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FLIGHT RESEARCHES OF VISCOSITY INFLUENCE ON SHARP CONES AERODYNAMICAL CHARACTERISTICS IN HYPERSONIC LOW DENSITY FLOW

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Abstract. This paper presents free-flight test technique and the results of investigations of hypersonic viscous interaction influence on skin friction and pressure over sharp cones surface. Semivertex angles of cones are 9,6 and 15 degrees. Investigations were carried out at ranges of Mach number 5,5...9 and flight altitude 50...96 km.

The local skin friction coefficient was determined on the basis of direct measurement of the force, which acts on surface element. At the time of flight there were also made measurements of the pressure and temperature on cones surface. On the basis of flight experimental data there was carried out the validation of flow calculations method over sharp-nosed axisymmetric bodies in a hypersonic low density flow.

INTRODUCTION

The aerodynamic characteristics of flying vehicles making flight with hypersonic speed at altitudes 60...100 km depend on a great large number of the factors: compressibility, viscosity, flow rarefaction, non-equilibrium of physics-chemical processes, character of interaction of molecules of gas with surface etc. Modern ground aerodynamic installations don't provide on these regimes of full simulation of real processes occurring in a flow field about hypersonic flying vehicles.

In these conditions flight experiment gets a great value.The advantage of flight experiment is the capability of an implementation of real combination of number of major similarity criterions and the estimation of the influence of the above mentioned factors. The purpose of the pesent paper is the experimental research in the real flight conditions of a local skin friction coefficient on a surface of the sharp cones in hypersonic low density flow.

TECHNIQUE OF FLIGHT EXPERIMENT.

Experimental rocket.

The flight researches were carried out with the help of experimental ER-10D rockets.

The experimental ER-10D rocket represents a three - stage rocket, started from the ground launcher. As a booster of the first stage a solid propellant rocket engine is used. In tail part of the first stage engine three stabilizers are installed. The second stage consists of a liquid propellant rocket engine with fuel tanks. In a tail part of a second stage four stabilizers are placed.

The third stage consists of a nose conical part, a cylindrical part and a truncated cone. In volume of the third stage power sources, onboard equipment and instrumentation for radiotelmetry and trajectory measurements are placed.The general view of ER-10D rocket is shown on Fig.1.

The ER-10D rocket concerns to the unguided rockets class. To minimize disturbance effects, caused by eccentricity of an engine thrust and also for maintenance of steady flight at high altitudes, the rocket rotation around a longitudinal axis was given.

The ER-10D rocket started from the ground launcher with an initial launch angle equal to 86 degrees. At the fourth second after start the first stage engine was separated and the liquid propellant sustainer was started. Sustainer operating time was 56 sec. The flight test path was selected on the basis of requirements of trajectory and radiotelemetry measurements and requirements of a safety in zones of rocket stages falling.

The scheme of flight experiment realisation is given on Fig.2.

Methods of measurement.

The measurements were carried out on the sharp cones located in the nose of the rocket third

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stage. The design of cones consists of high-temperature strength steel and a framework. The cones sizes and scheme of its instrumentation are shown on Fig.3.

For the researches of a local skin friction coefficient the method of direct measurement of skin friction force acted on a surface element was selected. This method doesn't demand any assumptions concerning the character of the near surface flow . Feature of the apparatus intended for direct measurement of local friction force in real flight conditions at high altitudes is the measurement of very small values of force which act on the floating surface element at influence on the measuring system of large linear g-loads, angular rates, rotary accelerations and vibrations.

Specially for the present experiment SLF-4M sensor was developed by A.Ushakov. The sensor measuring scope of the force is within the limit from 1 up to 6 grammes. The overall dimension of SLF-4M sensor are 87*205*208mm. The sensor mass is about 3,5 kg.

The sensor operation is based on a principle of a load-carrying compensation of a measuring force.. On Fig-4 SLF-4M sensor kinematic and electrical scheme is submitted. The floating surface element is located on the rigid cross-shaped lever with the fixed axis of rotation. The cross-shaped lever is balanced for elimination of an influence of the linear g-loads and angular rate. For exeption of influence on the measuring system of the rotary acceleration the sensor is supplied with the ring-type fly-wheel, which is kinematically connected with the cross-shaped lever and located with it on the same axis. The skin friction force, acted on a sensor floating element is counterbalanced by force of a tension of a spring, which is regulated by the automatic device.

At disturbance of the moments equality the cross-shaped lever is deflected and the central contact switches one of the electrical engines. The rotation from the electrical engines through the gearbox is transmitted to the lead screw, connected with the spring. After counterbalance of the moments the central contact again takes a mean position between contacts, located on a sensor body. The size of a spring stretching is measured with the help of the potentiometer kinematically connected with the lead screw.

For maintenance of maximum accuracy of measurements the sensor was subjected to careful balancing on the ground installations in the full ranges of linear g-loads,ungular rates and rotary accelerations. With the purpose of exception the vibrations influence occured in the working second stage rocket engine the measurement of the skin friction force was carryed out on a passive flight regimes.

Therefore the errors of force measurements did not exceed 0,1 grammes.

For in flight measurements of the pressure on the cone surface the low pressure apparatus is used which consist of the electrical pressure sensors ESPT-3 and the transducer. V.Kushnerev is presure sensor designer.

The sensor work is based on a principle of heat transfer between the thin hot wire and air in the sensor case volume.The case of pressure sensor is made from a quarz and is supplied with the thermometer for measurement its temperature.

The range of the pressure measurement are within the limit of $5*10^{-1}...5*10^{-3}$ mm Hg. The processing of the experimental data obtained as a result of measurement of pressure on a cone surface was hold in view of changing temperature conditions,hydrodynamic lag and low density orifice effects.

In flight temperature of the cones surface was measured by means of resistance thermometers. During the experiment speed and altitude of the flight was measured with help of onboard and ground radio-technical means. The destribution of parameters of atmosphere in range of altitude of flight $H \leq$ 80 kms was received on the basis of statistical processing of long-term rocket sounding results, which was made in the region of flight experiment realization for monthly period appropriate to time of the given launch. At altitude more than 80 kms the parameters of atmosphere were determined under the standart atmosphere data in view of distribution of appropriate parameters at altitudes $H \leq 80$ kms.The angle of attack in flight was determined on the basis of pressure measurement on diametrically located points of a cone surface.

RESULTS OF RESEARCHES

Result of research of a local skin friction coefficient.

The experimental values of a local skin friction coefficient on a sharp cones where obtained in altitude bands H = 65-96 kms and Mach number M=7-9 during launching of five ER-10D rockets. On an experimental part of flight trajectory amplitude of angles of attack didn't exceed the values $\alpha =$ 3 deg. The temperature ratio varied in limits $T_w \backslash T_0 =$ 0,15-0.20, where T_w - temperature of a surface, T_o - stagnation temperature. The local skin friction coefficient was determined under the formula:

$$C_F = \frac{F}{q_\infty * S}$$

where F - the skin friction force, which acts on floating element of a surface, S - the area of a floating element, q_{oo} - dynamic pressure.

The results of experiment are submitted on Fig.5, 6 as a dependence of the ratio C_F/Θ_K^3 upon the hypersonic similarity parameter $\Theta_c^{4/5}Re_o^{1/5}$, where

$$Re_o = \frac{V_\infty \cdot \rho_\infty \cdot x}{\mu_o}$$

Reynolds number Re_o was determined on values dynamic viscosity behind a normal shock μ_O and free stream velocity V_{oo} and density ρ_{oo}. Here x - distant along generatrix from a cone nose up to centre of floating element.

The experimental data of a local skin friction coefficient are compared to the data of the author on calculation of hypersonic low density flow over sharp cones.

The technique of calculation is based on the use of equations of a laminar boundary layer in view of viscous hypersonic interaction effects and slip boundary conditions. The results of flight experiment are satisfactorily agreed with the data of calculations and confirm a prediction of the hypersonic interaction theory of a significant increasing of a skin friction coefficient over sharp cones with increasing of flight altitude.

Results of researches of the hypersonic viscous interaction influence on pressure over sharp cones surface.

The results of researches of a pressure on a sharp cone surface in hypersonic low density flow are shown on Fig.7 as the ratio P_W/P_{INV} depending on hypersonic similarity parameter $\Theta_c^{4/5}Re_o^{1/5}$. Here P_W - in flight measured pressure, P_{INV} - pressure on cone surface in inviscid flow.

The experimental values of pressure were obtained in ranges of Mach number M=5,5-8,8 and altitudes H=50-88 kms. As follows from Fig.7 experimental results are satisfactorily agreed with the data of calculations. The influence of viscous hypersonic interaction results in growth of pressure more than in 1,5 times in comparison with pressure on surface of a cone in an invisced flow.

Thus the low density flow effects render the strong influence on values of the skin friction and sharp cones surface pressure.

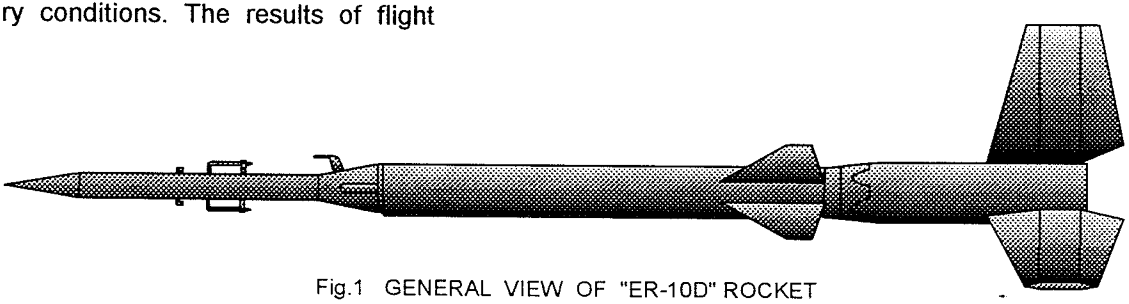

Fig.1 GENERAL VIEW OF "ER-10D" ROCKET

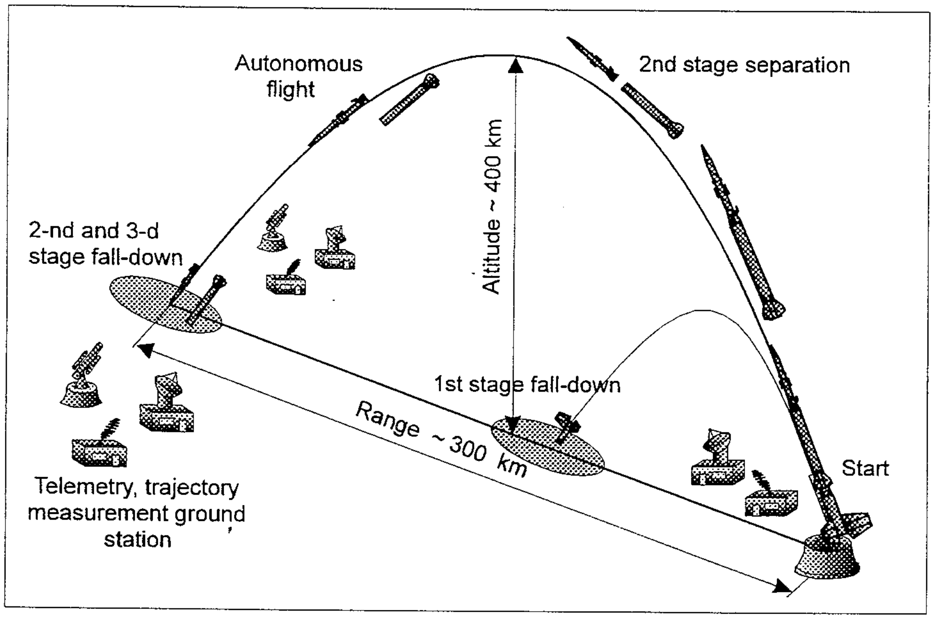

Fig 2 THE SCHEME OF FLIGHT EXPERIMENT

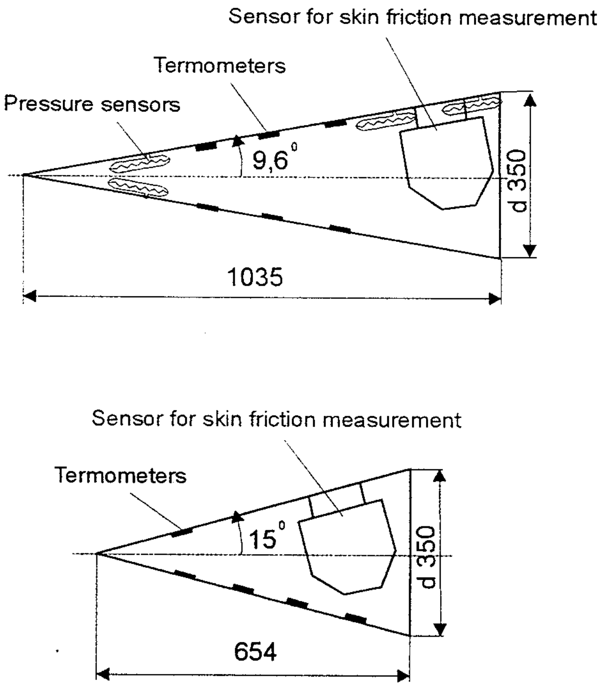

Fig.3 SHEME OF CONES INSTRUMENTATION

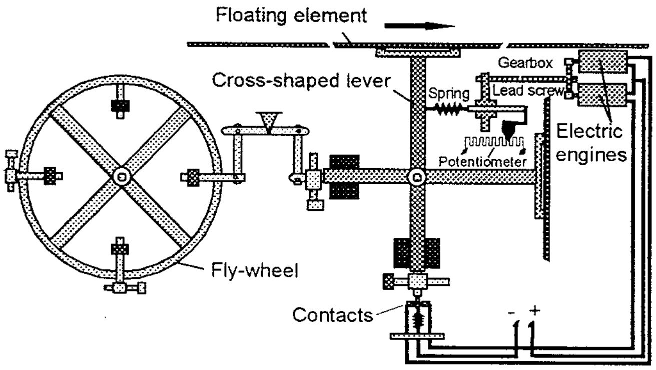

Fig 4. SENSOR SCHEME FOR LOW DENSITY FLOW SKIN FRICTION MEASUREMENT

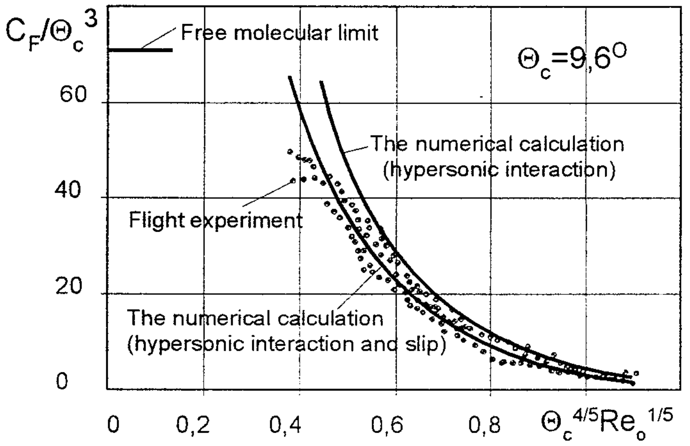

Fig 5 SKIN FRICTION COEFFICIENT OVER SHARP CONES

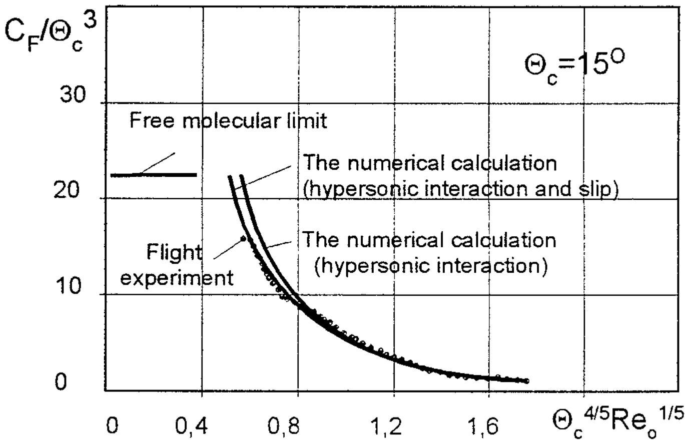

Fig 6 SKIN FRICTION COEFFICIENT OVER SHARP CONES

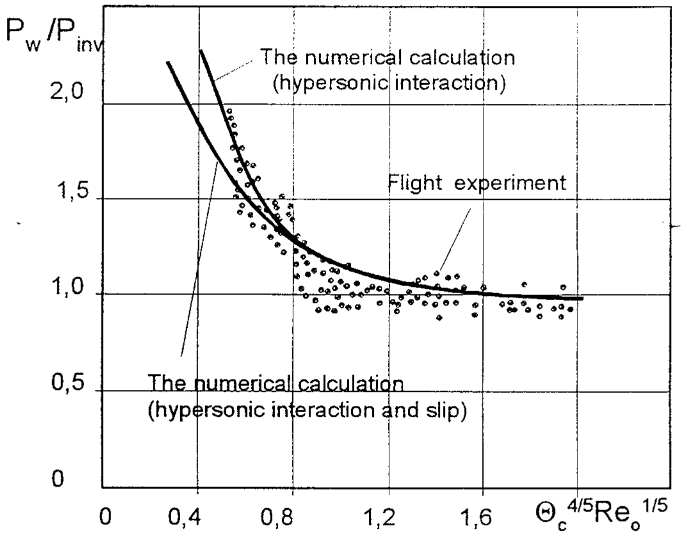

Fig 7 PRESSURE ON SHARP CONE SURFACE (Θ_c=9,6°)