Investigation of Deceleration Supersonic Flow in a Long Cylindrical Channel with Formation Pseudoshock

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Keywords: Long cylindrical channel, Pseudoshock, Supersonic flow.

Abstract. In the present paper deals with the results of experimental studies of viscous supersonic gas flow in a tube of constant section with formation a pseudoshock. Made a number of series of experimental studies of the braking process of a supersonic flow in the short and long channels (L/D=32 and L/D=64). Data agree with the known data in the literature for a short channel. It was shown that the formation of pseudoshock in long channels (up to L/D=68) can occur without throttling the output section, i.e., in the absence of backpressure. Changing the pressure in a certain range does not affect the pseudoshock position.

Introduction

Subsonic flow in the channel forms a boundary layer, the thickness of which increases in the longitudinal direction. With sufficient length of the channel is formed Poiseuille flow. In this flow deceleration at the walls requires an increase in the rate of non-viscous core (to save the mass flow rate) [1]. In consequence of, the sound speed (M = 1) can be achieved in the output section of the channel, but only at a certain (critical channel length). Further increase length of channel is decreasing the velocity in the inlet section and, respectively, to reduce flow rate. Herewith, the velocity in output section of the channel saved critical velocity M = 1.

If there is a supersonic flow in channel there is a different situation. It also formed the boundary layers. But the former balance between the development of boundary layer and inviscid supersonic kernel anymore. Flow mode is realized by definition Crocco may already be supercritical, and can occur a transition to subsonic flow. Transition, as shown by experiments, going through a complex structure of the jumps and parietal regions of separated flow, called the whole pseudoshock.

With a certain (critical), flow channel length reduces its speed to a Mach number equal to one (M = 1) at the output [2]. Further increase length of channel is generates in a certain section of the channel system pseudoshock, followed by subsonic flow region is formed. In subsonic flow behind the pseudoshock occurs flow acceleration, wherein at the exit the flow velocity can reach speed of sound (M = 1).

Investigation of supersonic flow in the channel to form pseudoshock devoted quite a lot of work. The urgency of such problems associated with the design of jet engines (WFD), wind tunnels, and various types of air intakes. In all these works is considered a small channel length (L / D ≤ 30) and pseudoshock formed by compression of (throttling) the flow at the outlet [3,4]. In the work we investigate the process of deceleration a supersonic flow in the short and long channels (L/D = 32 and L/D=64) in the presence and in the absence of counter-pressure at the outlet of the channel.

Experimental Setup

Experimental setup was designed to conduct the study, the general form of which is shown in Figure 1. And Figure 2.
To minimize the influence of the roughness was used honed pipe with inner diameter of 50 mm and a surface roughness Ra=0,1 ÷ 0,04. Equipment allowed the study, both the short channels (L/D=32), and the long channels (L/D=64) providing formation pseudoshock. The initial section of the channel has joined with different profiled supersonic nozzle (Figure 1, 2), which allows to create supersonic flow at the inlet to the channel with a given value of the Mach number of M=4.

The supersonic nozzle was connected with settling chamber which volume is 10 dm3, from where occurring the expiration of the working gas in the course of the experiment. The settling chamber application allowed creating different flow stagnation pressure at the inlet of the nozzle (in the range of 1 to 5 bar). Stagnation temperature is always equal to room temperature To=290 K. In some experiments settling chamber was connected to the atmosphere, then, accordingly, the stagnation pressure is equal to atmospheric pressure.

The output end of the channel was connected to a vacuum tank with a volume of 6 m3, in which was creating the necessary initial pressure (about 1000 Pa). During the experiment, the pressure in the vacuum vessel gradually increased, which allows obtain the flow regimes with a different pressure on the outlet.

Along the length of the test duct were installed static pressure sensors (placing shown in Figure 1) for the registration of pressure in the current study. At the same time was detecting stagnation pressure in the settling chamber and the vacuum vessel pressure. In the output section channel is installed receiver Pitot comb for measuring the total pressure in the flow at the outlet. All sensors were connected to the recording system of the LA-20USB, which allows recording the signal of any...
sensor with a frequency up to 16 kHz. In these experiments, the registration rate was 1 kHz. Before starting the experiment, in a vacuum container and duct the required pressure was created. Then, the registration system was turned on, and then (after about 2 seconds) was opening a high-speed shutter and began feeding compressed air into the settling chamber. At the same time beginning gas flow through the nozzle, there is a realization quasi-steady flow regime in the test channel. Figure 3 shows typical pressure over time in one experiment, the channel length of 68 gauge. Inflow occurred from the atmosphere through a nozzle with a Mach number $M = 4$. Marked by the arrow line indicates the pressure change in the vacuum container (S6). The other curves show the recording of static pressure sensors located along the channel. Sensor 1 is located almost at the entrance to the channel, for 13 seconds shows a pressure $P = 0.016$ bar, which corresponds to the stationary supersonic flow at the inlet with Mach number $M = 4$.

Figure 3. Typical results.

**The Results Studies of Deceleration Supersonic Flow in a Short Channel**

On the results of the experiments were built distribution of static pressure along the channel, allowing pseudoshock locate and show the distribution of static pressure along the tract. Results obtained for a short channel ($L / D = 32$) are shown in Fig. 4. Each curve corresponds to the distribution of static pressure along the channel at each given time. Selected points indicate the pressure in the vacuum vessel for a particular time. For ease of interpreting the results of the pressure presented in dimensionless form - measured pressure ($P_1$) divided by the pressure in settling chamber ($P_{0pc}$). The graph shows that at low pressures in vacuum container pseudoshock absent. Pseudoshock appear near the output section at a relative pressure of more than 0.06. Then, after increased the pressure in the vacuum vessel pseudoshock moves towards the inlet section and at a pressure greater than 0.1 is formed the subsonic flow along channel. It should also be noted that with constant pressure in the vacuum container pseudoshock it remains in one place. At position shock of $L / D \leq 10$ appears zone of subsonic flow, where the flow begins to accelerate. Also, studies were carried out at different Reynolds numbers.
A similar behavior of pseudoshock gotten by increasing the number Reynolds (Figure 5).

It should be noted that the results are completely consistent with the results presented in [1] for the channel length L/D= 7 (see. Figure 6).
The Results Studies of Deceleration Supersonic Flow in a Short Channel

The main interest is the study of such supersonic flow in a long channel. The results show the pressure change for a long channel $L/D = 68$.

Figure 7 shows the pressure distribution along the long channel $L/D=68$, with different pressures in the vacuum vessel. Inflow occurred from the atmosphere through a nozzle with a Mach number $M = 4$. The graph shows that even in the absence of counter pressure, pseudoshock formed due to friction and located at a distance 10 caliber from the inlet section of. By increasing the back pressure to 0.06, its position remains unchanged. With an increase in back pressure over 0.06 pseudoshock moves toward the inlet section, and reaches the inlet section when pressure is 0.08.

Summary

Studies have shown a different flow pattern when considering education pseudoshock. For example, at low pseudoshock channel length is formed on the channel output and increasing back pressure moves toward the inlet section. What saying about the of separations properties formation type. However, when considering a long channel the formation of pseudoshock to determine type of it becomes difficult, because in initially time of the flow regime, pseudoshock established in a certain section and retains its position even with a significant increase in backpressure. This fact seems to be interpreted in the sense that pseudoshock has properties of separated flows and unseparated flows.

The structure of the flow, conditions for the occurrence of boundary layer separations and return flows, their impact on the total pressure loss and the area of decrease velocity are not well understood and require more detailed consideration.

References

[1] O.V. Guskov, V.I. Kopchenov, I.I. Lipatov, V.N. Ostras`, V.P. Starukhin Braking process of supersonic flows in channels. Moscow: FIZMATLIT, 2008. – 168p.

[2] Abramovich G.N. Applied Gas Dynamics. M. Science: Ch. Editorial Sci. lit., 1991. – 600 p.

[3] E.A. Meshcheryakov, V.V. Yashin Quasione dimensional tear model pseudoshock in channel // TsAGI Scientific Notes 2013 b. 44, №5, pp.46-62.

[4] Matsuo K Shock train and pseudo-shock phenomena in internal gas flows // Progress in Aerospace Sciences 35-1999 33-100.