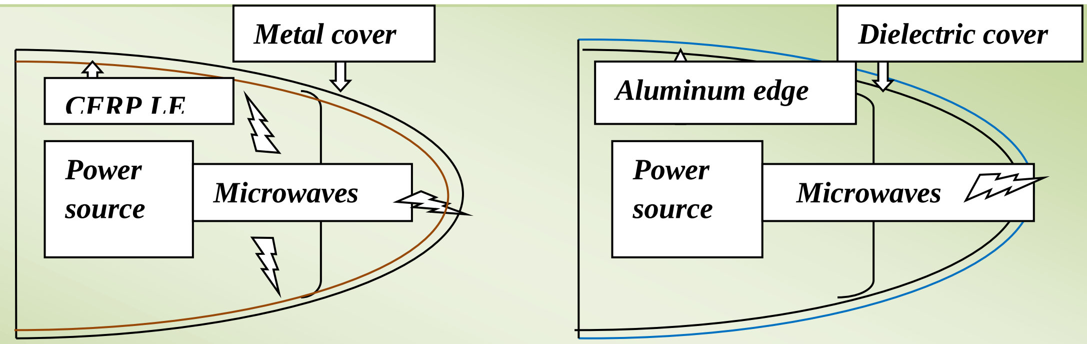

Figure 1. Structural diagram of microwave anti-icing system for carbon-fiber reinforced leading edges

Figure 2. Structural diagram of microwave anti-icing system for aluminum leading edges

Figure 1. and figure 2. Structural diagram of microwave anti-icing system for carbon-fiber reinforced and aluminum leading edges

However, the microwave anti-icing system for aluminum front edges only has a de-icing function, which heats and melts the accumulated ice by absorbing microwaves. In this case, the microwave absorption process is not very high, and therefore the system efficiency usually causes energy loss below 70% when the system is in operation [1,2,3]. A structural diagram of the microwave anti-icing system for aluminum front edges is shown in figure 2.

In general, this system is designed for the wing, rotor and aerodynamic profile of the aircraft. The working principle is that the radiated microwave energy is absorbed in the propagation tube of the leading edge of the wing of the aircraft and eventually turns into heat energy. In order to ensure the most efficient conversion of microwave energy into heat energy, a highly absorbent coating and a mirror-insulator are placed on the inner surface of the tube. As a result, heat energy is transferred to the wing, rotor and aerodynamic profile through special heat transfer channels, so the temperature of the wing parts, rotor and aerodynamic profile increases. and melting of ice formed even at temperatures above freezing occurs and is preventable. So, we can use Maxwell's equations and Lambert's law to describe the absorption of microwave energy. Since Maxwell's equations are complex equations, we can give a numerical model of the report using these two equations that represent the absorption of microwave energy. Using these, it is possible to compare the numerical model's predictions based on the two equations that show the absorption of microwave energy. As a result, it can be concluded that the penetration depth, which is a function of the predictions of the two formulas, depends on the critical density. According to Lambert's law, melting occurs during microwave heating, and as a result, the microwave power P_o at a normal surface is expressed as a distance x from the surface. This dependence can be characterized by the following dependence:

$$P(x) = P_0 e^{-2\delta x} \quad (1)$$

where δ is the attenuation constant, specified in units of 1/m. The penetration depth δ_p is defined as $\delta_p=1/(2\delta)$, where $P(x)/P_0 = 1/e$ [2]. From here it can be said that if the thickness of the surface is 2.7 times greater than the depth of penetration, then the two formulas will have the same results. Therefore, for sufficiently thick surfaces, models based on the absorption of microwave radiation can be performed using Lambert's law. The exact determination of the P_0- quantity is very important for the development of the microwave model algorithm. The surface power can be expressed as a function equal to the absorbed power and the absorbed surface power. The proposed equations are shown to correspond to this approach for cylindrical samples. However, the powers calculated by the calorimetric model are averaged over absorbed powers rather than surface powers. In this case, the absorbed power can be defined by the following expression:

$$P_{abs} = \int_V P(x)dV = \int_0^H \int_0^{2\pi} \int_0^R P_0\, e^{-2\delta x} = dxd\theta dz \tag{2}$$

and after integration, the following equation related to the force can be obtained in terms of the surface force absorption equation:

$$P_0 = \frac{P_{abs}\delta}{(1-e^{-2\delta R})\pi H} \tag{3}$$

However, in a cylindrical body, the volume element is not *(dxdθdz)*, and the dimensions on the left and right sides of equation are inconsistent. The aim of the present work is to design a difference model to predict the experimental data, using the absorbed power and surface power as well as the estimated surface power in a finite way using the approach related to. The unsteady state heating for microwave radiation on a long cylindrical surface can be modified by the equation of conductivity for solids with constant physical properties by adding the absorption term of microwave power.

$$\rho C_p \frac{\partial T}{\partial t} \equiv \frac{k\partial}{r\partial r}\left(\frac{\partial T}{\partial t}\right) + \frac{P}{V} \tag{4}$$

where the P/V ratio is the volumetric heat generation time.

It should also be noted that the surface power for a certain geometry and charge at a certain position in microwave radiation should not depend on the irradiated samples, this movement is associated with inaccuracies in the attenuation constants, and the non-uniformity in the microwave field or its absence reduces the probability of the assumption of normal energy transfer. I would like to note that the microwave de-icing and anti-icing system for airplanes is usually designed for airplane wings, rotors, and airfoils. The principle of operation can be briefly explained as follows: microwave energy is absorbed by the rising tube inside the front leading edges of the wing and eventually turns into heat energy. Therefore, placing a highly absorbent coating and a mirror insulator on the inner surface of the tube ensures the conversion of microwave energy into thermal energy. And as a result, the heat energy spreads to the surface of the wing, rotor and airfoils through the heat transfer channels, and at the same time, the temperature in the wing part, rotor and airfoils increases, the elimination and formation of icing is prevented [4].

Microwave technology in the field of aviation. Microwave technology is widely used for point-to-point telecommunications (ie, non-broadcast uses). Microwave ovens are particularly well suited for this use because they are more easily focused into narrower beams than radio waves, allowing frequencies to be reused; their relatively high frequencies allow for large bandwidths and high data rates, and antenna sizes are smaller than those at lower frequencies because the size of the antenna is inversely proportional to the transmitted frequency. Microwaves are used in spacecraft communications, and much of the world's data, TV and telephone communications are transmitted over long distances by microwaves between ground stations and communication satellites. Microwave radiation is also used in microwave ovens and radar technology. A microwave oven passes microwave radiation at a frequency near 2.45 GHz (12 cm) through food, causing dielectric heating primarily by absorbing energy in water. Microwave ovens became a common kitchen appliance in western countries after the development of cheaper cavity magnetrons in the late 1970s. Water in its liquid state has many molecular interactions that broaden the absorption peak. Water molecules isolated in the vapor phase are absorbed at a frequency of 22 GHz, which is almost ten times the frequency of a microwave oven. Many semiconductor processing techniques use microwaves to generate plasma for purposes such as reactive ion etching and plasma-enhanced chemical vapor deposition. The word "beam" refers to energy emitted from a source, not radioactivity. The main effect of microwave absorption is to heat materials; electromagnetic fields cause polar molecules to vibrate. Microwave radiation (or other non-ionizing electromagnetic radiation) has not been conclusively proven to have significant adverse biological effects at low levels. Some studies, but not all, show that long-term exposure can have a carcinogenic effect. Considering that the two plates located inside and the electromagnetic rays passing through that plate cause the substance to be heated from negative temperature to positive temperature [5].

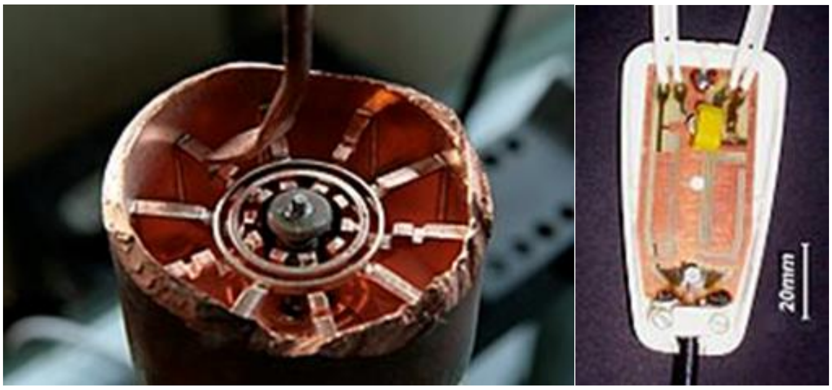

Figure 3. Cutaway profile view of a magnetron

At low frequencies, open-wire and coaxial transmission lines are replaced by waveguides and strip lines, and lumped-element tuned circuits are replaced by cavity resonators or resonant stubs. In turn, at higher frequencies, when the wavelength of electromagnetic waves is small compared to the size of the structures used to process them, the microwave technique becomes inadequate and optics methods are used. High power microwave sources use special vacuum tubes to generate microwave beams. These devices operate on different principles than low-frequency vacuum tubes, using the ballistic motion of electrons in a vacuum under the influence of controlling electric or magnetic fields, and are divided into magnetron (used in microwave ovens), klystron, traveling wave tube (TWT) and gyrotron types. These devices operate in density modulation mode rather than current modulation mode. This means that instead of using a continuous stream of electrons, they operate on piles of electrons that fly ballistically over them. A cutaway view of the inside of a cavity magnetron used in a microwave oven (left). Antenna splitter: microstrip techniques become increasingly necessary at higher frequencies (right) figure 3. [6].

Effect of ice accumulation on wing aerodynamics and perspective reporting methodology and scheme. One of the main objectives of this project is to determine the effects of icing on aerodynamics according to the performance of the aircraft configuration (since each geometric surface accumulates ice differently and a general study would be impossible). The effect of ice on the airflow depends on the location of the ice and is regulated by the pressure distribution of the airflow. The ratio of the height of the ice formation to the length of the chord of the wing determines the shape of the ice wing and its geometry. Furthermore, its effects do not appear to be linear or proportional in any sense. In general, icing has the effect of increasing wind resistance by increasing the vertical load of the structure and increasing the open area of its wings. This leads to reduced performance, loss of lift, variable control and eventual stalling and subsequent loss of control. The least thing to do is that icing directly changes the shape of the variable airfoil, which will increase its aerodynamics (changing the airflow) and also its mass (important in UAVs, more so than other types of aircraft due to their smaller mass), and most importantly, change the center of mass, which, currently we will analyze it. Aerodynamic problems in airplanes are mainly observed with a decrease in lift force and an increase in wing drag. These two forces are the forces that control aerodynamics, and their variation is what gives us the aerodynamic degradation caused by icing. The drag force is the force parallel to the flow direction, and the lift force is the force perpendicular to it. Lift is the (ideal) upward force created by the aircraft as a result of its motion in the air. However, how air flow creates lift can be explained by Bernoulli's principle (as well as Newton's laws). According to Bernoulli's principle, we know that there is a direct relationship between pressure and velocity. Like air flow, a pressure imbalance occurs, so that the air passing through the upper part flows at a different speed than the lower part [7,9]. This pressure difference is exactly the lifting force. Also, the lifting force depends on the air density, the square of the speed of the plane, the area of the wing, the shape of the wing and the angle of attack.

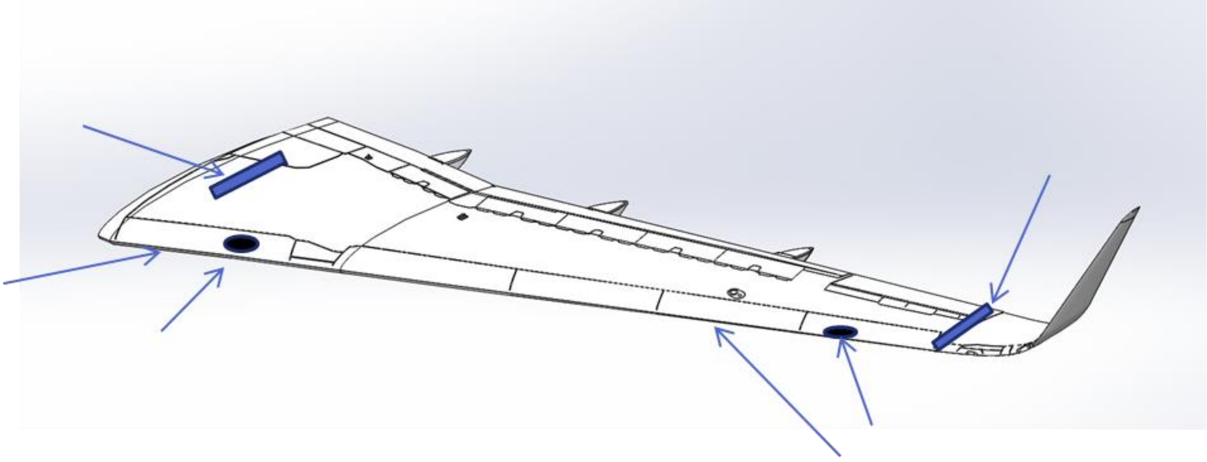

Figure 4. The principle of location of magnetrons and temperature transmitters on the airfoil

▬ Magnetrons

● Temperature transmitters

This is the angle of attack and its shape (the lift coefficient in the lift force formula is expressed in the form of the equation (5)). Icing greatly affects the shape of the wing, resulting in reduced lift and lift. We will refer to the lift force as the lift coefficient, as this is what FENSAP will output. Its equation is shown in (5). This coefficient is dimensionless and will be perfect for comparison between the cases we will be working with here, FL - is the lifting force, S - is the surface area, V- is the velocity of the air flow, and ρ - is the density of the liquid.

$$C_L = \frac{2F_{Lift}}{\rho V^2 S} \tag{5}$$

Drag is the opposite force of air, a force that opposes the relative motion of an object, or in this case (aerodynamic drag), a force directed against the direction of flow. This force is viscous and we will also work with a dimensionless drag coefficient. Its equation is shown in expression (6). Similarly, the lifting force coefficient depends on the liquid density ρ and the square of the flow rate V. However, this coefficient depends on the cross-sectional area (A) unlike S.

$$C_D = \frac{2F_{Drag}}{\rho V^2 A} \tag{6}$$

The change in the center of mass is also very important. Generally, water droplets hit near the front leading edge of the wing, and most of the ice accumulates on the leading edge. This changes the mass distribution and center of mass of the fuselage. For this reason, the change in center of mass caused by ice accumulation can be very detrimental to flight.There are two different approaches to numerically calculate fluid dynamics: one is Lagrangian and the other is Euler. The Lagrangian specification of the field is a way of tracking the fluid motion followed by an individual fluid particle as an observer moves through space and time. The position of an individual particle over time gives the trajectory of that particle. The Eulerian approach, on the other hand, focuses on specific locations in the space through which the fluid flows, instead of following a fluid particle. With this approach, we can see the motion of the fluid particle at all observed locations. The problem is that CFD analysis usually fails to accurately determine the lift and drag forces and results in low Reynolds numbers with free passage. This is due to laminar separation effects, which cannot be fully captured by common CFD methods [8-11].

Microwaves are a form of electromagnetic radiation with wavelengths of about one meter to one millimeter, corresponding to frequencies between 300 MHz and 300 GHz, respectively. Different sources define different frequency ranges as microwaves; the broad definition above includes the UHF, SHF and EHF (millimeter wave) bands. A more common definition in radio frequency engineering is the range between 1 and 100 GHz (wavelength between 0.3 m and 3 mm). Microwaves travel in the line of sight; unlike low-frequency radio waves, they do not diffract around hills, follow the earth's surface like ground waves, or reflect from the ionosphere, so that terrestrial microwave communications are limited to about 40 miles (64 km) beyond the visual horizon [12,13]. At the high end of the range, they are absorbed by gases in the atmosphere, limiting practical communication distances to a kilometer. In modern times, microwaves are used in aviation, medicine and other fields, including household applications. It should also be noted that microwave ovens are used in modern technology, for example, in point-to-point communications, wireless networks, microwave radio relay networks, radar, satellite and widely used in spacecraft communications, medical diathermy and cancer treatment, remote sensing, radio astronomy, particle accelerators, spectroscopy, industrial heating, collision avoidance systems, garage door and keyless entry systems, and microwave cooking, etc. Microwave radiation occupies a place in the electromagnetic spectrum with a frequency above ordinary radio waves and below infrared light:

Electromagnetic radiation			
Name	Wave length	Frequency	Photon energy
Gamma radiation	< 0.01 nm	> 30 EHz	> 124 keV
X-ray	0.01 nm – 10 nm	30 EHz – 30 PHz	124 keV – 124 eV
Ultraviolet	10 nm – 400 nm	30 PHz – 750THz	124 eV – 3 eV
Visible light	400 nm – 750 nm	750THz –400THz	3 eV – 1.7 eV

Infrared	750 nm – 1 mm	400THz–300 GHz	1.7 eV– 1.24 meV
Microwave	1 mm – 1 m	300 GHz–300Mhz	1.24meV –1.2 μev
Radio	≥ 1 m	≤ 300 MHz	≤ 1.24 μeV

Microwave radiation is also used in microwave ovens and radar technology. A microwave oven passes microwave radiation at a frequency near 2.45 GHz (12 cm) through food, causing dielectric heating primarily by absorbing energy in water.

Figure 5. Newly designed 1.5k W microwave magnetron

The characteristics of a microwave magnetron are as follows:
Output voltage: 3.8kV~4.4kV
Output current: Max.480mA
Destination: magnetron
Dimensions: 254 (L) x 173 (W) x 92 mm (H)
Output power: 100~2000W
Input voltage: 220V
Product name: New design 1.5kW microwave magnetron
Efficiency: more than 90%

As the main result of our research, we can say that the development of a mathematical model that simulates the operation of the anti-icing system with the conversion of microwave energy into thermal energy will provide ample opportunities for the application of this system to a specific type of aircraft in the future [14]. And as a new proposal, through the placement of microwave magnetrons in the wing profile, it is possible to use about 2kW of power as a result of pulsed electromagnetic radiation.

As a result of the analysis, it was determined that the anti-icing system based on the microwave generator is the most promising system. It has been shown that the use of carbon-fiber-based reinforced plastic leading edges for a specific aircraft type can be achieved in this work. As an innovation, it is considered appropriate to place the microwave generator to be used in the system in the form of a block, consuming less energy and having a minimum weight in the parts of the system that are subject to icing.

Conclusion. As a result of the analysis, it was determined that the anti-icing system based on the microwave generator is the most promising system. It has been shown that the use of carbon-fiber-based reinforced plastic leading edges for a specific aircraft type can be achieved in this work. It has been determined that this system, besides being reliable in terms of its working capacity, is capable of performing both de-icing and anti-icing functions. In the article, as an innovation, the placement of the microwave generator to be used in the system in the form of a block is justified by consuming less energy and having a minimum weight in the parts of the system that are subject to icing of a specific type of aircraft. In general, with the application of temperature transmitters, magnetrons cause the melting of ice and the prevention of icing on aerodynamic surfaces that may be subject to icing with the heat energy released as a result of electromagnetic radiation. Harmful radiation can be relatively avoided by operating in 1.5kW pulse mode.

Ислам Искендеров, Сахават Амирбейли

СТРУКТУРНАЯ МОДЕЛЬ И МЕТОДИКА ОТЧЕТНОСТИ ПЕРСПЕКТИВНОЙ ПРОТИВООБЛЕДЕНИТЕЛЬНОЙ СИСТЕМЫ ДЛЯ САМОЛЕТОВ ГРАЖДАНСКОЙ АВИАЦИИ

Аннотация: *В статье анализируются эксплуатационные и технические характеристики противообледенительных систем, применяемых на современных гражданских самолетах, в качестве перспективной противообледенительной системы предложена структурная модель системы, оснащенной СВЧ-генератором, которая может быть установлена на крыле самолета, а также на других поверхностях самолета, которые могут подвергаться обледенению. Разработана схема применения такой системы для передних кромок из углепластика и алюминия, а используемый в системе СВЧ-генератор будет использован в виде блока с малым потреблением энергии и минимальным тяговым усилием на обледенелых частях конкретного типа самолета.*

Ключевые слова: *противообледенительная система, передние кромки, углеродное волокно, противообледенительная защита, противообледенительная защита, беспилотный летательный аппарат, композитный материал, диэлектрик, аэродинамическая поверхность, тепловая* *противообледенительная система, пневматическая противообледенительная система, ламинарный поток, турбулентный поток, микроволновая энергия.*

Ислам Искендеров, Сахават Амирбейли

АЗАМАТТЫҚ АВИАЦИЯНЫҢ ҰШАҚТАРЫНЫҢ ҚҰЗҒА ҚАРСЫ ЖЕТІЛДІК ЖҮЙЕСІНІҢ ҚҰРЫЛЫМДЫҚ МОДЕЛІ ЖӘНЕ ЕСЕПТІК ӘДІСІ

Аңдатпа: *Мақалада көктайғаққа қарсы перспективті жүйе ретінде қазіргі азаматтық әуе кемелерінде қолданылатын мұздануға қарсы жүйелердің эксплуатациялық және техникалық сипаттамалары талданады, қанатқа орнатуға болатын микротолқынды генератормен жабдықталған жүйенің құрылымдық үлгісі ұсынылады; әуе кемесінің, сондай-ақ мұздануға ұшырауы мүмкін әуе кемесінің басқа беттерінде. Көміртекті талшық пен алюминийден жасалған алдыңғы жиектерге арналған мұндай жүйені пайдалану схемасы әзірленді және жүйеде қолданылатын микротолқынды генератор мұзды бөліктерде энергияны аз тұтыну және ең аз тарту күші бар блок түрінде қолданылады. ұшақтың нақты түрі.*

Түйін сөздер: *мұзға қарсы, жетекші жиектер, көміртекті талшық, мұзға қарсы, мұзға қарсы, ұшқышсыз ұшақ, композиттік материал, диэлектрик, аэродинамикалық бет, термиялық мұз, пневматикалық мұз, ламинарлы ағын, турбуленттік ағын, микротолқынды энергия.*

References

1. PhD course in Aerospace, Naval and Quality Engineering XXIII PhD course in Aerospace Engineering, Author: F. De Rosa Tutor: Prof. G.P. Russo, 2008-2010
2. G.C. Botura, D. Sweet, “Concept Development of Low Power Electro-thermal Deicing System”, AIAA 2006-864, 2006.
3. Icing of aerodynamic surfaces: conditions of occurrence and calculation methods, Prikhodko A.A., Alekseenko S.V. O. Gonchar Dnipropetrovsk National University, Ukraine. 2012.
4. A mathematical model for predicting the temperature profiles during microwave heating, Coskan İlicalı Kyrgyzstan, Turkey, Manas University, Faculty of Engineering, Department of Food Engineering, 2011.
5. Amirbayli S.Z., Abdullayev P.Ş. Structural model of perspective ice protection system for civil aviation aircraft, "February Reports 2021 Creative Potential of Youth in Solving Aerospace Issues" VI International Scientific and Practical Youth Conference, Baku February 2-4, 2021, on page 65-67.
6. The experimental investigation of a rotor hover icing model with shedding, Edward W. Brouwers, Research Assistant, Aerospace Engineering, Jose L. Palacios, Research Associate, Aerospace Engineering, Edward C. Smith, 2010.

7. “Electrically heated composite leading edges for aircraft anti-icing applications” By Francesco De Rosa 2010.

8. Study of the Effects of In-Flight Icing on Fixed Wing UAV's Aerodynamic Performance,Eloi Soldevila Dalmau, Narvik, Codirectors: Muhammad Shakeel Virk (UiT), Josep Maria Olm (UPC), June 2018.

9. Beads and Rivulets Modelling in Ice Accretion on a Wing / P. Louchez, G. Fortin, G. Mingione, V. Brandi // 36th Aerospace Sciences Meeting &Exhibit, American Institute of Aeronautics and Astronautics, Reno, Nevada. – 1998.

10. Dillingh, J.E. Accumulation of Ice Accretion on Airfoils during Flight [Text] / J.E. Dillingh, H.W.M.Hoeijmakers // Federal Aviation Administration Inflight Icing and Aircraft Ground De-icing, Conference, Chicago, Illinois. – 2003.

11. Langmuir, I. A mathematical investigation of water droplet trajectories / I. Langmuir, K.B. Blodgett. – Program Press 196, Report No. RL-224. – Vol. 10. – 1945.

12. Szilder, K., & Yuan, W. (2017). In-flight icing on unmanned aerial vehicle and its aerodynamic penalties. Progress in Flight Physics–Volume 9, 9, 173-188.

13. Shin, J., Bond, T. (1992). Results of an Icing Test on a NACA 0012 Airfoil in the NASA Lewis Icing Research Tunnel. NASA Technical Memorandum 105374.

14. Amirbayli S.Z., Isgandarov I.A., Abdullayev P.Ş.. Structural model of perspective ice protection system for civil aviation aircraft, "February Reports 2021 Creative Potential of Youth in Solving Aerospace Issues" VI International Scientific and Practical Youth Conference, Baku February 2-4, 2021, on page 65-67.

Islam Isgandarov	Ph.D., Professor, Head of the Department "Aerospace Devices" of the National Aviation Academy of Azerbaijan, E-mail: islam.nus@mail.ru, Baku, Republic of Azerbaijan
Ислам Искендеров	ф.-м. ғ. к., профессор, Әзірбайжан Ұлттық авиация академиясының "Аэроғарыштық аспаптар" кафедрасының меңгерушісі, E-mail: islam.nus@mail.ru, Баку қ., Әзірбайжан республикасы.
Ислам Искендеров	к.ф.-м.н., профессор, зав. каф. «Аэрокосмические приборы» Национальной авиационной академии Азербайджана, E-mail: islam.nus@mail.ru, г. Баку, республика Азербайджан

Sakhavat Amirbayli	Master's degree, Chief Laboratory Assistant of the Department of Aerospace Devices of the National Aviation Academy of Azerbaijan, Baku, Republic of Azerbaijan E-mail: Sakhavat.Zahid 92@gmail.com
Сахават Амирбейли	Магистр, Әзірбайжан ұлттық авиациялық академиясының "Аэроғарыштық аспаптар" кафедрасының бас зертханашысы, Баку қ., Әзірбайжан Республикасы E-mail: Sakhavat.Zahid 92@gmail.com
Сахават Амирбейли	Магистр, главный лаборант кафедры «Аэрокосмические приборы» Национальной авиационной академии Азербайджана, г. Баку, республика Азербайджан E-mail: Sakhavat.Zahid 92@gmail.com