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Investigation of the Stream-Traced Intake Starting within the HEXAFLY-INT Project

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Abstract

Investigation of starting process of the stream-traced intake is presented. It's shown that starting of the intake could significantly correlate with boundary layer state at the compression surface. Results of the experimental investigation of the internal characteristics with different boundary layer tripping devices and vortex generators (and without them) are presented.

Keywords: *stream-traced intake, boundary layer, tripping device, vortex generator, experimental investigation.*

Nomenclature

Latin
M – Mach number
Re – Reynolds number
f – air mass flow rate
Greek
α – angle of attack

At the present time, various concepts of high-speed passenger aircraft are being developed and studied. Such vehicles should be able to fly between diametrically opposite points of the Earth for several hours. One of these concepts is the concept of a passenger aircraft called HEXAFLY-INT. This concept was developed by European scientists in the framework of LAPCAT-II and a related sub-scaled flight test vehicle in HEXAFLY [1]. TsAGI together with other Russian partners (CIAM, LII and MIPT), in close cooperation with European and Australian scientists, participates in the research of this concept within the HEXAFLY-INT project.

In the project, two layouts are considered: a glider for flight testing (examined by participants from the Russian Federation, the EU and Australia) and a powered concept (investigated within the framework of this project only in the Russian Federation for high-speed and in Australia for low-speed). The propelled concept is shown in Figure 1. After conducting successful flight tests of the glider, it is planned to start preparing for a flight experiment with a propelled concept, therefore, advanced research of its elements is conducted at TsAGI to ensure a stable and long cruising flight of the vehicle.

The key element of the investigated propulsion system, which ensures its stable and efficient operation, is a convergent air intake device located on the upper surface of the fuselage [2]. For carrying out experimental studies in TsAGI, a multifunctional aerodynamic model, which geometry is connected with HEXAFLY-INT vehicle, has been designed and manufactured that allows testing both

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to determine the internal characteristics of the air intake device and the aerodynamic characteristics of the layout (Figure 2).

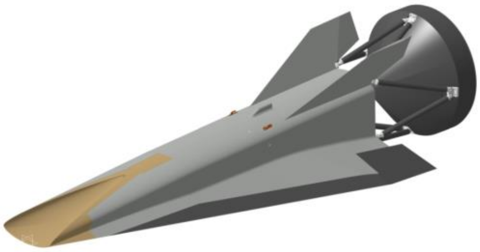
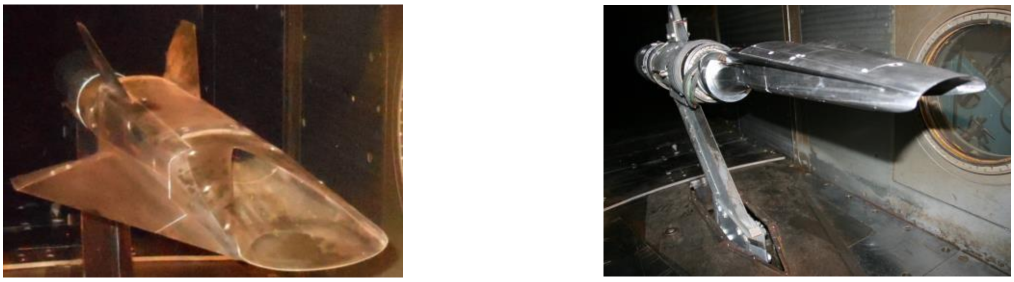


Fig. 1a. Propelled concept HEXAFLY-INT under investigation

Fig. 1b. Propelled concept HEXAFLY-INT at MAKS 2017 exhibition



Assembly for aerodynamics tests

Assembly for intake tests of the propelled concept

Fig. 2. Aerodynamic model

Tests of this model were carried out in a T-116 TsAGI wind tunnel (WT) with a test section having a square cross-section with dimensions of 2.35 m × 1 m × 1 m, allowing studying the aerodynamic characteristics of aircraft models and their components at supersonic and hypersonic speeds. The range in Mach numbers in the working chamber of the wind tunnel varies from M = 1.8 to M = 10 and unit Reynolds numbers from $Re=2.5{\cdot}10^6$ to $Re=42{\cdot}10^6$. T-116 is a blow down ejector type facility with an adjustable supersonic diffuser and a three-stage ejector.

The first experimental studies of the model with a "smooth" surface of the air intake braking in the WT T-116 TsAGI gave completely different results than the previously performed computational studies showing the presence of a stable start of the intake in the range of Mach numbers M = 7-8 and angles of attack α = -4° ÷ 8°. In an experiment conducted at angles of attack α = -4° ÷ 10°, the airflow factor f> 1, which clearly indicates the starting of the intake, was obtained only at M = 8, α = -4° ÷ -1°. While at M = 6-7, α = -4° ÷ 10° and at M = 8, α = 0 ÷ 10°, the flow coefficient was less than 0.6, which indicated that the air intake was unstarted. The similar result was achieved in most conducted runs.

Fig. 3 Intake model testing in WT T-116 TsAGI

Such a critical difference between these calculations and the experiments indicated that the numerical flow simulation in the region of the air intake assuming fully turbulent flow is incorrect. Presumably, the boundary layer flow on the investigated regimes is rather laminar (or transitional) and, consequently, less stable.

The main determining factor of the flow physic at the entrance region of this intake is the relative position of the laminar-turbulent boundary layer transition onset on the compression surface and separation point of the boundary layer. If the beginning of the laminar-turbulent transition is located upstream, the turbulent boundary layer is more stable on the compression area in comparison with a developing laminar boundary layer resulting into a separation weakening (closed bubble) or eventually a complete disappearance. Geometry of the compression surface, presence of the tripping devices and heating of the intake model could influence on the BL transition.

During this investigation, it was suggested to consider possibility of using additional element on the compression surface such as tripping devices or vortex generators. Thus, it was possible not to change geometry of the intake.

To date, some experience has been accumulated on the turbulence of the boundary layer in high-speed air intakes (for example, for the Hyper-X configuration) and some principles for the development of passive tripping devices are formulated:

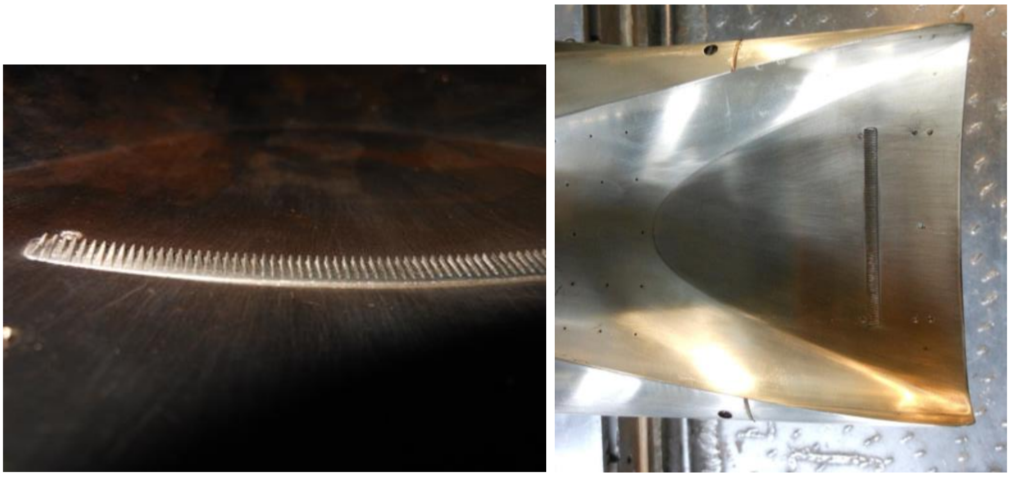
- it is necessary to create a series of pairs of vortices that rotate in opposite directions and propagate downstream from a number of drop irregularities acting as tripping devices (vortex generators);

- take into account the effects associated with the distances between neighboring tripping devices;

- height of the tripping devices should be enough in order guarantee transition close to the roughness element;

- when testing tripping devices in wind tunnels, one must take into account the effect of aerodynamic noise in the oncoming stream; for this, experiments must be performed in several facilities.

Numerical and theoretical studies were carried out to select the shape of the boundary layer tripping devices, during which the ramp-type tripping devices was designed with a height less than the thickness of the boundary layer at the site of installation (Fig. 4).



a) b)

Fig. 4. 'Ramp' type tripping device

The effective height of ramp-type elements h_{eff} was calculated using the Van Drist and Blumer correlations [3]

$$Re_{\delta^*} = 1025\left[1 + 0.9\left(\frac{T_w}{T_e} - 1\right) + 0.28\left(\frac{T_{ad}}{T_e} - 1\right)\right]\left(h_{eff}/\delta^*\right)^{-2},$$

where $Re_{\delta^*} = U_e\delta^*/\nu_e$ is the Reynolds number calculated from the boundary layer parameters and δ^* the displacement thickness for the unperturbed flow at the location of the unevenness, T_w - the wall temperature, T_{ad} - the temperature of the heat-insulated wall; the subscript "e" indicates values at the outer boundary of the boundary layer.

The profiles and thicknesses of the laminar (unperturbed) boundary layer were calculated by a self-similar solution for a perfect gas with an adiabatic exponent γ = 1.4 and Prandtl number Pr = 0.72. The dependence of the viscosity coefficient on temperature was calculated from the Sutherland formula.

When carrying out experimental studies for all variants of ramp-type tripping devices, the width of the tooth base was 1 mm and the width of the apex of the tooth was 0.25 mm. The geometric parameters of the tripping devices are shown in Table 1.

Table 1 – Ramp-type tripping devices parameters

Tripping device	Tooth apex h, mm	Tooth length l, mm	Installation
Ramp № 1	0.5	3	direct
Ramp № 2	0.7	4	direct
Ramp № 3	0.9	5	direct
Ramp № 3a	0.9	5	reverse

The ramp-type tripping devices were installed parallel to the leading edge of the model at a distance of 32.5 mm. The width of the tripping device is 80 mm. The "ramp" can be set by the apexes of the prongs forward (in the flow - direct installation) and the base of the prongs - the reverse installation.

Vortex generators of the "screw" type (in the amount of 3 or 10 units) that were distributed along the width of the braking surface of the intake and whose height was larger than the local thickness of the boundary layer were also investigated (Figures 3-4).

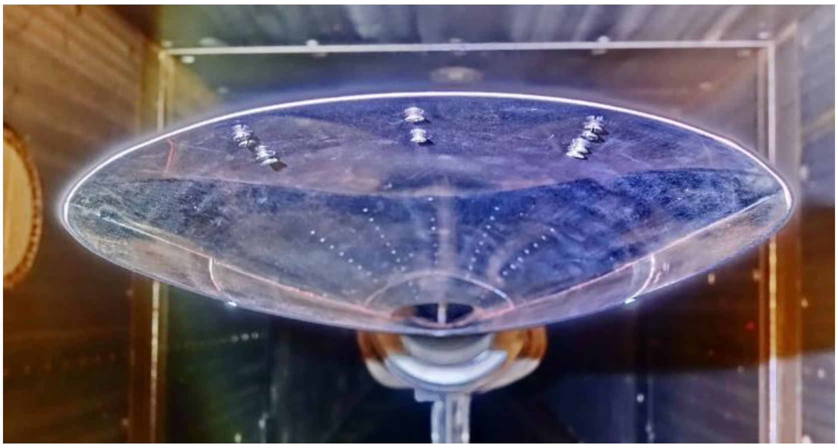


Fig. 5. 'Screw' type vortex generator

Screw-type tripping devices are screws M2 with a countersunk head, which protrudes above the surface of the model by 1.2 mm. Screws has installed in various combinations: 2 pcs. in the plane of symmetry and / or 4 pcs. left and right at a distance of 75 mm from the plane of symmetry. The tests were carried out with 10 screws and 3 screws. In the case with 3 screws, the vortex generators were installed in the following way: on the left, on the right and in the center at a distance of ~ 33.6 -39.2 mm from the leading edge of the model.

The performed experimental studies of the model with '10 screws' type vortex generators at Mach = 7 showed the possibility of starting a streamline-traced air intake and revealed a hysteresis with respect to the angle of attack α. The hysteresis of the air mass flow rate of the intake is manifested as follows (Figure 6).

At the beginning of the test, with an angle of attack α = 0 the intake doesn't start, but when the angle of attack of the model changes to a negative value α = -6° or to a positive α = 3°, the intake does start. After that, the intake start is preserved when the model is returned back to α = 0 and to any other value of the angle of attack in the range from -6° to 4°. When the angle of attack is increased by more than 4 °, the flow pattern in the air intake breaks and it returns to the unstarted state. Similar consumption characteristics of the intake with '10 screws' type vortex generators, with a similar hysteresis, were also obtained at a M = 6 flow.

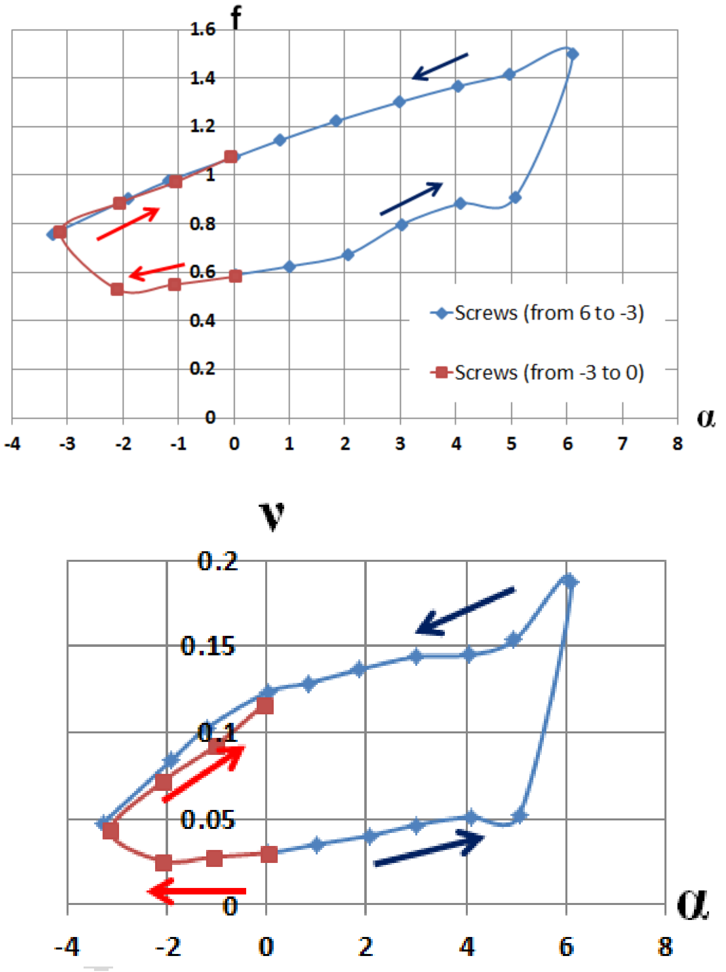


Fig. 6. Air mass flow rate and total pressure recovery coefficients hysteresis with '10 screws' type vortex generators at Much number M=7

Tests of the model with variants of TD - both of the 'ramp' type and '3 screws' type - with the Mach number M = 7 showed no starting of the intake and no hysteresis of the air mass flow rate in the range of angles of attack α = -6° ÷ 8° . The obtained air mass flow rate coefficient of the intake at angles of attack α = -6° ÷ 4° is lower (Δf ≈ 0.3 - 0.5) than for the started intake with '10 screws' type vortex generators.

If one reduces the number of screws from 10 to 3 and install them at a distance of ~ 35 mm from the leading edge, the air intake works in the same way as with the 'ramp' type TD in the unstarted mode. Further studies have shown that the arrangement of the vortex generators in the symmetry plane (type '2 screws') or only on the right and left (type '8 screws') also did not allow intake starting. The 'ramp' type TD located along almost the entire width of the intake and '3 screws' vortex generators didn't provide starting either.

According to these test results, the greatest efficiency in the conducted studies was shown by '10 screws' type vortex generators.

Acknowledgments

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