EXPERIMENTAL AND THEORETICAL INVESTIGATIONS OF AIRCRAFT ICING IN THE CASE OF CRYSTAL AND MIXED-PHASE FLOWS

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Theoretical investigations of icing physics in TsAGI include the next main branches:

a) physical thermomechanics of the supercooled liquid droplets in the vicinity of the streamlined aircraft part, evolution of droplets, rivulets and the liquid film on its surface, water solidification with arising of the different ice shapes;

b) investigations of the thermal stresses evolution in the ice, caused by the crystallization latent heat and the active power supply;

c) estimation of the droplets and aircraft charges influence upon the icing process.

Experimental studies of the ice formation on the surface of various materials on the prototype of the modern installation of artificial icing conditions were started in the Flight Research Institute named after M.M. Gromov more than fifty years ago. The classical monograph “Icing systems of flight vehicles. Fundamentals of design and experimental methods” was published based on their results. The modern installation for the investigations of the aviation materials and aircraft parts icing was created in TSAGI on the basis of the FRI prototype installation and the exiting ejector facility EU - 1.

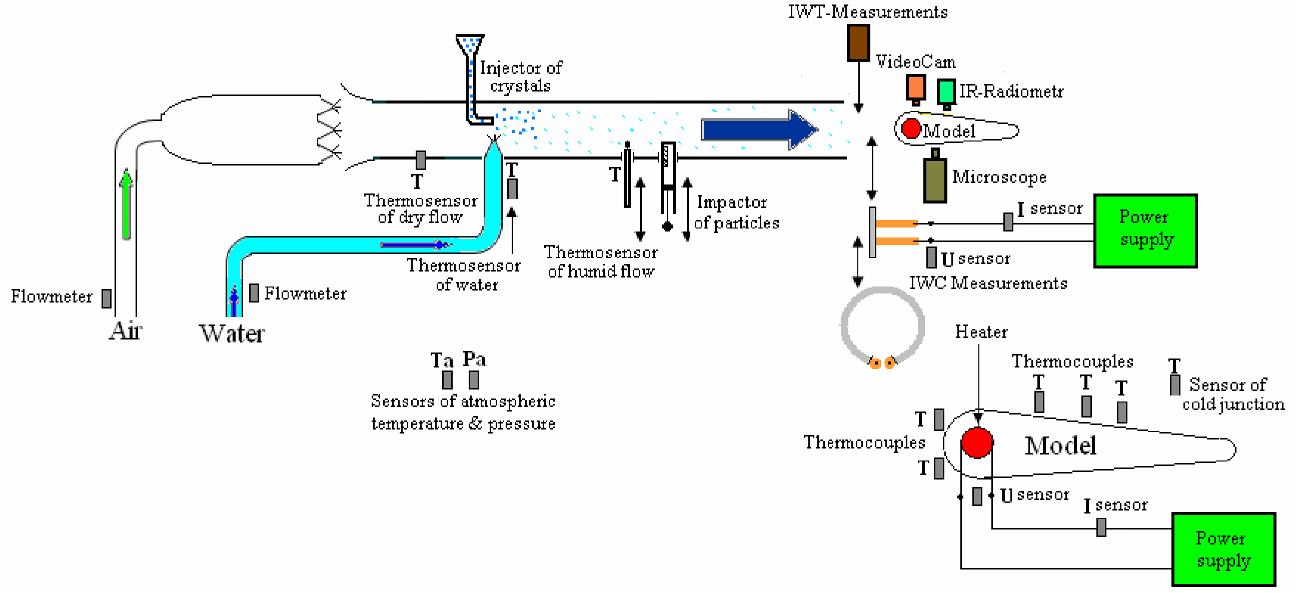

Fig. 1. Scheme of the ground facility

The facility (Fig. 1) consists of the aerodynamic channel with multiple-nozzle ejector, water spraying system with swirl injectors, system of the supplying and regulation of the ejecting air pressure. The type of facility is climatic wind tunnel, so the investigations can be carried out only at the negative temperatures of the ambient air. Besides the system of liquid nitrogen droplets injecting was created for the air cooling in the aerodynamic channel. This system allows to perform experiments at the small positive (less than 10 ^{0} C) temperatures of the ambient air.

The installation is equipped with a modern data gathering and processing system, measuring devices, including thermovision and contact devices for determining the temperature of the streamlined bodies and of their ice cover, has an optical and impact systems of measuring the drop sizes as well as the unique electrical liquid water content meter and adhesiometer developed by our scientific team. Now we are working on the facility equipment by the IWC measurement device of the original construction and the system consisting of the long-focus microscope and the high speed video camera for the investigations of the single droplets and crystals interaction with the surface.

The facility allows to carry out both physical multi-factor experiments (including the investigations of the influence of the geometric parameters and streamlined body surface structure, blow-off of water and suction of the water film, electric fields and ultrasonic radiation on the icing process, interaction of a single drop with the surface by the methods of microscopy and macro-photography and others) and the investigations of real aviation sensors (Pitot probes, sensors of the angles of attack, icing indicators) quickly and efficiently.

Fulfilled also in 2009 – 2010 were a number of contract works on:

the investigation on the installation of the aviation sensors of various types under the icing conditions, recalculation of the obtained results for the flight conditions, elaboration of engineering recommendations for the improvement of the heating systems of sensors for compliance to the norms setting the standard icing conditions;

experimental investigations of the runback ice formation on the models of aircraft parts and on the surfaces of the materials with different coatings. The last work is performed in the frames of the Clean Sky Program, IceTrack Project in the collaboration with the Fraunhofer Institute (IFAM), Germany.

The main parameters measured during the experiment on the icing facility are following: characteristics of the two-phase flow (velocity, temperature, droplet sizes), model characteristics (surface temperature field, power of the leading edge heating), ice surface adhesion force, electric charge (Fig. 2)

One can estimate the electric charge of droplet airfoil by the expression

$$q_{\mathrm{d}} = \left(\frac{m_{\mathrm{d}} v_n^2}{2} \varepsilon_0 \right)^{1/2} \left(\frac{|\Delta\Phi|}{4\sigma} \right)^{1/4} \mathrm{sign}\Delta\Phi \cdot \psi ,$$

Φ – electron affinity to the surface substance, ψ – matching parameter, m_{d} – droplet mass, v_n – droplet normal velocity, ε_0 – electrical constant, σ – water surface tension coefficient. In accordance to experiments (Fig. 2),

$$(\Phi_{\mathrm{H_2O}} - \Phi_{\mathrm{D16}})/(\Phi_{\mathrm{H_2O}} - \Phi_n) \sim 25.$$

Indices: H_2O – water, D16 – aluminum alloy, *n* – nanomodified surface.

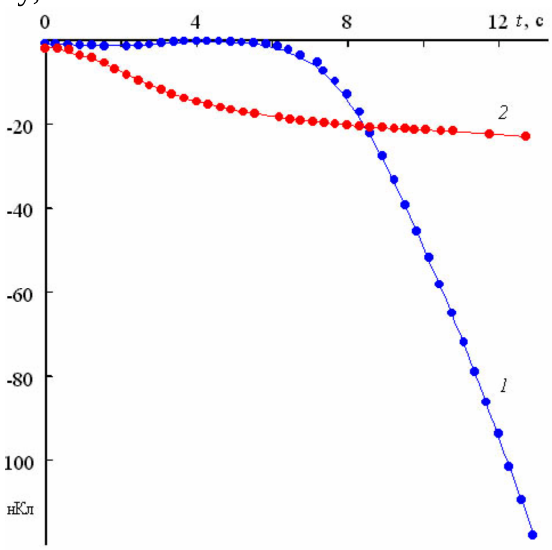

Fig. 2. Time evolution of airfoil electric charge: *1* – aluminum alloy D16, *2* – nanomodified surface

Our scientific team is now elaborating ice generator system for investigation of icing in the ice crystal clouds and mixed phase conditions. Two main methods were taken into consideration. In the first one, the ice generator will consist of the chamber with walls, cooled by the liquid nitrogen, and a collector of vortex or ultrasonic injectors. In the second method the crystals will be generated in the special grinder device.

The results of the investigations, carried out by the scientific group of TsAGI, in the area of icing are published in Russian and Foreign reviewed scientific periodicals (more than ten papers for the last three years), reported in some conferences and forums of Russian and international levels.

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