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ADVANCED DE-ICING SYSTEM OF REGIONAL AIRCRAFT

Ua Розроблено методологію розрахунку параметрів пневматичної протиобледенювальної системи літаків. Вона включає визначення зон захисту, розрахунок системи наддуву протекторів, розрахунок системи вакуумування протекторів. Розраховані параметри протиобледенювальної системи на прикладі регіонального літака Ан-140. Наведений порівняльний аналіз параметрів традиційної повітряно-теплової протиобледенювальної системи і пневматичної протиобледенювальної системи показав ефективність останньої для регіональних літаків. Розроблена методологія може використовуватися при проектуванні протиобледенювальної системи літаків.

Ru Разработана методология расчета параметров пневматической противообледенительной системы самолетов. Она включает определение зон защиты, расчет системы наддува протекторов, расчет системы вакуумирования протекторов. Рассчитаны параметры противообледенительной системы на примере регионального самолета Ан-140. Приведенный сравнительный анализ параметров традиционной воздушно-тепловой противообледенительной системы и пневматической противообледенительной системы показал эффективность последней для региональных самолетов. Разработанная методология может использоваться при проектировании противообледенительной системы самолетов.

Statement of problem

Ice is flying longtime enemy. Under certain atmospheric conditions, ice can be built rapidly on airfoils. On days when there is visible moisture in the air, ice can be formed on aircraft leading edge surfaces at altitudes where freezing temperature start. Water droplets in the air can be supercooled to below freezing without actually turning into ice unless they are disturbed in some manner. This unusual occurrence is partly due to the surface tension of the water droplet not allowing the droplet to expand and freeze. However, when aircraft surface disturbs these droplets, they immediately turn to the ice on the aircraft surface. In-flight icing destroys the smooth flow of air, increasing drag and decreasing the ability of an airfoil to lift. Ice accumulates on every exposed frontal surface of the aeroplane – the wings, stabilizer, propeller, windshield, antennas, vents, intakes, and cowlings. Sharp components such as thin leading edges of wing and stabilizer gather ice more readily than other components. The resulting malfor-

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mation of the airfoil could decrease both maximum lift coefficient and critical angle of attack [Fig. 1].

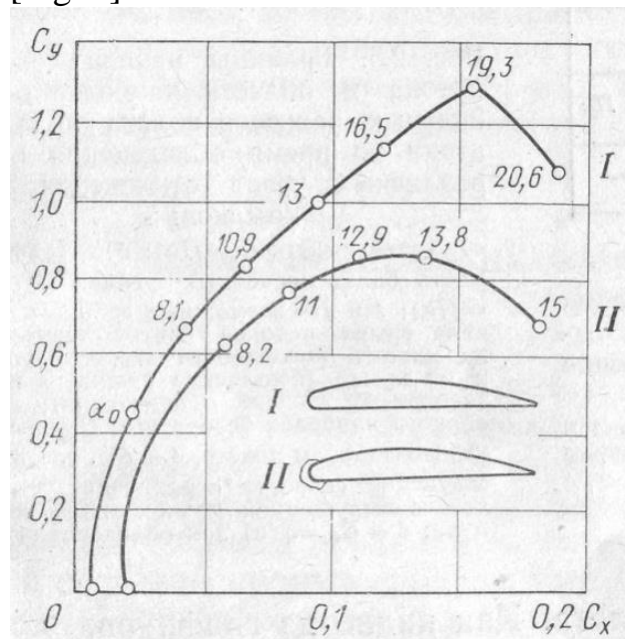


Fig. 1. Influence of icing: I – clean wing; II – icing wing

Ice formations at stabilizer can lead to stall at little wing angle of attack [Fig. 2]. So designing of effective deicing systems of wing and stabilizer is actual problem.

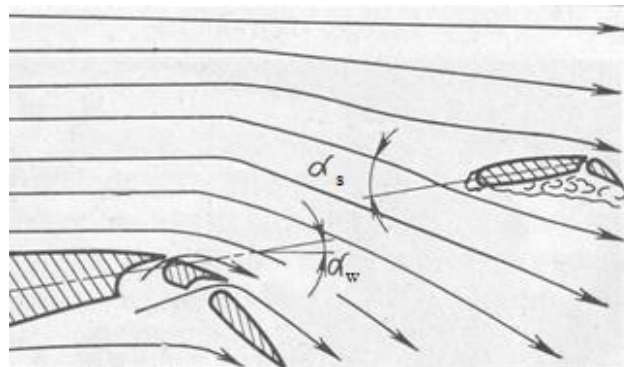


Fig. 2. Stall at stabilizer

Analysis of last achievements and publications

The problem of flights in icing conditions appears in the late 1920s, when it was a matter of flying 24 hours a day all weather conditions. An active study of aircraft flights in icing conditions began in the 30s of the twentieth century. Despite the fact that almost everything is known about flights in icing conditions, icing remains a dangerous factor that occasionally leads to accidents. Investigations of flights in icing conditions include investigations of icing conditions [1, 5, 6, 7, 8, 9], effects of ice accretions on aircraft aerodynamics

[3, 5 - 20], airworthiness requirements, accident investigation [7, 8], recommendations for de-icing [2, 3, 4, 5, 9, 18].

Formulation of purpose

Icing can occur at different parts of aircraft: wing, tail, propeller, racks, cables, navigation aids. However, the most dangerous is icing on wing and horizontal stabilizer. Depending on the type, characteristics and purpose of aircraft, the best method and anti-icing system is selected. Currently, the following anti-icing systems are available: pneumatic, electrical thermal, electro-pulse, liquid, and air-thermal. Each system has advantages and disadvantages. Choice of anti-icing system type is a complex engineering task that requires many factors to be considered. All anti-icing systems are divided into systems of continuous and cyclic action. Anti-icing systems of continuous action prevent the ice formation during flight. Cyclic de-icing systems allow the ice formation to a certain thickness, and then remove the ice (economy mode).

Pneumatic de-icing systems have relatively low mass and energy intensity. The principle of operation of the pneumatic de-icing system is shown in Fig. 3. Pneumatic de-icing boots of flexible material with pneumatic tubes is fixed on the protected surface. Air under pressure is supplied inside boots in a certain order. When the air is supplied, the boots inflate, tear and split the ice, which is carried away by the incoming stream from the protected surface [Fig. 4].

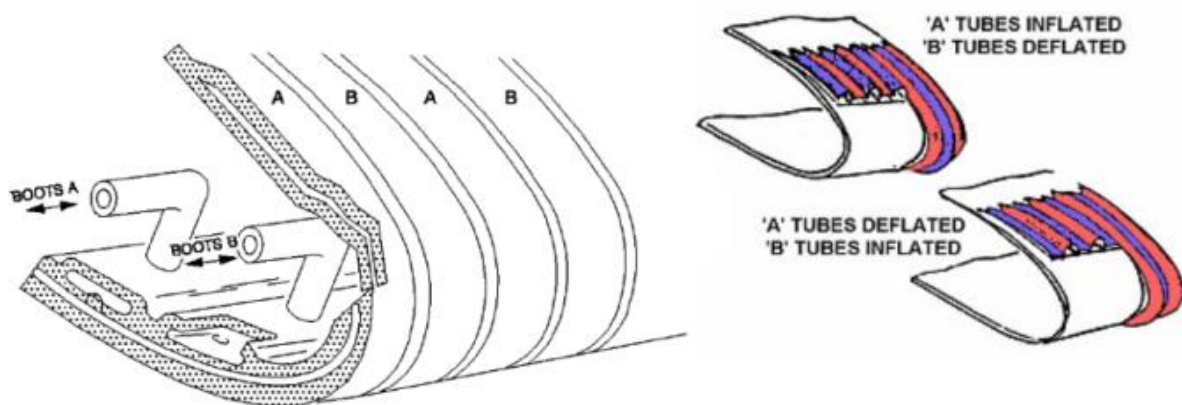


Fig. 3. Inflation of boots



Fig. 4. Action of pneumatic de-icing system

Presentation of basic material

Calculation of airframe pneumatic de-icing system includes stages: determination of protection zones, calculation of boot pressurizing system, and calculation of boot depression system. Pneumatic de-icing system of the regional aircraft An-140 was considered and calculated [Fig. 5].

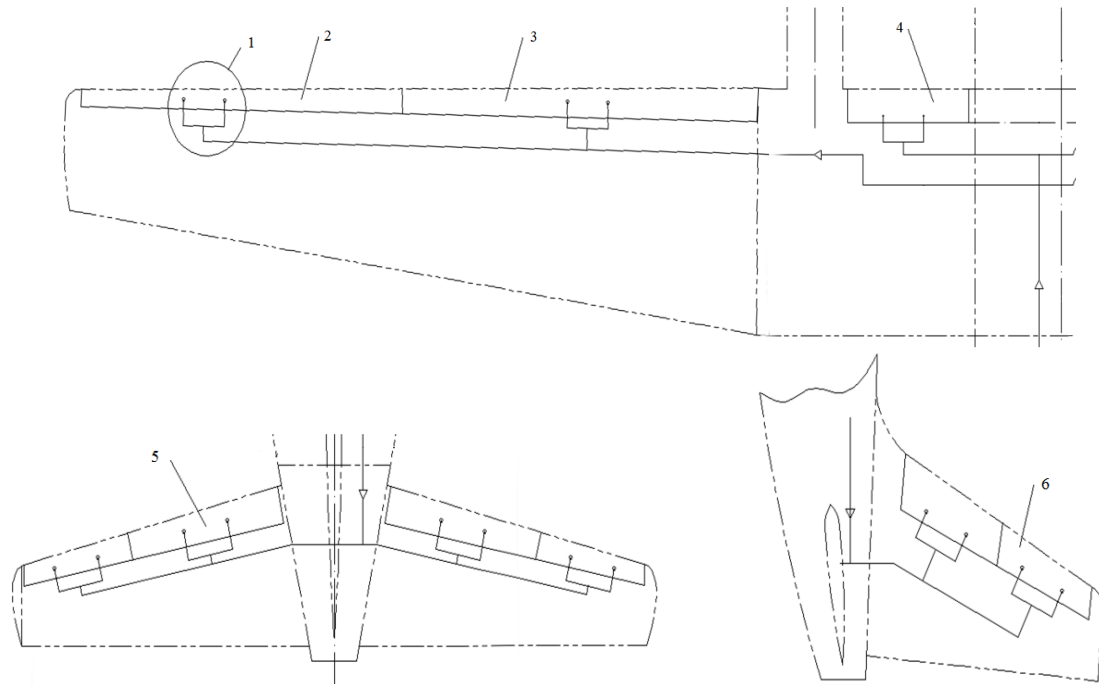


Fig. 5. Schematic diagram of pneumatic de-icing system:

1 – connection for supplying air to the boot; 2, 3 – boot of the wing leading edge; 4 – boot of the centre wing section; 5 – stabilizer boot; 6 – fin boot

Determination of protection zones

According to airworthiness requirements, such values of parameters were taken: liquid water content = $0,7 \text{ g/m}^3$; drop diameter = 20 mm; altitude = 3000 m; temperature of outside air = -5°C ; airspeed = 520 km/h; coefficient of lift = 0,8. Capture on the wing will be on the upper surface 170 mm and on the lower surface 120 mm. The protection zone is accepted: on the upper surface 112 mm; on the lower surface 129 mm. The area occupied by boot is assumed: on the upper surface 150 mm; on the lower surface 170 mm. Such values are taken for fin and stabilizer.

Airframe protection along the wingspan: center wing 2640 mm; wing leading edge of the 1st section 4260 mm; wing leading edge wing of the 2-nd section 4258 mm; total 22316 mm. Protection of tail: stabilizer (2) 4080 mm; fin 3900 mm.

Calculation of boot pressurizing system

The inflation area is determined as the segment area:

$$S_i = \frac{1}{2} [L_s R_s - a(R_s - H_s)] = \frac{1}{2} [2,98 \cdot 2 - 2(2 - 0,7)] = 1,47 \text{ cm}^2$$

$$L_s = \sqrt{a^2 + 16/3 \cdot H_s^2} = \sqrt{2,5^2 \cdot 16/3 \cdot 0,7^2} = 2,98 \text{ cm}^2,$$

where L_s is the length of the segment arc; R_s is the segment radius; H_s is the segment height; a is the segment chord.

An air volume for inflation is calculated by the formula

$$V_B = (L_C / A_{\Pi}) \cdot S_i \cdot L_z,$$

where L_C is the section length; L_z is the length of protection zone; A_{Π} is boot step, 30 mm.

The initial data for the volume calculations and the results of the calculations are shown in Table 1.

Table 1.

No	Name	Section length $L_s, \text{ cm}$	Protection zone $L_z, \text{ cm}$	Number of steps n	Air volume $V_B, \text{ l}$	Boot length L_b	Boot area $S_b, \text{ m}^2 \cdot 10^{-2}$
1	End Section	425,8	23	141	4,9	33	1,405
2	Center wing	264,0	23	88	3,1	33	0,871
3	Stabilizer	488,0	21	136	4,7	31	1,510
4	Fin	390,0	19	130	4,5	29	1,130
5	Root section	426,0	23	142	5,0	33	1,406

In order to avoid deterioration in aircraft aerodynamic performance an air distribution by consumers was organized as follows: end section and root sections of the wing leading edge $V_1 = (4,9 + 5) \cdot 2 = 19,8$ litres; center wing $V_2 = 3,1 \cdot 2 = 6,2$ litres; stabilizer and fin $V_3 = 4,5 + 4,7 \cdot 2 = 13,9$ litres; supplying pipelines $V_4 = 0,00314 \cdot 863 = 2,7$ litres. Total air volume is

$$V_1 = V_1 + V_2 + V_3 + V_4 = 19,8 + 6,2 + 13,9 + 2,7 = 43 \text{ litres.}$$

The air density in the boot

$$\Gamma = P/RT = 2,4 \cdot 1000/29,2 \cdot 310 = 2,75 \text{ kg}^3/\text{m} = 0,00275 \text{ kg/litre,}$$

where $P = 2,4 \text{ kg/cm}$ is pressure in the boots; $R = 29,27$ is gas constant; $T = 300^\circ K = 23^\circ C$ is air temperature.

The mass of the required air for 1 cycle is:
 $M_1 = 19,8 \text{ liters} \cdot 0,00275 \text{ kg/liters} = 0,05445 \text{ kg};$

$$M_2 = 6,2 \text{ liters} \cdot 0,00275 \text{ kg/liters} = 0,01705 \text{ kg};$$

$$M_3 = 13,9 \text{ liters} \cdot 0,00275 \text{ kg/liters} = 0,03822 \text{ kg};$$

$$M_4 = 2,7 \text{ liters} \cdot 0,00275 \text{ kg/liters} = 0,0074 \text{ kg}; \text{ total is } 0,1171 \text{ kg}.$$

Consumption of air during the cycle (5 sec of inflate and 55 sec of pumping) is $G = 0,1171 \text{ kg}/5\text{s} = 0,023 \text{ kg/s}$.

Selected vacuum pump 5866 has good performance, low mass, low power consumption and is appropriate for this system.

Calculation of boot depression system

For satisfactory operation of the pneumatic de-icing system, it is necessary to provide appropriate air pressure in the pipelines. For this purpose hydraulic calculation is performed.

The pressure loss in the lateral channels is calculated by the formula
$$\Delta p_k = \left(\zeta_{in} + c_f \cdot \frac{l}{d_g} \right) \cdot \frac{\rho V_k^2}{2} \cdot N/m^2$$
, ζ_{in} is input loss factor; c_f – is coefficient of friction.

Pressure drop in the longitudinal air channel along the leading edge is
$$\Delta p_k = c_f \cdot \frac{\rho V_k^2}{2} \cdot \frac{l}{d_g} \cdot N/m^2$$
. If the lateral channels are in the form of double skin, then the value of the friction coefficient is $c_f = 0,184/R_c^{0.2}$.

The pressure loss on straight sections of pipelines that supply air to the protected surface is calculated by the formula
$$\Delta p_k = \sum_{i=1}^n \cdot (\zeta_i + f_i \cdot l/d_p) \cdot \rho V_i^2 / 2$$
.

Assume that at the beginning of the pipeline the velocity is greater than at the end before the last hole, that is $V_{beg} > V_{end}$. For constant static pressure along the entire length of the line, it is necessary to maintain
$$\rho V_{beg}^2 / 2 - \rho V_{end}^2 / 2 = \sum (\Delta p_p + \Delta p_l)$$
, where Δp_p is the total loss of friction pressure along the length of the distribution pipe, Δp_l is pressure loss in local resistances of all pipeline holes. For simplicity of calculation, it was assumed that the pipeline diameters so that the air velocity after each hole decreases with the same value
$$\Delta V = \frac{V_{beg} - V_{end}}{n}$$
, where n is the number of pipeline holes. The pressure loss between the adjacent holes due to the velocity change during flow division will be equal
$$\Delta p = 1/3 \cdot (V_{beg} - V_{end} / n)^2 \cdot \rho / 2 = 1/3 \cdot \rho \cdot (\Delta V)^2 / 2$$
. Since there are n holes along the pipeline, the total pressure loss on the local resistances will be
$$\sum \Delta p_l = 1/3n \cdot (V_{beg} - V_{end})^2 \cdot \rho / 2$$
. As a result of the calculation, it was

obtained the distribution of pressures and flow rates at the time of full pneumatic inflation.

Based on the schematic diagram and the results of hydraulic calculation, the mass of the pneumatic de-icing system was calculated. The mass of pipelines is $S = \pi(D^2 - d^2)/4 \cdot L \cdot \rho = 11,6$ kg, where $L = 73$ m is the total pipeline length; $D = 20$ mm is the outer pipeline diameter; $d = 18$ mm is the inner pipeline diameter; $\rho = 2700$ kg/m³ is the aluminum density. The mass of the pipeline was multiplied by 1,2 in order to take into account mass of attaching parts. The total mass of the pipe installation is 13,9 kg. The total boot length is 34,3 m. The specific mass of one boot meter is 1,5 kg/m. Therefore, the total boot mass is 51,5 kg. The mass of each unit of the pneumatic de-icing system is shown in table 2.

Table 2.

No.	two-position valve	throttle valve	reverse valve	safety valve	Vacuum pump
Number of units	3	1	5	1	1
Total mass, kg	1,2	1,2	1,2	0,5	2,5

The mass of the control system should not exceed 2,5 kg.

The total mass of the pneumatic de-icing system is 80.0 kg. The mass of the de-icing system on the AN-140 is 110.0 kg.

Conclusion

Cyclic pneumatic de-icing system has significant advantages for regional aircrafts. It is safe, reliable and easy to operate. The analysis and the conducted calculations indicate its effectiveness and low mass.

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