INVESTIGATION OF NEAR-SURFACE ELECTRICAL DISCHARGE ON PERFORMANCES OF MODEL INLET

M. Goldfeld
Khristianovich Institute of Theoretical and Applied Mechanics SB RAS, Novosibirsk, 630090, Russia
F. Falempin
MBDA-France, 92358 Le Plessis-Robinson Cedex, France
S. Leonov
Joint Institute for High Temperature RAS, Moscow, 125412, Russia

The attempts at finding modern methods for improvement of the streamlining and aerodynamic characteristics of supersonic and hypersonic vehicles have stimulated significant researches on the application of energy deposition by means of plasma, laser- and microwave radiation, and so forth, for the flow control. The active flow control at hypersonic speeds can be divided conditionally into two groups: the control of an external flow for the purpose of decrease of the drag reduction, the thermal protection or change of aircraft position in space and the flow control in channels for enhancement of the air inlet efficiency, improvement of ignition and combustion stabilization. The present work refers to second group and is devoted to the investigation of the flow control in a supersonic inlet.

To avoid performance penalties at off-design Mach numbers, a variable geometry inlet or change of the shock position relative to cowl can be used. However, the mechanical control of geometry would be quite heavy and unreliable. Plasmas and magneto-hydrodynamic devices may offer feasible flow control. One of the possible candidates for the inlet flow control technology is near-surface electrical discharge (NSED).

The performed researches in the attached channel have shown that NSED allows fulfilling the control of flow, change of the flow structure and the position of the shock waves concerning their initial state. At the same time, applicability domain of NSED at real full-size devices still requires the further studying and experimental verification.

In this connection the main purposes of the present work have consisted in the following: a) estimation of effect of near-surface electrical discharge on flow structure, pressure distribution on external compression surfaces and in the inlet channel; b) investigation of influence of change of mass flow rate, pressure recovery coefficient and flow homogeneity; c) performance check of the high-voltage power supply at the tests conditions of a wind tunnel; d) stability check of the discharge at the tests in a wind tunnel

Model inlet and facility. The model of the inlet (Fig. 1) with design Mach number 2 was installed for tests in the blow down wind tunnel on bottom strut thus that it was possible to visualize flow in the area of the discharge (the first shock wave) and in the area of the inlet channel entrance (cowl leading edge). The mass flow ratio of air through the model inlet was determined by means of measurements of static pressure in the throat measuring nozzles of flowmeter and total pressure at the exit from one (see Fig. 1).

Optimal 11-electrodes configuration was used to create electric discharge. The arrangement of ceramic insertions and electrodes location are shown in Fig. 1. The special developed energy source with power up to 20 kW and with voltage of a direct current (4-10) kV was used for dc supply to the discharge electrodes. Duration of the discharge could be changed from 0.2 sec up to 10 sec. For the main series of tests the power supply device has been modified for maintaining the steady work and for possibility of change of the discharge power during experiment. For this purpose the system of cooling of electrodes by means of the liquid carbonic dioxide has been developed.

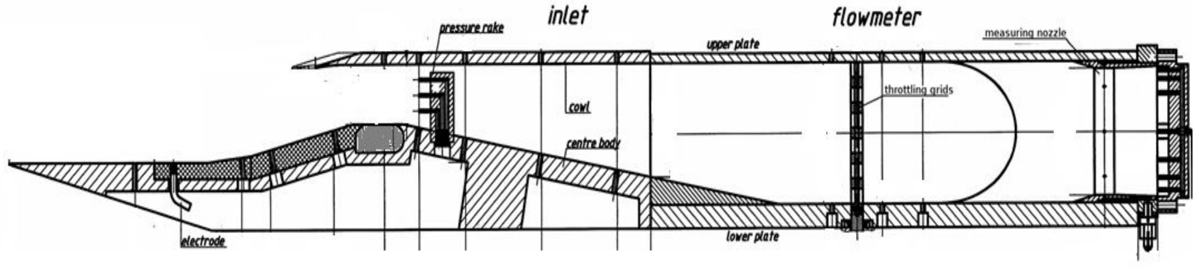


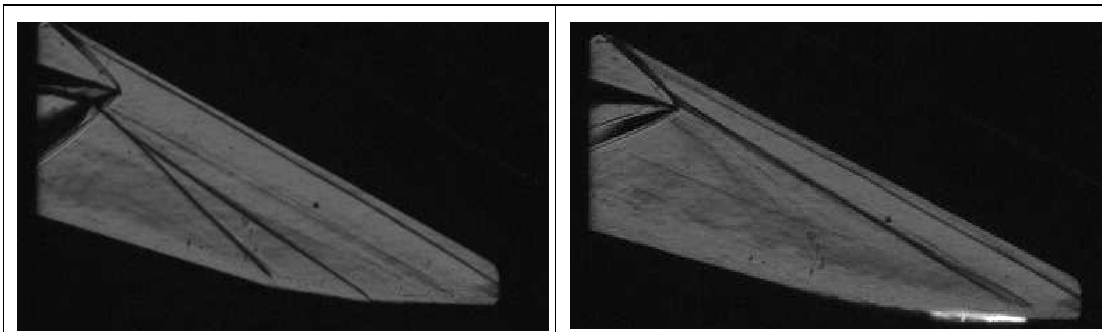
Fig.1. Scheme of inlet model

The following measurements have been carried out in each run: a) static pressure distribution in plane of symmetry of central body and the cowl; b) determination of total pressure recovery coefficient using Pitot rakes, installed in the throat; c) determination of mass flow ratio is by means of the flowmeter; d) schlieren visualization of inlet entrance; e) current and voltage measurements on electrodes system. High-speed camera with frequency of the frame up to 1кГц was used at photographing of the flow the discharge on surface

Tests were carried out in supersonic blow down wind tunnel T-313. The changeable nozzles allow getting the regimes with Mach number from 1.75 to 7. Operation section size is 600×600×2000mm. Flow parameters are realized during experiments: at Mach number M=3: T_{st}=283K, P_{st}=11.17kPa; at M=2.5: T_{st}=283K, P_{st}=15.070kPa; at M=2.0: T_{st}=287K, P_{st}=25.40kPa.

Experiment results. Main feature of inlet flow with near-surface discharge consists in the fact that increase in power of the discharge leads to change of the configuration and lengths of the surface discharge that is accompanied by increase of the thickness of the vortical layer behind discharge area. As a result, structure of shock wave can be transformed.

Flow visualization at Mach number 2.5 at the angle of attack 0º has demonstrated that the inlet was started. Under these conditions oblique shock wave interacts with boundary layer on the cowl internal surface and, as a result, the separation zone is formed (Fig. 2, a). Discharge generation is accompanied by disappearance of two shock waves and focusing of bow shock wave, initiated by the discharge, on the leading edge of cowl (Fig. 2, b). Generation of discharge with power 5-6.5kW has led to fact that the nose shock wave disposed before the channel entrance As a result, the boundary layer separation on the cowl internal surface disappears. It is necessary to notice also that the angle of slope of the shock wave from the first ramp practically coincides with an angle of the shock wave slope initiated by the discharge.



Power W=0	W=4.5kW

Fig. 2. Flow visualization at M=2.5 without and with discharge

At Mach number 3 and at angle of attack 0° more high discharge power was necessary for realization of the flow with bow shock wave before the cowl leading edge. It was obtained the increase of the separation zone on cowl and appearance of local separation in angular configuration before the ramp. At the discharge generation shock waves, as well as earlier, disappear together with the local separations on the cowl.

Pressure behind the discharge increases by approximately 14 % but already on the second ramp pressure has reduced by approximately the same value (16%). Attention attracts an appreciable local gap of pressure by approximately 60% in the middle part of cowl. Such behavior of pressure distribution is typical for all of investigated Mach numbers and angles of attack.

Influence of the discharge power on change of the inlet performances can be estimated on base of comparison of the data for the inlet with and without discharge. it was revealed that at Mach number 2.5 and low discharge power (3.0kW) the mass flow ratio remains almost invariable or occurs weak growth, which is not exceeding 1 %. The increase of discharge power up to 6kW is accompanied by decrease of mass flow up to 3 %, which does not remain monotonous and depends on change of the discharge power during experiment. The further increase of power up to 10 kW leads to further weak reduction of the mass flow ratio. Influence of the discharge power on pressure recovery coefficient was opposite. At the power increase the total pressure recovery coefficient increased by 2-4%.

The feature of the influence of the near-surface discharge at Mach number 3 consists in the increase of the mass flow ratio at the generation discharge. Measurements confirmed this result and showed that mass flow ratio weakly depends on increase of the discharge power, at least, at Mach number 3 and angle of attack up to 5°. The total pressure recovery coefficient at Mach number 3 practically remains constant at the increase in the discharge power more than in 2 times. The gap of total pressure recovery coefficient is situated at the end of the discharge operating time and this is connected with uncontrollable rise of the current (power) at this time interval.

Numerical simulation. Calculation of three-dimensional undisturbed flow in configuration of experimental set up was performed by using ANSYS® CFX®, SolidWorks® Flow Simulation, and FlowVision™ software. Numerical modeling of flow in experimental configuration was based on solution of 3D time-dependent Navier-Stocks equations with the utilization of the wide used two-equation SST-model of turbulence (ANSYS®, FlowVisionᴛᴍ) or two-equation k-ε model of turbulence (SolidWorks®). Model of perfect gas was used at modeling of supersonic flow. Numerical copy of described inlet model was used in CFD simulations of inlet in free flow. No-slip and adiabatic conditions were specified on walls of the inlet. Direct current electric discharge between 11 electrodes was simulated by introducing 11 volumetric heat sources. Symmetry conditions were used in central plane of the duct to decrease the calculation domain which contained about 2×10^6 mesh points. Comparison of simulation with the experimental data for M=2.5 and 3 was shown that results obtained by CFD calculation are in good agreement with experimental data. Plasma filaments in the inlet model produce the same effect on the flow as it was in the attached pipe configuration.

Conclusion. As a result of the performed tests of it was revealed the followings.

1. The surface discharge allows to control the position of shock waves on the external compression surfaces. Two-shock structure has been transformed into one-shock configuration with initial shock wave before the discharge.
2. Influence of the surface discharge leads to decrease of the mass flow ratio of air.
3. The total pressure recovery coefficient increases by 2-4 % owing to reduction of losses in the shock waves at their replacement by isentropic compression.
4. The near-surface discharge at any power does not lead to essential change of pressure distribution in the channel of the model inlet.
5. At the discharge generation, bow shock wave has been moving upstream equidistantly to shock wave from first ramp. Value of the displacement depended on Mach number and discharge power.