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Cooling effect of gas injected through a non-symmetric slit of the wedge leading edge in a high speed flow

Pavel V. Chuvakhov,**, Ivan V. Ezhov*,**, Andrey V. Novikov*,**, Eduard B. Vasilevsky**
** Central Aerohydrodynamic Institute (TsAGI), Zhukovsky, 140180, Russia*
*** Moscow Institute of Physics and Technology (MIPT), Dolgoprudny, 141701, Russia*
iezhov@yandex.ru

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 body. In this paper, we consider the problem of active thermal protection of the sharp edge of an aircraft or air intake by blowing a gaseous substance through a slit against the flow.

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.
In this paper, we consider the problem of active thermal protection of the sharp edge of an aircraft or air intake by blowing a gaseous substance through a slit against the flow. The vapors blown into the flow partly push aside the hot boundary layer and, thus, significantly (several times) reduce the heat flux to the surface of the body. With this method of protection, there are practically no restrictions on the permissible convective heat flux and on the duration of the process of the effect of the gas flow on the body. This method can ensure the preservation of the shape and size of the body of the body for the entire flight of the aircraft. The device may have a practically sharp leading edge or toe. The degree of surface cooling can be adjusted by changing the amount of substance supplied to the external surface. An important positive feature of this method is the possibility of multiple use of the structure. The requirement of repeated use of the thermal protection system is essential for high-speed aircraft being developed.

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 Pj and temperature Tj 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).

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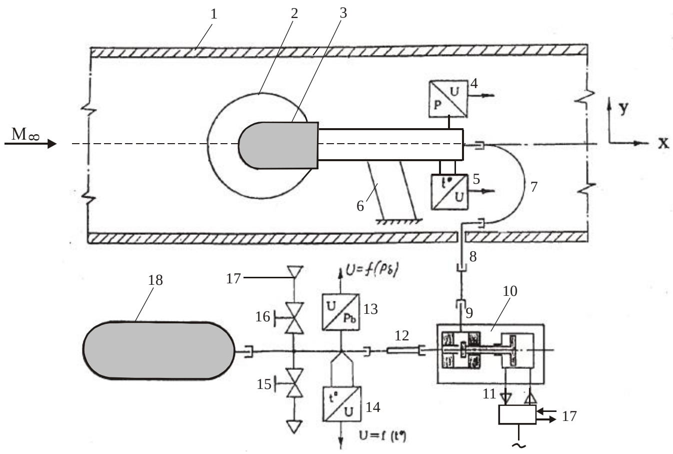

Figure 1: The supply system for gas injection into the model. 1 – walls of test section, 2 – optical window in UT-1 test section, 3 – blunt body, 4 – pressure gage at model inlet, 5 – temperature gage at model inlet, 6 – pylon of model, 7-9,12 – gas supply pipe, 10 – main pneumatic-electrical valve, 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 case

3.1. Tangential gas injection along the surface of sharp wedge

The model under study is a sharp wedge (blunt radius less than 0.01 mm) with a half-angle of θ = 20° and a length along the axis of the model L = 77 mm, the height of the model in the aft section Ht = 30 mm. Width of model is 90 mm. The model is a channel for the supply of cooling gas, ending with a gap. The upper boundary of the slit coincides with the plane of symmetry, the height of the slit hs = 0.2 mm, the distance of the plane of symmetry of the slit from the plane of symmetry of the wedge δ = hs / 2 = 0.1 mm (see Fig.2). 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. Corresponding unit Reynolds number is $Re_{\infty 1}$=(6.5±0.2)×106 1/m. The model was set at a zero angle of attack and at an angle in the azimuth direction Θ = 0° and 90°.To measure the heat flux, the method of luminescent coatings was used [2]. To study the flow pattern, a straight-shadow method was used.

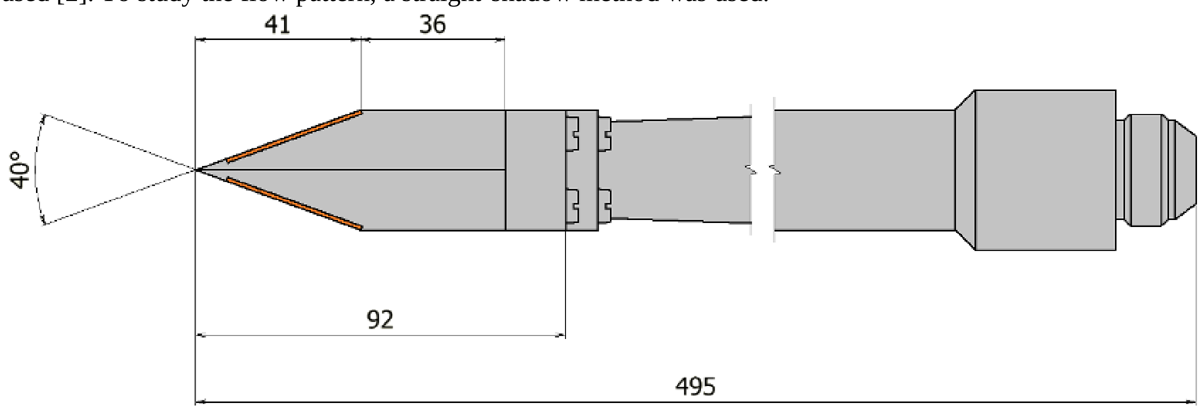

Figure 2: The schematic of the sharp wedge

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4. Experimental results

4.1. The position of the shock wave

The negative side of cooling by blowing is, in addition to the flow rate of the cooler, an increase in body resistance to flow. The parameter describing the impact of the body on the incident flow and, thus, its resistance, can be the shape of a head shock wave, clearly visible in shadow photographs.

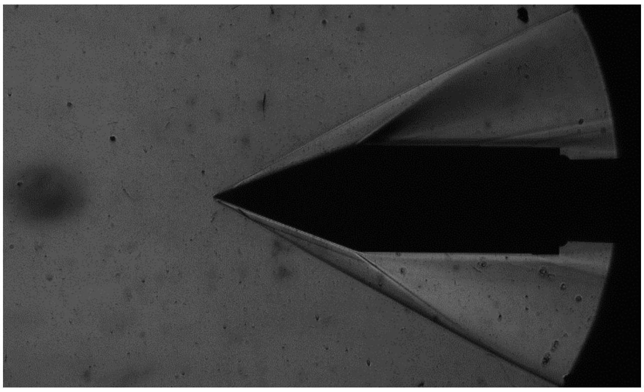

Figure 3: Shlieren image, without blowing

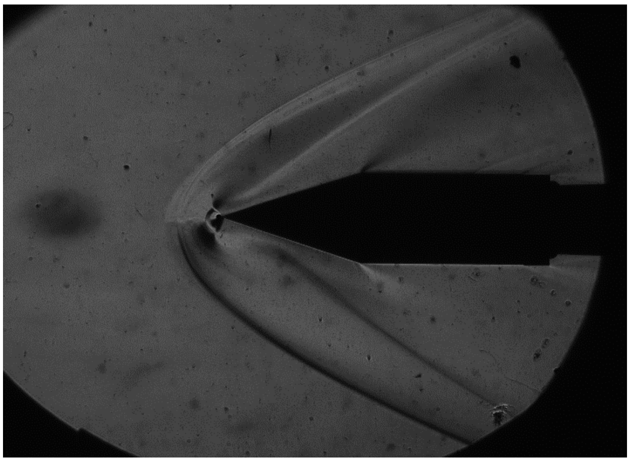

Figure 4: Shlieren image, Pj=8.0 ata

For convenience of analysis, shock waves with different parameters of blowing are collected in one figure.

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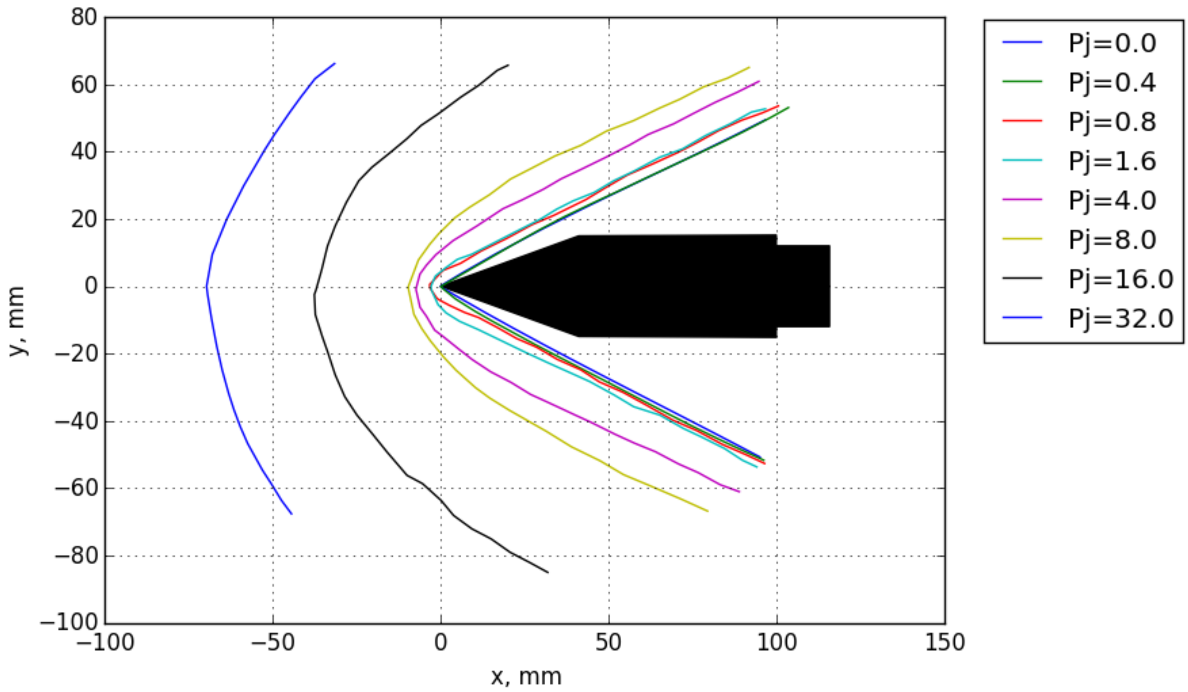

Figure 5: Shock wave form

4.2. Heat flow distribution

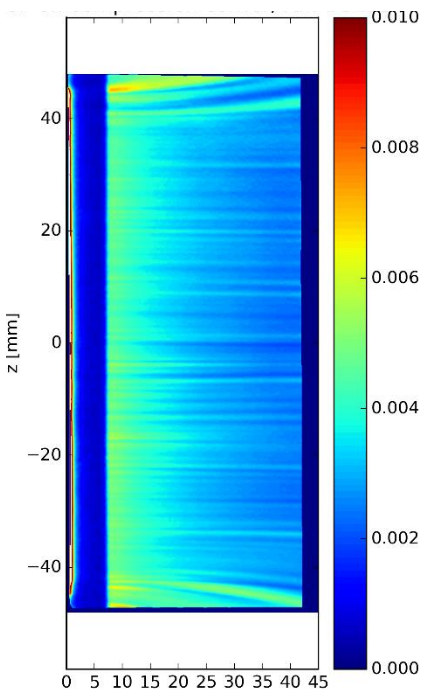

Figure 6: Heat flow distribution, slit side, without blowing

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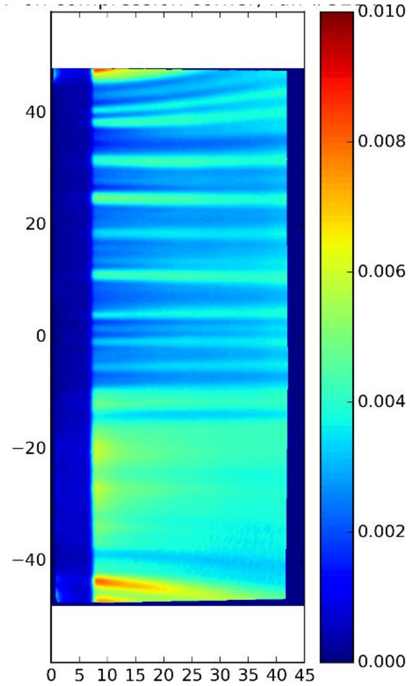

Figure 7: Heat flow distribution, slit side, Pj=0.8 ata

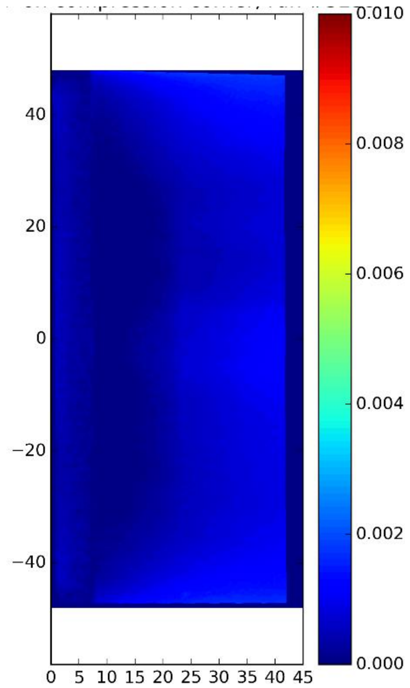

Figure 8: Heat flow distribution, slit side, Pj=8 ata

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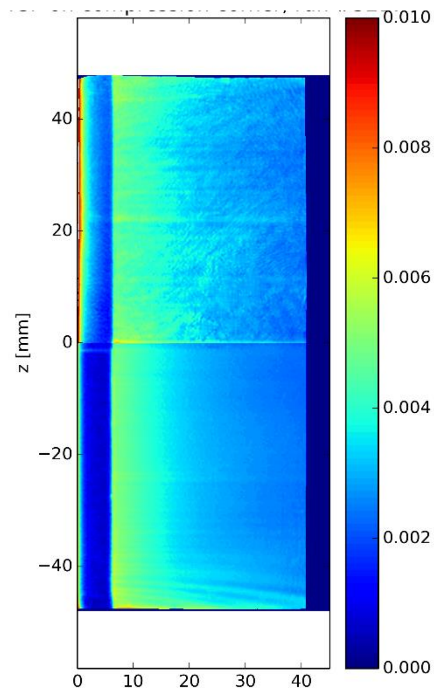

Figure 9: Heat flow distribution, no-slit side, without blowing

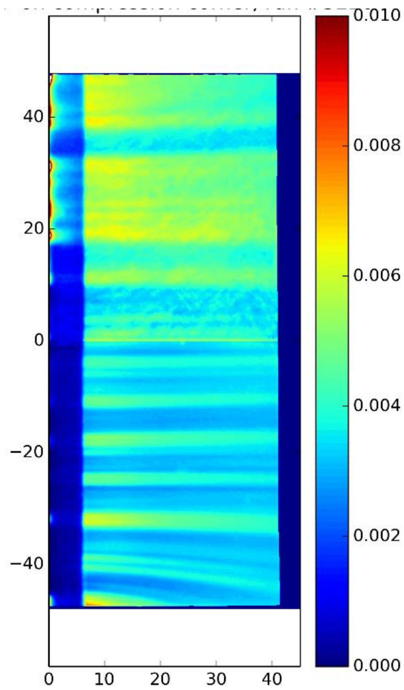

Figure 10: Heat flow distribution, no-slit side, Pj=0.8 ata

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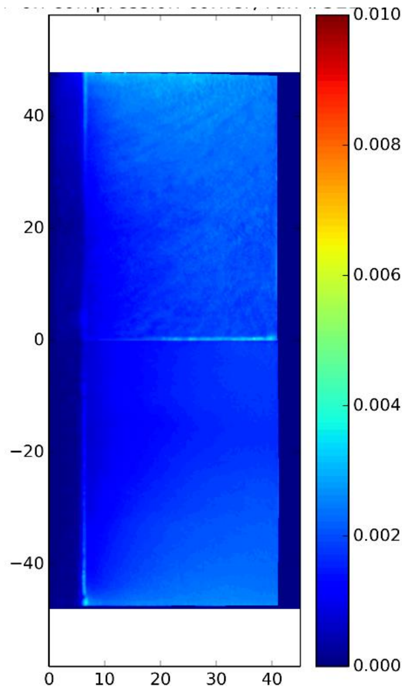

Figure 11: Heat flow distribution, no-slit side, Pj=8 ata

This model of the wedge was made of heat-insulating materials AG-4 and Plexiglas GSWH01. It turned out that the optical inhomogeneity of the material AG-4 when combining images significantly increases the noise of the resulting temperature fields.
In order to study the effect of blowing on the heat flux and minimize the influence of the non-uniformity of the blown-off flow, the heat flux was averaged over the span. The results are presented in the graph:

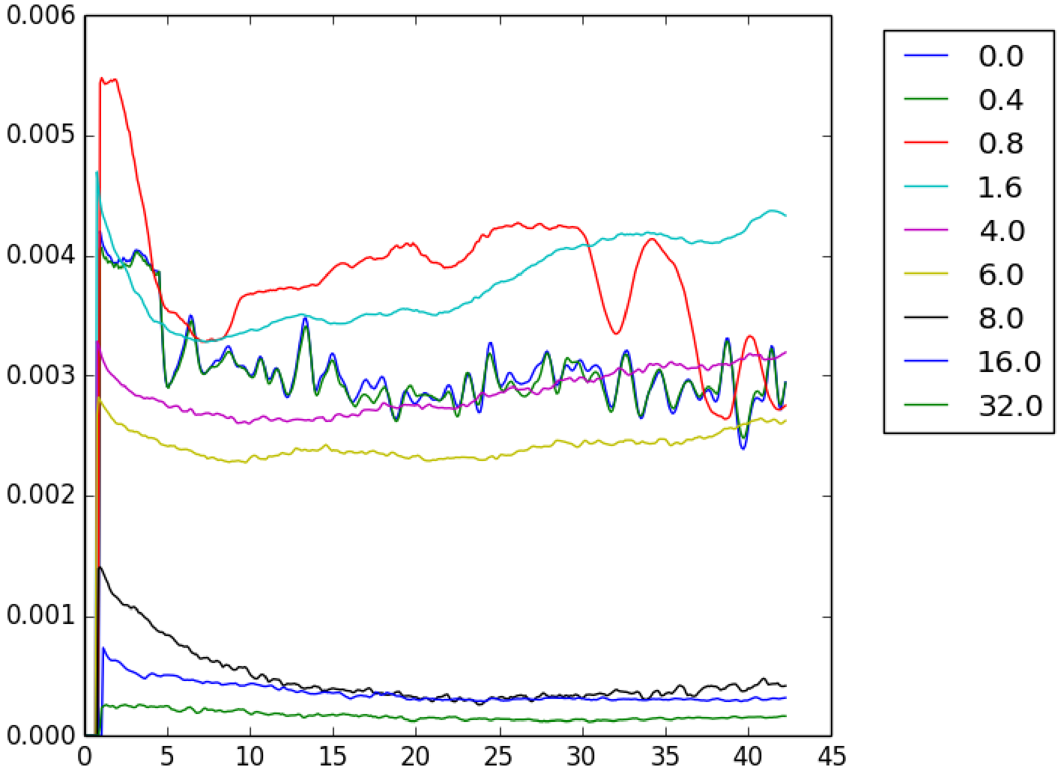

Figure 12: The averaged heat flux depending on the blowing pressure (slit side)

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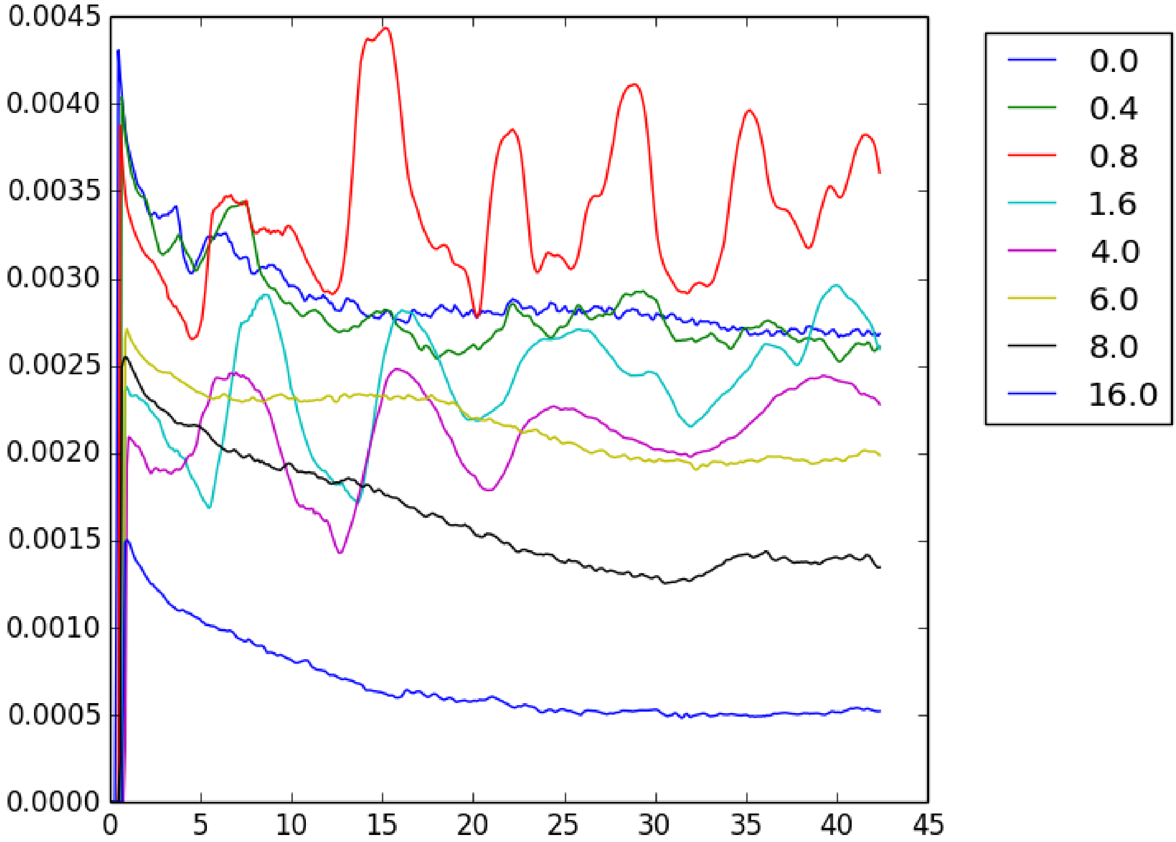

Figure 13: The averaged heat flux depending on the blowing pressure (no-slit side)

The presented graphs demonstrate that the blowing effect is practically absent before the blowing pressure becomes equal to the pressure behind the direct shock wave, which corresponds to the picture of the shock wave position. When the pressure of the blower, slightly exceeding the pressure behind the direct shock wave, there is a paradoxical increase in heat flow, which can be explained by turbulization and flow mixing, which increases the flow of hot air from the outside flow to the surface. With a further increase in the pressure of the blown gas, the flow at the surface stabilizes, and the blown gas pushes the external gas from the surface, reducing heat flow.
It is seen that at significant blowing pressures, when the effect of it is stable, cooling is achieved on both the slit and non-slit sides.

5. Conclusions

Blowing gas leads to a cooling of the surface, but at the same time, the body's action on the external flow and its resistance to flow increase.

5. Acknowledgements

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References

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