SUPERSONIC FLOW STRUCTURE ON COMPRESSION SURFACES OF MODEL INLET UNDER PLASMA IMPACT

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Summary This paper reports the results of experimental and computational study of compressible flow control by weakly-ionized plasma of electrical discharge. Particular objective of this activity is to demonstrate the steering effect of near-surface electrical discharge on supersonic flow structure in a model two-dimensional aerodynamic configuration with two-shock compression ramp. CFD efforts manifested extra 3D information about particular details of flow parameters' modification due to plasma thermal effect. Such a technique can be considered as a feasible method for accurate control of shocks position and angle in supersonic inlet.

INTRODUCTION

The general objective of the work is to study the gasdynamic phenomena associated with near-surface plasma – high-speed flow interaction and to demonstrate a steering effect of electrical discharge in model high-speed inlet. Two models were designed for experiments: in attached pipe configuration (1) and the model inlet for tests in supersonic free-stream (2). The models contain a special insertion with flush mounted plasma generator arranged ahead of the first rupture of two-wedge ramp. Surface plasma generation near the inlet wedge and supposed effect are shown in Fig.1. The principial idea consists in returning the air inlet at Mach number greater than estimated Mach number to design mode. At Mach number greater than estimated one the shock caused by first wedge hits into the inlet throat, but at plasma «on» the first shock is moving forward and at adjusting parameters of plasma generator can hit to the leading edge of air inlet. The angle of a new shock and the shock's hit position depend on the discharge power, geometrical configuration, and some other parameters. The first experiments [1] were made in connection pipe scheme to adjust the plasma generator and to study main peculiarities of the interaction. The second test (mostly considered in the paper) is aimed to study a model inlet in free stream and to measure as much characteristics as possible in frames of specific experimental approach. The experiments are supported by 3D NS simulations.

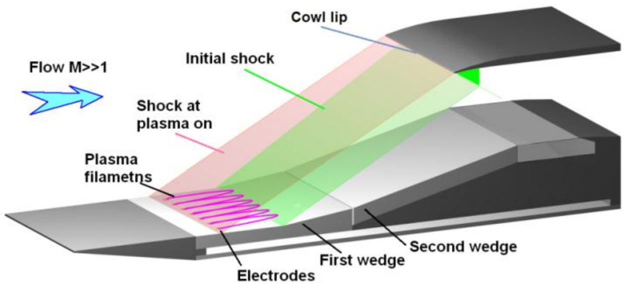


Fig.1. Draft scheme of experiment for demonstration of plasma steering effect in inlet.

TEST FACILITY DESCRIPTION

The experimental configuration is close to the geometry of a simple two-dimensional inlet of supersonic air-breathing engine. The test was performed in wind tunnel T313 of ITAM SB RAS [2]. Incoming flow streamlines the model inlet with height Y0=60mm and width Z0=72mm at following free stream flow parameters: Mach number M=2.0, 2.5 and 3.0; static pressure P_{st}=250-110mBar; angle of attack AoA=0-8degr. The model ramp consists of two consequent planar wedges $\alpha1=7°$, $\alpha2=14°$ and divergent part. The electrodes' row includes 11 cooper tabs arranged by sequence cathode-anode-…-cathode and locates in X=18mm upstream of the first wedge. All electrodes were flush-mounted and don't affect the flow themselves. The major properties of the near-surface quasi-DC electrical discharge were described in [3]. The discharge appears in the form of oscillating plasma filaments. The individual filaments are blown down due to main flow at velocity a bit less than the core value. The frequency of oscillations depends on flow speed, inter-electrodes gap, and parameters of power supply. In the most cases this value was F=10-50kHz under the experimental conditions. In this test series the total electrical power deposition was in a range W_{pl}=3-10kW.

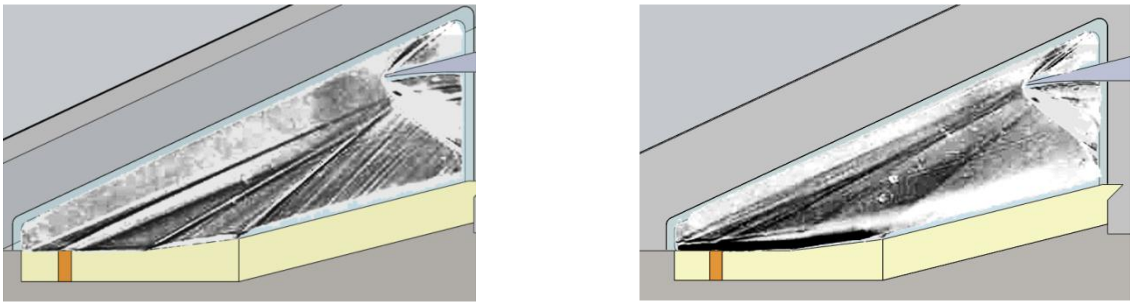
The measurements were focused on the following three issues: (1) change of the shock wave structure of supersonic flow in compression ramp model; (2) pressure redistribution in vicinity of forebody wedges and cowl depending on plasma power and the test geometry; and (3) the flow parameters modification behind the interaction area. In accordance with these objectives the electrical probing, schlieren visualization and pressure measurements were performed in each test.

EXPERIMENTAL AND COMPUTATIONAL RESULTS

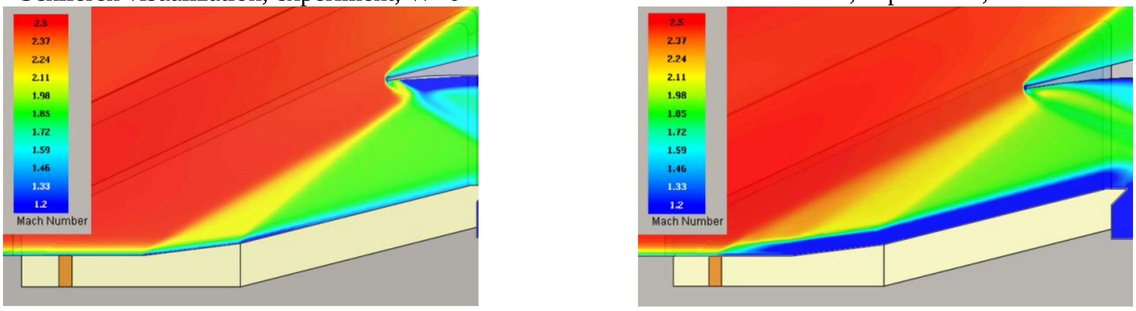
The flow pattern in the inlet entrance, acquired by visualization technique, reveals that plasma generation forestream of the compression ramp leads to significant modification of the flow structure and location of oblique shock waves in respect of external compression surfaces. It was considered the shock wave angle and position accurate regulation due to electrical discharge power in wide range of parameters. The Fig.2 demonstrates the schlieren images without plasma and at plasma “on”. In the last case the shock structure is close to design mode and excludes boundary layer separation on the cowl.

An example of pressure record is shown in Fig.3. It may be considered significant decrease of the pressure on the ramp surfaces under the plasma effect. At the same time the pressure recovery coefficient (PRC), measured in the inlet throat, has been modified weakly, not more than in a few percent.

Numerical copy of described inlet model was used in CFD simulations. 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 2×106 mesh points. The Fig.2 shows that the results of simulations are in a good agreement with the experimental data.



Schlieren visualization, experiment, W=0 | Schlieren visualization, experiment, W=3.3kW



Simulation, “plasma off” | Simulation, “plasma on”, W=3.3kW

Fig.2. Comparison of experimental data and simulation for M=2.5.

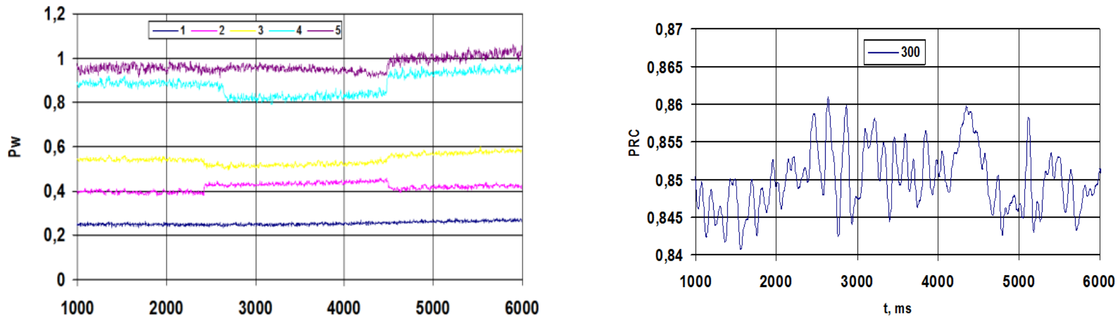


Fig.3. Pressure records(left) and pressure recovery coefficient (right). Charts: 1-upstream discharge, 2-between electrodes and the first wedge, 3-on the first wedge, 4 on the second wedge, 5 – in throat.

CONCLUSIONS

The impact of a transversal discharge on shocks structure has been studied under conditions of M=2-3 supersonic flow. The work examined several aspects of the problem, namely, the effect of discharge on supersonic flow structure and parameters; control of flow parameters in inlet’s configuration; reduction of pressure losses; etc. It was evidently shown that generation of surface localized discharges in a high-speed flow makes possible substantial change of the structure and parameters of the flowfield. For the better understanding of the problem the experimental findings were compared with the results of 3D NS numerical simulation. The long terms plans include the experimental, analytical, and computational study of plasma effect on overall performance of model inlet-combustor system.

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References

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