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Thermal Protection Of The Surface Of A High-Speed Aircraft From Convective Heat Flow By Gas Blowing

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Abstract

The aircraft, designed for long-term hypersonic flight, should have possibly small blunting of the leading edges. This is necessary to reduce the external resistance of the apparatus, as well as internal losses of the total pressure in the air intake. Reducing the blunting radius of the leading edges is prevented by overheating of the structure due to aerodynamic heating.
One promising method for thermal protection of the leading edges with a small blunting radius is the blowing of the cooling gas through a gap located on the critical line of blunt wedge.
In the following work several applications of this method are presented.

Keywords: *thermal protection, gas blowing, supersonic*

Nomenclature (Tahoma 11 pt, bold)

Latin
G – mass rate of coolant
K - degrees of Kelvin
R – radius of bluntness
Re – Reynolds number
Greek
α – angle of attack
π – Pi number
Superscripts
^{o} - degree
Subscripts
j - injection
0 - stagnation
w - wall

1. Introduction

To gain best aerodynamic quality of high-speed aircraft small bluntness radius is needed for fuselage nosetips, wing leading edges and other projected elements. Small bluntness is also needed for operating efficiency of inlet of a supersonic air-breathing jet engine. In some cases, low temperature of vehicle surface is wanted (e.g. for mounting optical window used by photo devices).

However, with high levels of stagnation temperature and pressure behind normal shock along with small bluntness radius of aircraft elements, the values of heat flux is so high that reliable reusable thermal protection can not be implemented by traditional methods, even using best materials.

Decreasing heat load towards vehicle surface is possible by means of coolant injection into free stream gas flow through permeable surface or special devices. The detailed analysis of spossible coolants showed that the most effective substances (in the sense of minimizing weight and volume of coolant system) are water, glycerol, ammonia, etc.

However in quite a number of cases, e.g. when gas is available aboard (hydrogen, nitrogen, and so on), the vehicle surface cooling is reasonable to be implemented via gas injection.

Below there are presented 4 experiments with surface cooling by gas injection. The experiments were accompanied by numeric calculations.

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2. Experimental facility

The experiments were conducted in the TsAGI UT - 1 wind tunnel [1].

The coolant supply system is shown in Fig. 1. Basic elements of this system are: the vessel 18 of about 40 litres capacity; the valve 16 for filling the vessel; the valve 15 for releasing pressure to atmosphere; the main pneumo-electric high-speed valve 10.

The maximum gas pressure in the supply system is 150 bar. When main valve 10 opens the pressure in the model is set in approximately 0.2 ms. Pressure P_j and temperature T_j in the gas supply system are registered at the vessel exit (gages 13 and 14 respectively) and at the model inlet (gages 4 and 5).

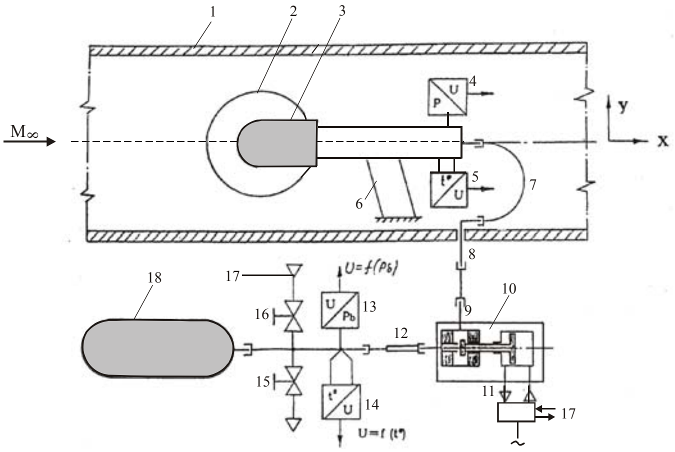

Fig 1. The supply system for gas injection into the model.
1 – walls of test section, 2 – optical window in UT-1 test section, 3 – blunt body, 4 – pressure gage at model inlet, 5 – temperature gage at model inlet, 6 – pylon of model, 7-9,12 – gas supply pipe, 10 – main pneumatic-electrical valve, 11 – control electrical valve, 13 – vessel pressure gage, 14 – vessel exit temperature gage, 15 – vessel pressure release valve, 16 – vessel filling valve, 17 – high pressure tube, 18 – vessel.

3. Experimental cases

3.1. Tangential gas injection along the surface of sharp cone

Experimental and numerical results of investigation of heat flux control with respect to surface of sharp cone with 8 degrees half-angle and full length of 400 mm (along cone axis of symmetry) in high speed air flow at Mach number 5, at stagnation temperature 700 K, at total pressure 50 bar are presented. Tangential slot with 3 degrees half-angle was designed at 10 degrees angle with respect to cone generating line. Critical section of the slot was at radius 6.5 mm, while slot height was 0.3 mm. Total pressure of ejecting gas (air) was in range between zero and 32 bar, and its stagnation temperature was 288 K. The model is presented in Fig.2.

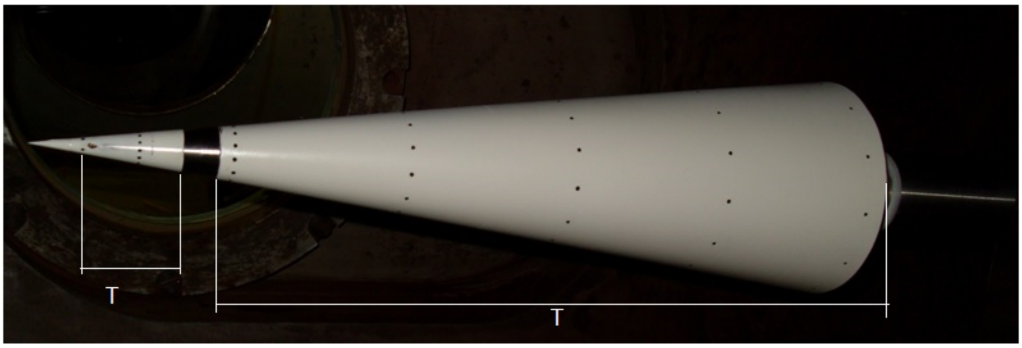

Fig 2. The model of the cone with the tangential slot

To measure the heat flux, the method of luminescent coatings was used [2]. To study the flow pattern, a straight-shadow method was used.

3.2. Tangential gas injection along the surface of sharp wedge

Experimental and numerical results of investigation of heat flux control with respect to surface of sharp wedge with 20 degrees half-angle and full length of the blowing feed channel of 77 mm and height of the model in the aft section of 30 mm (see Fig.3). Feed channel slit height was 30 mm. The experiments were carried out at Mach number 6, at stagnation temperature 800 K, at total pressure 4-16 bar. To measure the heat flux, the method of luminescent coatings was used [2]. To study the flow pattern, a straight-shadow method was used.

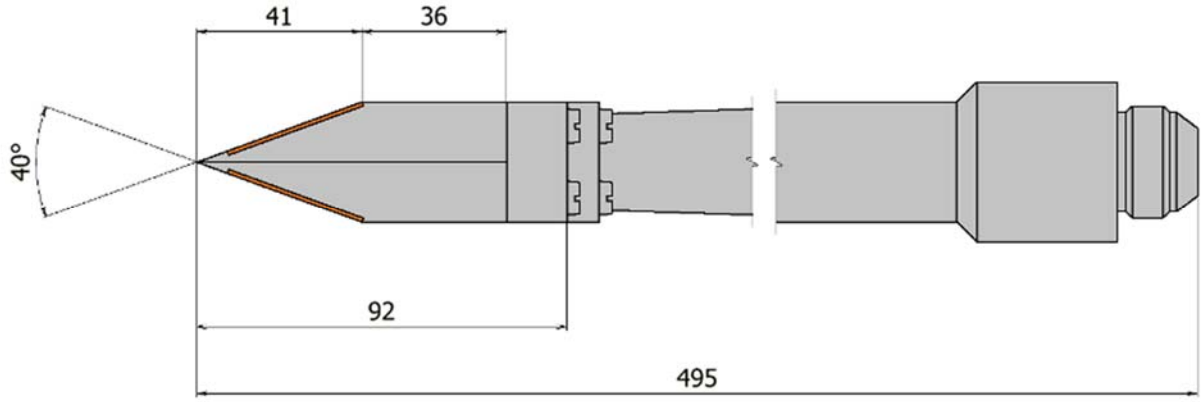

Fig 3. The schematic of the sharp wedge

3.3. Tangential gas injection into a supersonic stream

An experimental and numerical study of a tangential gas injection effect on a flow pattern and heat flux was carried out. The outline of the model is presented in Fig.4.

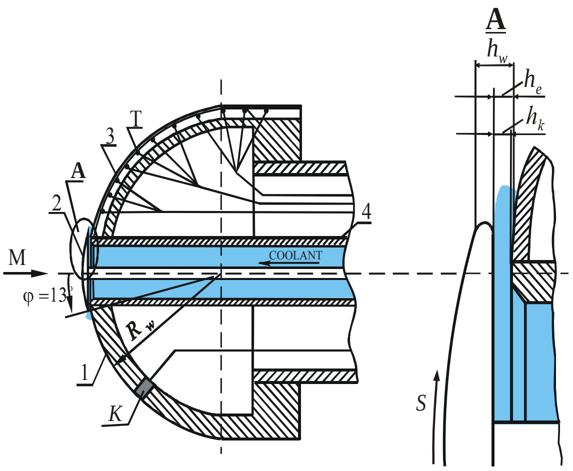

Fig 4. The model with the tangential slot on the spherical nosetip. 1 – nose, 2 – cup of slot, 3 – thin wall, 4 – coolant channel. T – thermocouples, K – calorimeters, h_k – slot.

The cooling gas (air) was injected in the flow (air) through the tangential axis-symmetric slot on the spherically blunted cylinder streamlined longitudinally. Experiments were conducted at free-stream Mach number 6, Reynolds number 0.76×10^6 (calculated for free-stream parameters and bluntness radius R_w = 37.5 mm), cylinder angle of attack α = 0…30°, slot width 0-0.021, free-stream stagnation temperature T_0 = 710 K, pressure behind the normal shock 0.5 bar. The mass rate of the injected gas G = 0...0.12. It is shown, that maximum of the heat flux toward the sphere surface could be sufficiently decreased. For example, for coolant mass rate G = 0.03 and angle of attack α = 0 the heat flux maximum is reduced by factor of two.

The results were outlined in [3].

3.4. The shock/shock interference region near front surface of blunt body

Results of experimental study of tangential gas injection influence on the flow and heat transfer in the region of interaction of the impinging plane shock generated by a sharp wedge and a bow shock wave generated upstream of the cylindrical blunted body (see Fig.5) are presented. The study was conducted at a free stream Mach number of 6, total pressure $P_0 = 20$ bar, stagnation temperature $T_0 = 570$K, Reynolds number based on the free stream flow parameters and bluntness diameter $Re_\infty = 0.4\times10^6$. A sharp wedge having angle of 15° was used as a shock generator. Gas (air and helium) was injected through a tangential slot located either at the symmetry line of the blunted body or at a distance of – 33° from the symmetry line. In the second case gas was injected in the direction to the symmetry line. In both cases gas was injected into the region of the shock waves interference. The shock generator location, the slot sizes, mass flow rate and pressure of the injected gas were varied. It is shown that the tangential gas injection reduces considerably the heat flux to the frontal body surface.

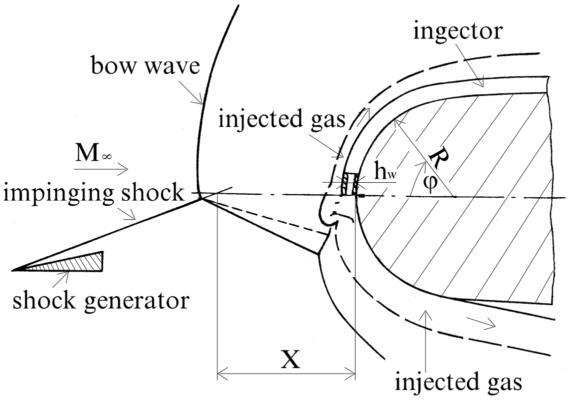

Fig 5. Schematic of model and gas flow in the case of the shock/shock interference region near front surface of blunt body

The results were outlined in [4].

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