Control of flow parameters in models of precombustion diffusers for ramjet engine

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Abstract

Results of experimental studies of flow in sectioned duct of precombustion diffuser models divided into compartments by longitudinal partitions are presented. It is shown, that the presence of a gas-dynamic connection between the channels reduces the flow irregularity, equalizes the flow parameters at the end of the channel, reduces the longitudinal dimensions of the flow deceleration area.

Keywords *intake, precombustion diffuser, shock train, experimental studies.*

Nomenclature

Latin symbols
M – Mach number
h - height
L, x - length
b, y - width
F - area
p – static pressure
p_0 – total pressure
L_{dec} – flow deceleration zone length

Subscripts
d – design parameters
f – freestream parameters
e – parameters in the model entrance
t – parameters in throat of the model

For some types of power plants there are modes of engine operation when a flow deceleration in a shock train occurs in the duct behind an air intake in a precombustion diffuser (isolator). In this case, it is necessary to ensure that the level of pressure increase in the air flow in front of the combustion chamber is as high as possible and uniform over the cross section, with acceptable lengths of the engine duct.

The goal of the studies was to improve the duct characteristics of the precombustion diffuser of a rectangular engine by aligning the flow parameters over the cross sections of the channel and increasing the pressure level in front of the combustion chamber. To do this, the precombustion diffuser in models was partitioned into compartments using dividing longitudinal partitions of various configurations. It should be noted that studies of flow behavior in the channel have been carried out in TsAGI earlier (for example, [1, 2]), but in these studies only isolated channels with no adjacent compartments were considered.

The studies were conducted on two models: 1 – model of an air intake device with a precombustion diffuser (was tested in SVS-2 wind tunnel in TsAGI), 2 - simulator of a precombustion diffuser - rectangular channel (research was conducted in TSSM wind tunnel in TsAGI). General view of model 1 and a scheme of its duct with the main geometrical parameters are shown in Fig. 1. The model is a rectangular air intake with a three-stage forebody (stage inclination angles 15°, 20°, 24.5°, lip angle - 5°) and a precombustion diffuser (ratio of the intake width to its height (b / h) = 1, length of duct of the model is ~ 4 h). The estimated Mach number M_d = 6, relative throat area of the intake F_t / F_e = 0.2.

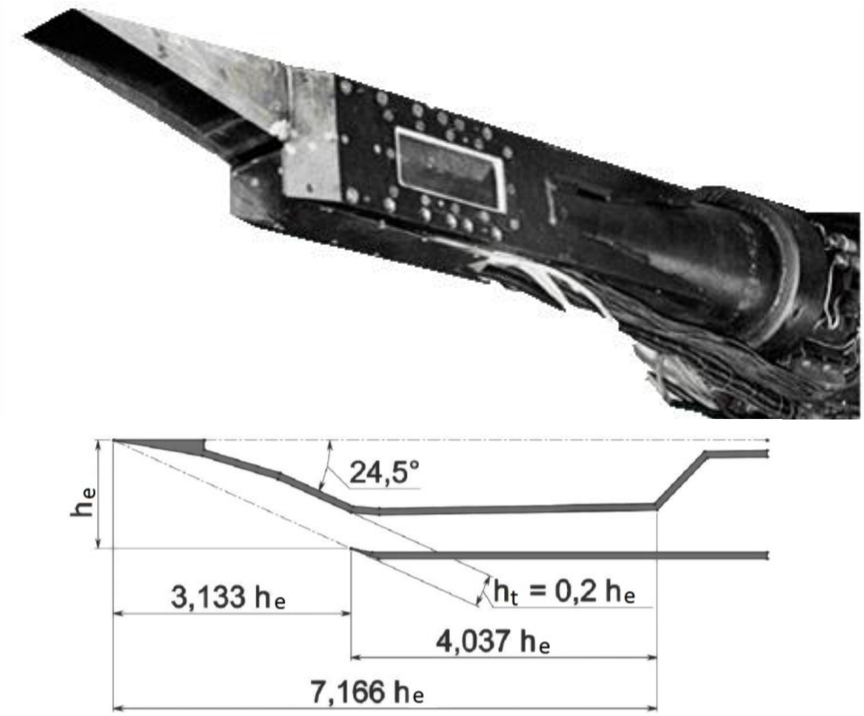


Fig.1 General view and scheme of model 1 – model of an air intake device with a precombustion diffuser for tests in SVS-2 wind tunnel

Mechanical throttling of the air intake device was carried out during tests.

In Fig. 2 a-c it is shown the distribution of the experimentally obtained relative static pressure p / p_t along the bottom wall of the precombustion diffuser without partitions (a), with an impenetrable partition (b) and with a partition with slotted holes (c) for the free-stream Mach number M_f = 4.9 during model throttling.

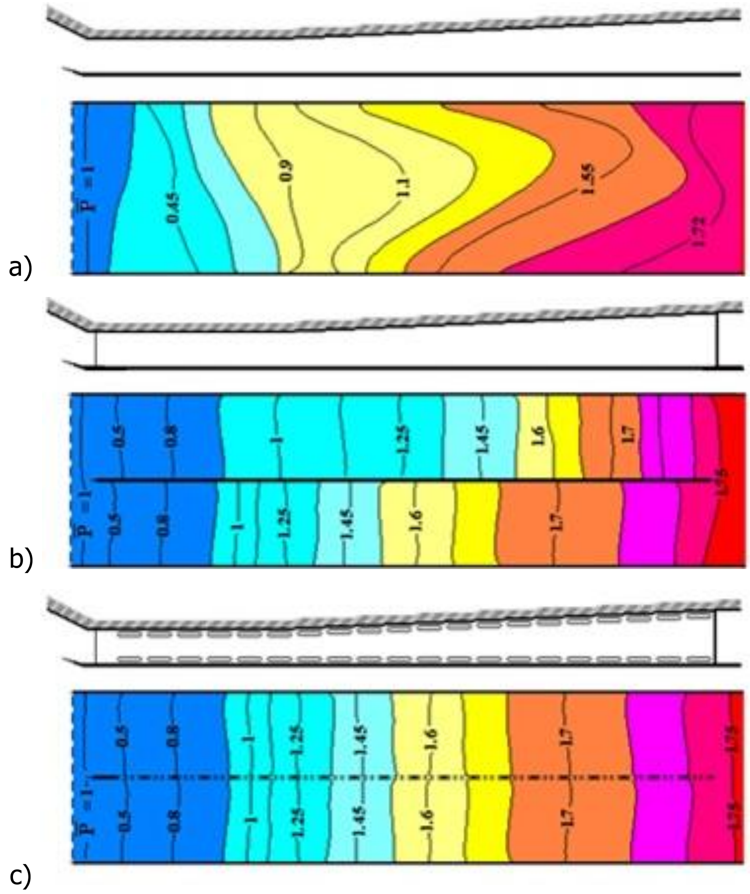


Fig.2 Relative static pressure distribution along the bottom wall of the precombustion diffuser: a - without partitions, b - with an impenetrable partition; c - with a partition with slotted holes

Analysis of pressure distribution presented in fig. 2, showed the following basic characteristic properties:

- in the absence of partitions in the channel of the precombustion diffuser, a flow is not uniform over the cross section with asymmetrical deceleration of the flow.

- if there is an impenetrable partition flow is uniform over cross section of each compartment, but level of the pressure increase in compartments is different. This negative fact can lead to the unstart of individual compartments, the transmission of disturbances through the boundary layer upstream and disruption of the flow in the air intake, and, consequently, asymmetrical loads on the duct.

- if there are slotted holes in partitions between the compartments, a gas-dynamic connection is established, the flow parameters in the compartments are equalized, parameters change along the length of the precombustion diffuser in the compartments uniformly and equally.

In Fig. 3, 4 the results of experimental studies of model 1 at free-stream Mach numbers M_f = 3 ... 4.9 are presented. Mach numbers at the entrance of the model in this case were M_e = 1.5 ... 2.2. These data reflect influence of channel sectioning with gas-dynamic connection between compartments on the characteristics of the flow at the end of channel. The number of compartments "n" was ranged from 1 to 4.

In Fig. 3 at Mach number M_f = 4.9 (M_e = 2.2), the distribution of relative static pressure p / p_t along the length of the duct of the model for variants with different number of compartments "n" with gas-dynamic connection between them is shown. Pressure dependences show that splitting the duct of the precombustion diffuser into compartments and using slotted holes can significantly increase the overall pressure level at the end of duct and reduce the area of flow deceleration in the shock trains. In Fig. 4 one can see the positive effect of the partitioning of the precombustion diffuser on the static pressure value p/p_t in the duct (a) and on the decrease in the length of the flow deceleration zone L_{dec}/h (b). The pressure p at n = 4 increases by ~ 17% (M_f = 3-4.9). At M_f = 4.9 the length of the flow deceleration zone decreases by up to 25%.

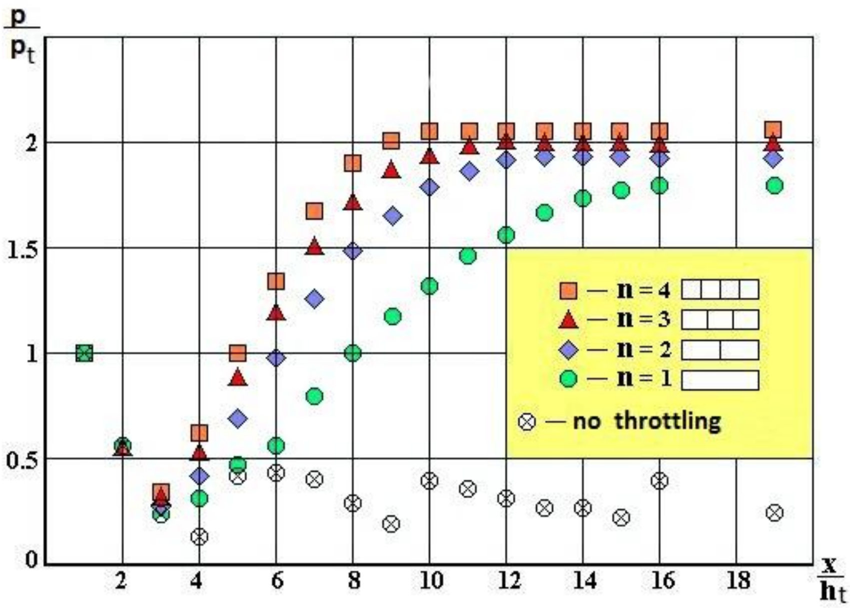
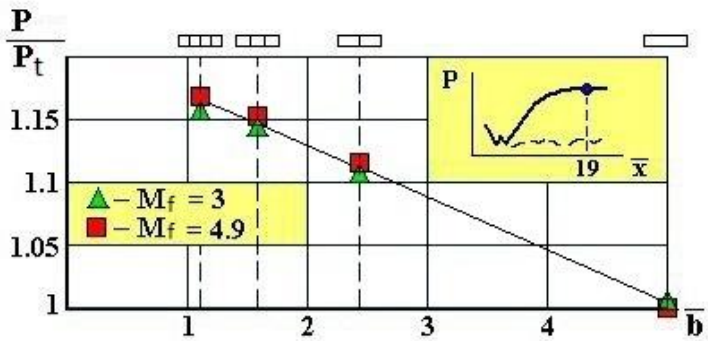
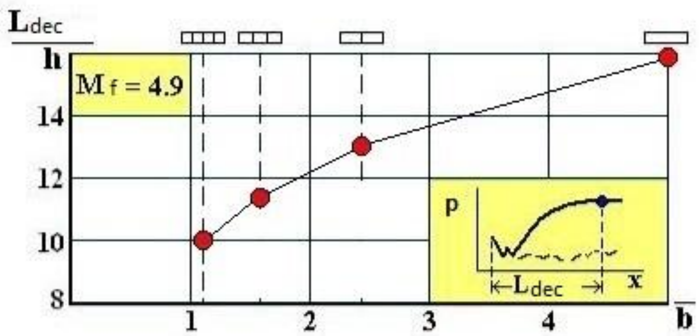


Fig.3 Distribution of relative static pressure for variants with different number of compartments. M_f = 4.9 (M_e = 2.2)



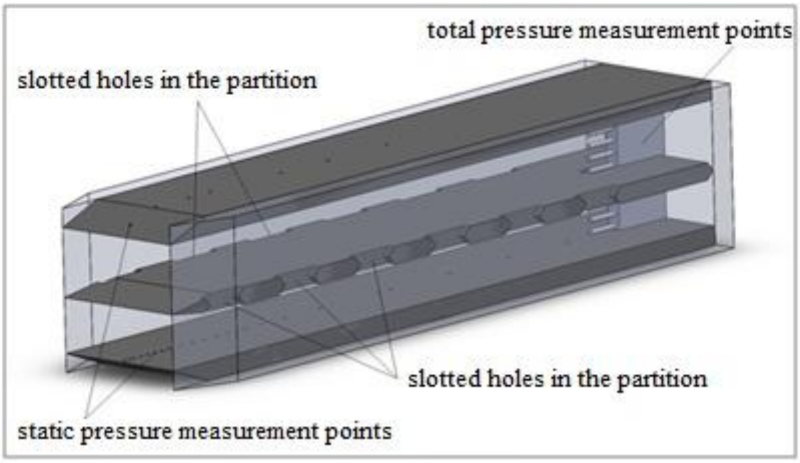
a)



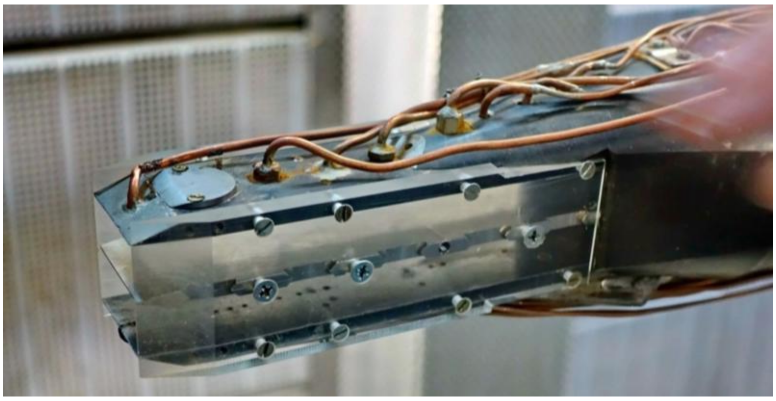
b)

Fig.4 Effect of the partitioning of the precombustion diffuser on the relative static pressure value in the duct (a) and on the length of the flow deceleration zone

A more detailed study of the flow deceleration in a shock train was carried out on model 2, which is a rectangular duct - simulator of a precombustion diffuser (ratio b / h = 1.11, length L = 5.55 h) with sharp leading edges. To visualize the flow structure, the channel was equipped with transparent side walls. Scheme of model 2 and its photo are shown in Fig. 5. To the side walls of the channel different variants of longitudinal dividing partitions are attached (thickness ~ 0.14 h, the apex angle at the leading edge is 15 °, fig. 6, 7). During tests duct was equipped either with a long horizontal dividing partition installed over the entire length of a rectangular duct and dividing the original duct into two channels of different height (Fig. 6 a, 7 a), or with two short partitions arranged in series with a gap between them (Fig. 7 b). One of the variants of the long partition was placed at an angle of 1 ° to the plane of symmetry (Fig. 6 b). The flow deceleration in adjacent channels with artificial disturbances in one of them was also investigated. A vortex generator located on the upper wall at a distance of 0.83 h from the entrance plane was used as a source of disturbances (Fig. 6c).



a)



b)

Fig.5 Model 2 – rectangular duct - simulator of a precombustion diffuser: a – scheme of model, b – photo of model

a)

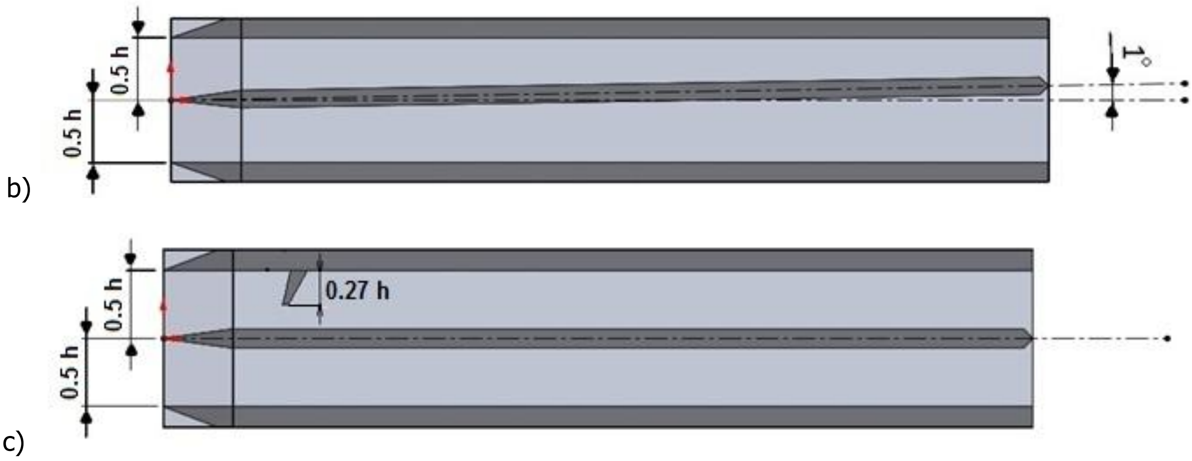


Fig.6 Variants of partition arrangement: a – partition divides the original duct into two channels of different height , b – partition, placed at an angle to the plane of symmetry, c – partition divides the original duct into two symmetrical channels, but with vortex generator in the upper channel

In these studies, all partitions were made in two versions: a solid impenetrable partition (Figures 7a, 7b) and a penetrable partition with longitudinal slots near the channel walls (Figures 7c, 7d). Tests were carried out in the wind tunnel TSSM TsAGI, at the free-stream Mach numbers M = 2–3.

To move the shock train upstream, throttling of the model channel with a mechanical throttle was performed. The static pressure distribution was measured along the channel length, and the total pressure fields at the end of the duct were determined.

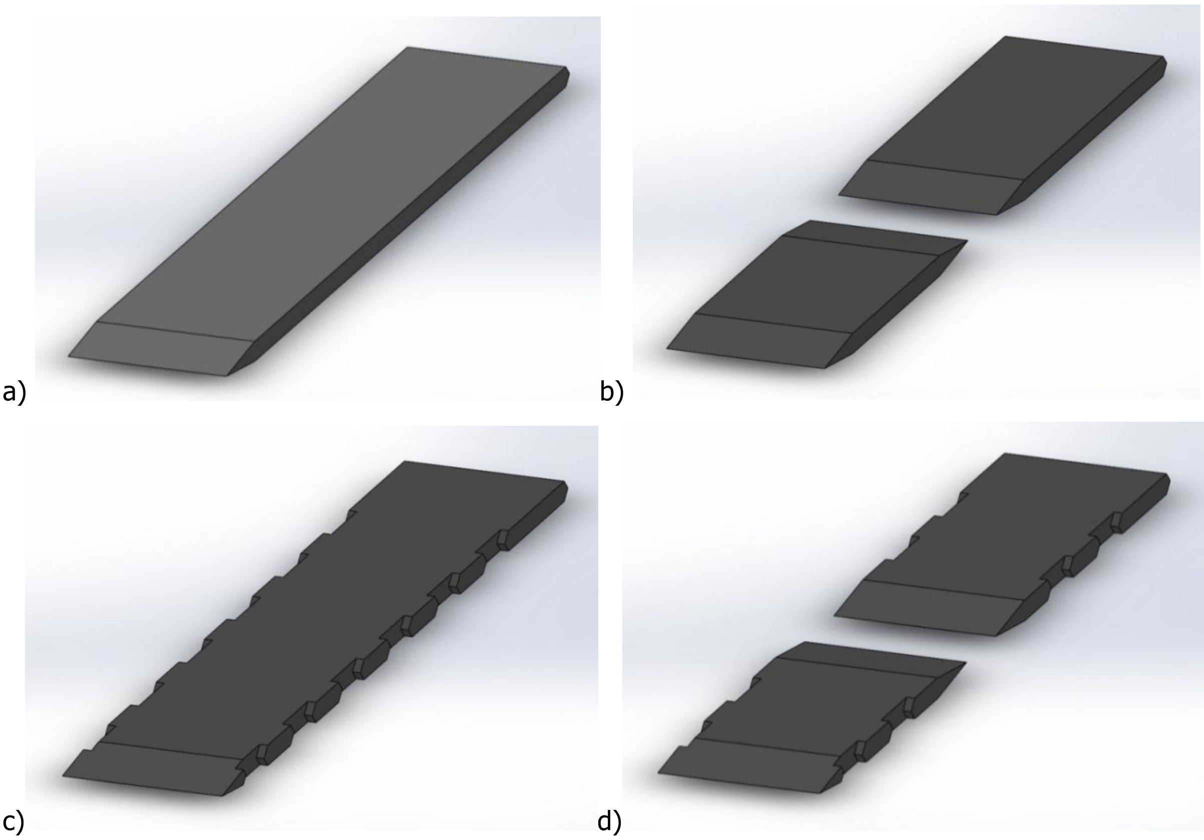
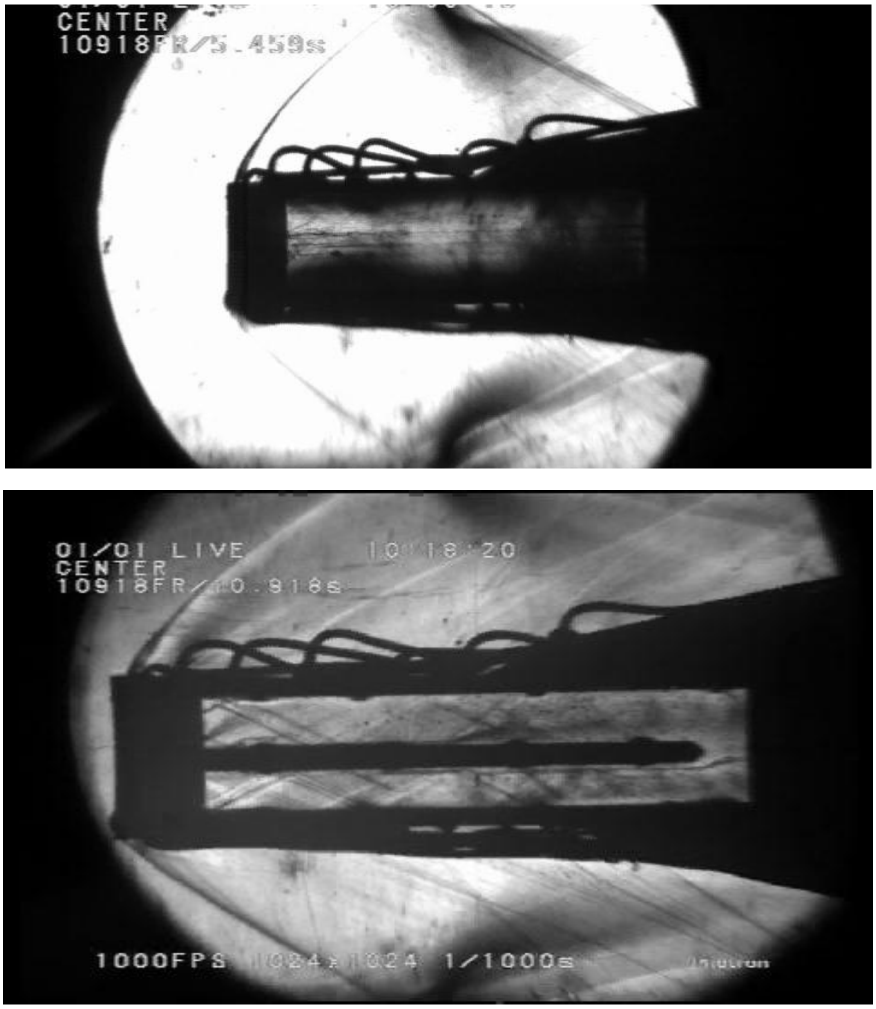


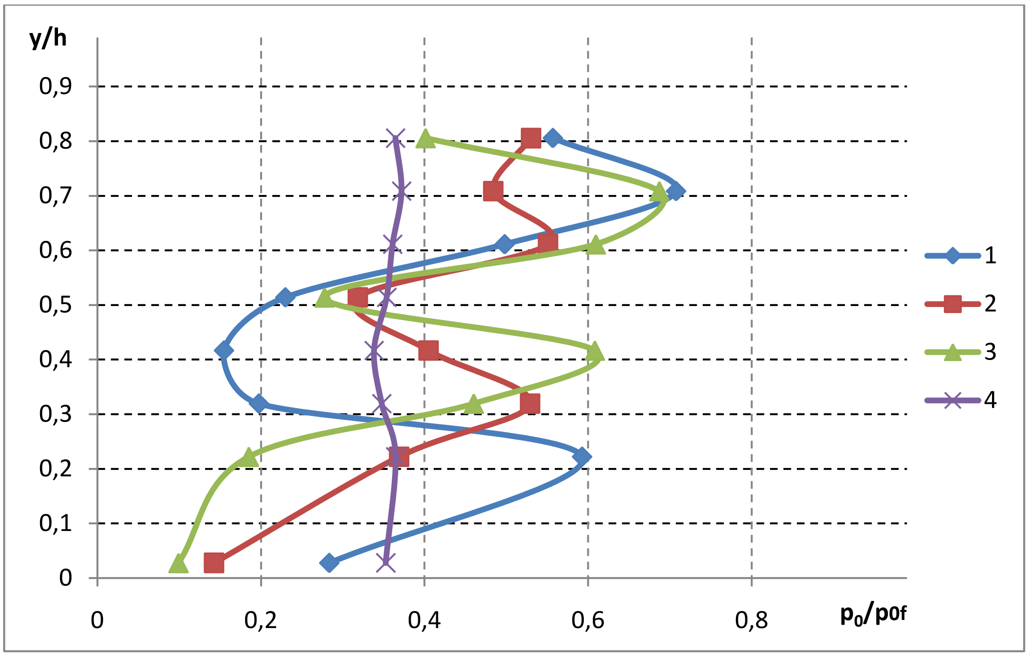
Fig.7 Variants of dividing partitions: a – long impenetrable partition, b – two short impenetrable partitions, c – long penetrable partition, d – two short penetrable partitions

For channel variants with and without a partition, a comparison of schlieren visualization and pressure distribution is given. In Fig. 8 photos of schlieren visualization are shown, and in Fig. 9 - graphs of the distribution of relative total pressure along the height of the channel p_0 / p_{0f} (pressure is related to total pressure in freestream p_{0f}; in this case, dependences 1, 2, 3, 4 are obtained at different stages of channel throttling). It can be seen that the flow in the channel without a partition is essentially uneven, after the installation of the partition some equalization of the flow field occurs.

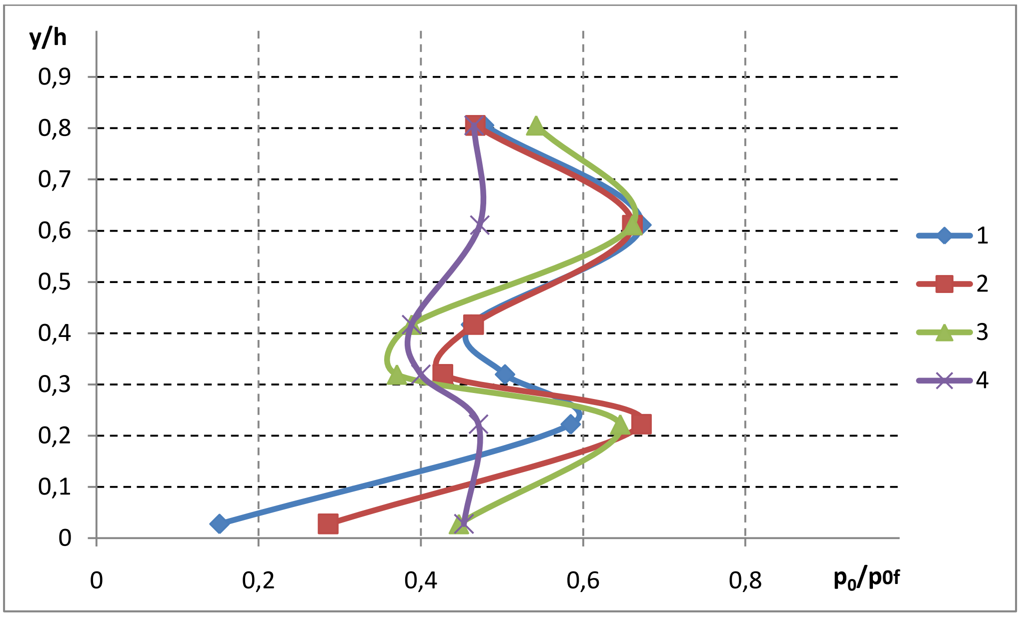


a) b)

Fig.8 Schlieren visualization at M_f = 2.9: a – duct without partition, b – duct with penetrable partition



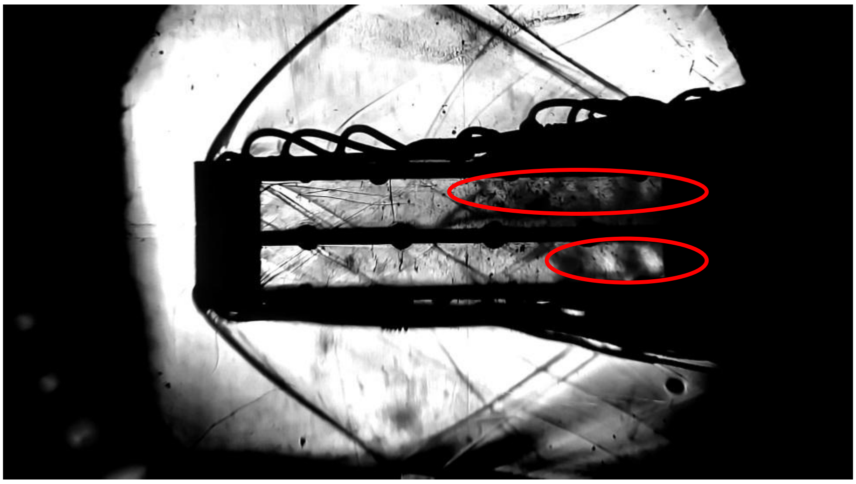
a)



b)

Fig.9 Relative total pressure distribution over the height of the model at different stages of throttling. M=2.9: a – impenetrable partition, b – penetrable partition

In Fig. 10 comparison of schlieren visualization for penetrable and impenetrable partitions arranged parallel to the plane of symmetry of the channel is given. It can be seen that in the case of an impenetrable partition, shock trains develop unevenly in the upper and lower channels during throttling. In the case of creating a gas-dynamic connection between the channels by installing a penetrable partition, flow parameters are aligned, and the shock trains develop approximately equally in the upper and lower channels.


a)

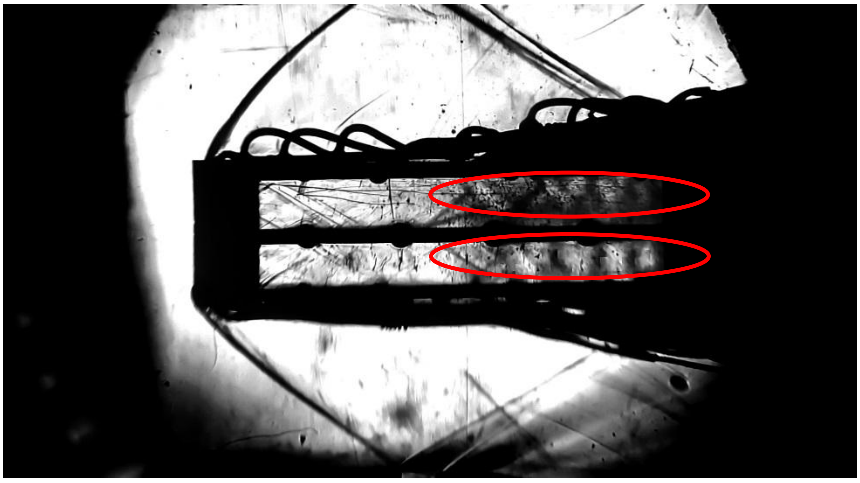

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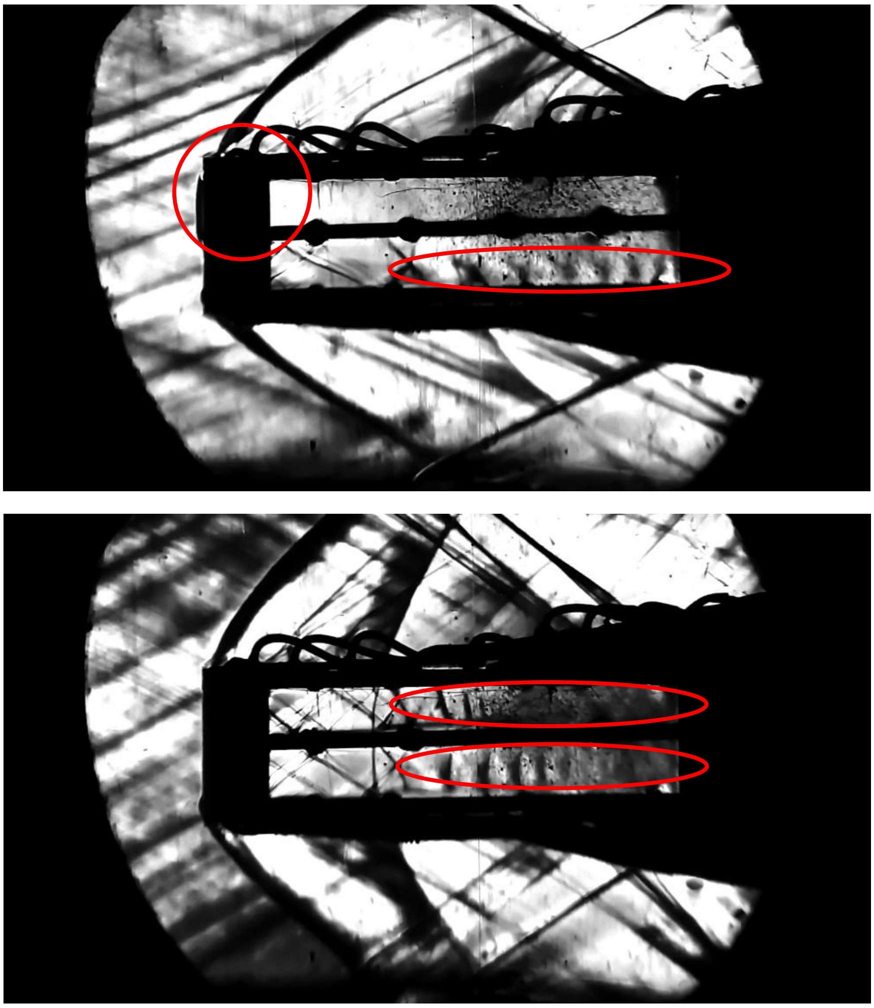
Fig.10 Schlieren visualization at M_f = 2.9: a – duct with impenetrable partition, b – duct with penetrable partition

For the variant of the model with the partition located at an angle to the plane of symmetry, the effect of the gas-dynamic connection between the channels is even more obvious. In the case of an impenetrable partition, the flow in the upper and lower channels is significantly different: the lower channel is "started" and shock train is realized in it, and in front of the upper one bow wave is observed (Fig. 11 a). In the case of the creation of a gas-dynamic connection between the channels, the flow parameters are aligned, both channels are "started" and shock trains are realized in them (Fig. 11 b). This is also illustrated by measured pressure distributions. In Fig. 10 and 11 comparable areas of flow are highlighted.

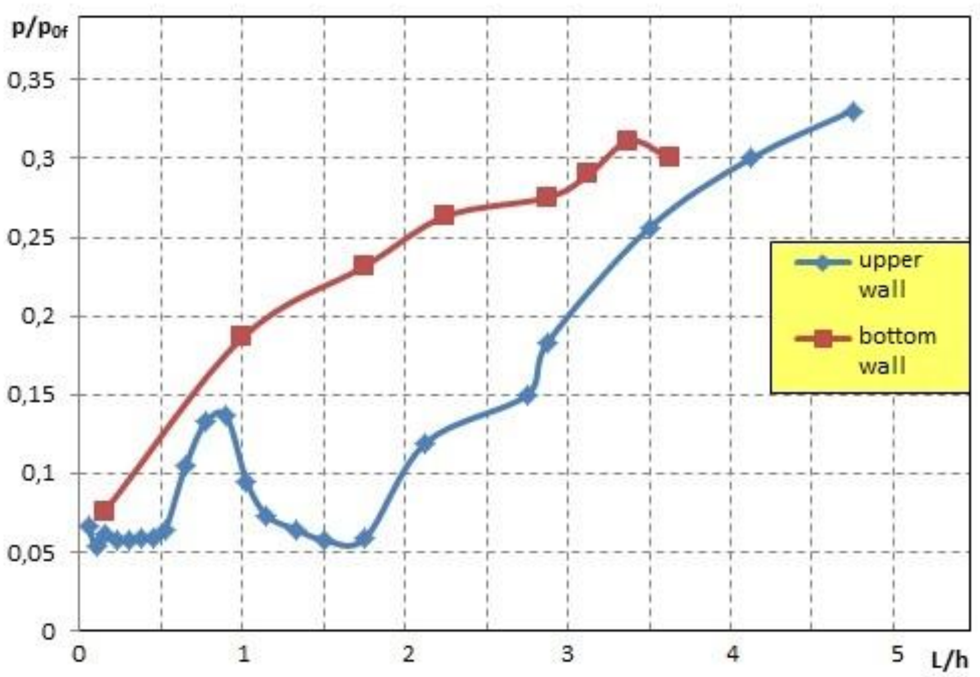


a)

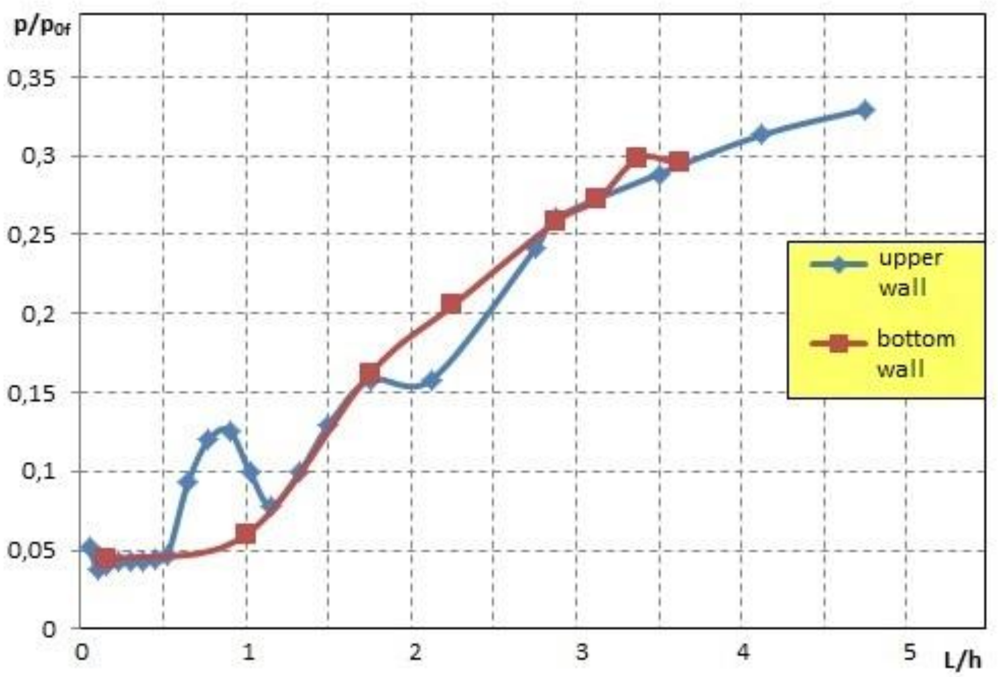
b)

Fig.11 Schlieren visualization at M_f = 2.9, partition located at an angle 1° to the plane of symmetry: a – duct with impenetrable partition, b – duct with penetrable partition

The possibility of equalizing the flow parameters in adjacent channels in case of artificial disturbances in one of them was also considered. A vortex generator in upper channel was used as a source of disturbances. In the presence of an impenetrable partition asymmetrical flow was realized in upper and lower isolated channels (Fig. 12a). If there were slotted holes in the partitions, the flow parameters were noticeably aligned. Thus, at a length of ~ 3.88 h, p / p_{0f} values for the upper and lower channels, separated by an impenetrable partition, differed by an amount of ~ 16%. When partitions with slotted holes were installed, this difference was reduced to ~ 3%.



a)



b)

Fig.12 Model with vortex generator in the upper channel. Relative static pressure distribution along the duct of the model. M=2.7: a – impenetrable partition, b – penetrable partition

Thus, as a result of research it is shown:

1. Improvement of the characteristics of decelerating flow in the rectangular duct of an engine precombustion diffuser can be obtained by installing dividing partitions parallel to the plane of symmetry. The installation of partitions reduces the flow irregularity, equalizes the flow parameters at the end of the channel, reduces the longitudinal dimensions of the flow deceleration area and the best results are achieved for penetrable partitions.

2. The use of a longitudinal penetrable partition, located at an angle of 1 ° to the plane of symmetry, leads to broadening of the the start conditions and an increase in the operational stability of the duct by comparison with the variant with an impenetrable partition.

3. If there is a disturbance source in the form of a vortex generator in one of the adjacent channels, the existance of a gas-dynamic connection between the channels also helps to equalize the flow in the adjacent channels.

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