Aerodynamic and Heat Problems of New-Generation Multi-Stage Launch Vehicles.

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Abstract— In the work a three layouts of new launch vehicles are investigated on the subject of flow field structure, pressure and heat flux distribution at hypersonic speeds M_∞=[6, 7.5 , 8 , 10.5]. Experiments are performed at TsAGI wind tunnels T-117 and UT-1M. Experimental methods used: flow field visualization, surface streamline visualization, heat flux measurements, pressure fluctuations on the model surface and the temperature in the external part of the boundary layer. It was fined the complicated interaction pattern of shock waves between each other and with the model surface. Such flow pattern is reflected on heat flux distribution on the model surface producing an essential heat flux picks.

Keywords— hypersonic flow, launch vehicle layout, aerodynamic interference, wind tunnel tests, flow field visualization, heat flux measurements.

I. Introduction

At the present time an active investigations aimed at new generation of launch vehicles (LV) designing are made in Russia. These rockets named as "Angara" and "Russia-M" are intended for crew and payload space transportation. New LV layouts are developed using multistage scheme with parallel connection of stages (modules) having comparable sizes (batch scheme). It produces the serious problems of aerodynamic interference between modules when the peak loads appear on the launch vehicle layout and frequently have unsteady behavior. At hypersonic velocities an aerodynamic problems of such launch vehicle layout aggravated by heat loads that also have peak distribution.

The main purposes of this work is to investigate the flow field structure, pressure and heat flux distribution on the three layouts of multi-stage launch vehicle, to determine regions and elements of vehicle layouts subjected by increased aerodynamic and heat loads, to develop methods and means for vehicle layouts protection from the loads obtained.

II. Experimental Results and Discussion

As the research objects the three LV multi-module layouts were chosen which correspond schematically to perspective carrier space rocket "Angara-5" (model designation MLV-A5) and two manned LV variants "Angara-5P" (model designation MLV-A5P) and "Russia-M" (model designation MLV-R). For aerodynamic experiments in TsAGI's wind tunnels a three models were made: one of them is similar to carrier LV and the other two are similar to manned LV variants. The main test volume was performed in a large hypersonic wind tunnel T-117 at Mach numbers M_∞=7.5 and 10.5. In addition to mentioned above it was carried out a number of experiments in TsAGI's shock tunnel UT-1M at Mach numbers M_∞=6 and 8. During these experiments Tepler's method or interferometer were used for flowfield visualization and surface streamline visualization was performed with the aid of spread oil points method. Heat flux measuring on the model surface was performed at T-117 using melting paints and by TSP-method (temperature sensitive paint - luminophor) at UT-1M. Also there were measured pressure fluctuations on the testing model surface and the temperature in the external part of the boundary layer by thermocouple sensors.

In the fig.1 the shadow pattern of flow field past MLV-A5P model is shown. It was obtained in the T-117 wind tunnel at Mach numbers M_∞=7.5 and $Re_{\infty,L}\approx5.3\times10^6$. It is seen the complicated interaction pattern of shock waves between each other and with the surface. The presence of lateral modules causes the unfavorable pressure gradient and the boundary layer separation on the central module surface.

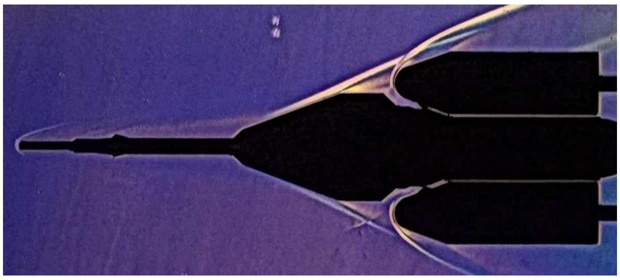

Fig.1 Shadow pattern past LV model MLV-A5P. Test in the wind tunnel T-117 at α=0, M_∞=7.5 , $Re_{\infty,L}$=5.3×10^6.

Complicated flow pattern is reflected on the surface heat flux distribution. Heat flux picks appearance is inevitable at mixing layer reattachment regions. In fig. 2 it is shown the model photograph with thermo sensor after the experiment. Here the white zones are the regions of unfused sensor but the dark zones correspond to the areas of high heat flux where the sensor have been melt. In this figure the values of relative heat flux q/q_0 at the most heated areas are placed (q_0 is the heat flux

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value on the head nose stagnation point.). On the future full-scale vehicle these areas should be protected obligatory.

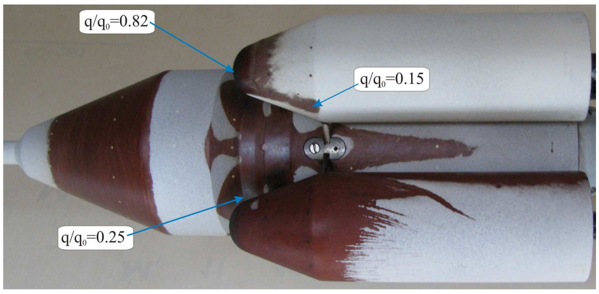

Fig.2 LV model MLV-A5P photograph with thermo sensor. Test in the wind tunnel T-117 at α=0, M_∞=7.5 , $Re_{\infty,L}$=5.3×10^6.

In fig. 3 it is shown the scheme of isocalorific lines distribution on LV model surface that was obtained as a result of tests analysis. Such scheme allows developing the temperature map of full-scale LV on the most high-heat part of the ascent trajectory and choosing the rational heat protection system.

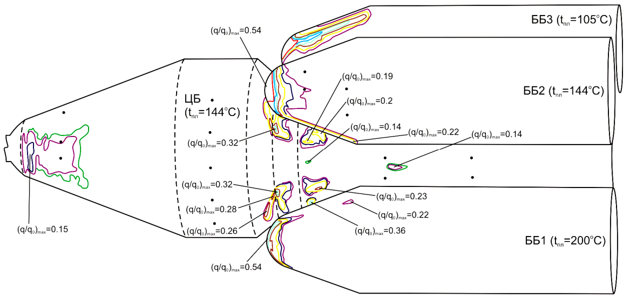

Fig. 3. Scheme of isocalorific lines on the model MLV-A5P. Test in the wind tunnel T-117 at α=0, M_∞=7.5 , $Re_{\infty,L}$=5.3×10^6.

The same investigations was performed for two other layouts of LV model. In fig. 4 the heat flux distribution on the model MLV-A5 is shown. It was obtained as a result of TSP mesurements in TsAGI's shock tunnel UT-1M at α=10° , M_∞=6 , $Re_{\infty,L}$=3.1×10^6.

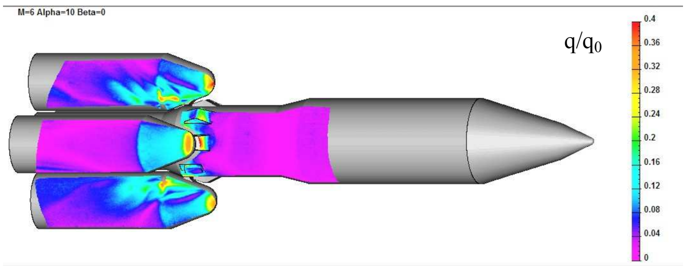

Fig.4. Heat flux on the model MLV-A5. Test in shock tunnel UT-1M at α=10° , M_∞=6 , $Re_{\infty,L}$=3.1×10^6.

In the fig.5 the shadow pattern of flow field past MLV-R model is shown. It was obtained in the T-117 wind tunnel at Mach numbers M_∞=7.5 and $Re_{\infty,L}$≈6.1×10^6 . It is seen the interaction of shock waves produced by side modules with the central body surface.

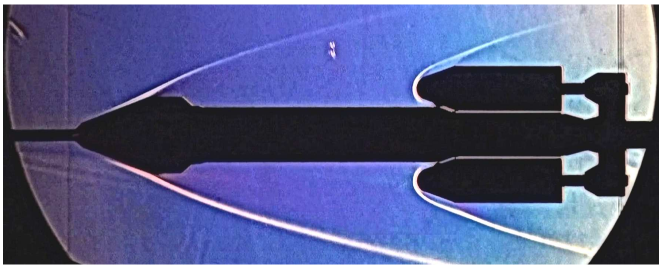

Fig.5 Shadow pattern past model MLV-R. Test in the wind tunnel T-117 at α=0, M_∞=7.5 , $Re_{\infty,L}$=6.1×10^6.

In fig. 6 it is shown the scheme of isocalorific lines distribution on MLV-R model surface that was obtained as a result of tests analysis. The most high-heat part is on the central body under the lateral module fairing.

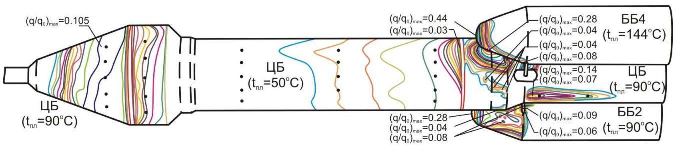

Fig. 6. Scheme of isocalorific lines on the model MLV-R. Test in the wind tunnel T-117 at α=0, M_∞=7.5 , $Re_{\infty,L}$=6.1×10^6.

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