Numerical investigation supersonic jet near field with a longitudinal slit cutout on the expiration channel

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Abstract. The effects of a slit cutout length on the parameters of a supersonic flow are studied. The flow in the nozzle with a Mach number $M = 2$ was simulated numerically. The jet from the nozzle passed through the 30 cm long tube and then exhausted into quiescent air. Two symmetrical longitudinal slits were cut at the end of the tube. Three cases with 3, 6, and 9 cm cutouts were considered. The slit width was fixed at 1 cm for all cases. The study showed that an increase in the cutouts length leads to a slight increase in the mixing zone width at the jet boundary. However, the mixing intensity gradient was decreased. This flow case is somewhat similar to the chevrons used in some practical applications. So the cutouts can be used to reduce the intensity of the acoustic noise in the far field.

1. Introduction

The supersonic jet noise is usually generated by the high-speed jet exhausting in the ambient stationary medium. This process is one of the main sources of the acoustic noise, in situations like the technical gases exhaust at the industrial facilities. Acoustic noise from a supersonic flow can lead to a deterioration in the people health in the vicinity. Therefore, the problem of reducing acoustic noise from a supersonic jet is relevant and important.

There are many options for reducing the supersonic jet acoustic noise. The best options include screening the jet with a gas screen [1], use of sector nozzles, multi-tube nozzles, use of periodic electric discharges, injection of a liquid into the main stream, using chevrons and other active methods [2].

The jet exhausting from bypass-ratio nozzles was considered by Sayed et al. [3], where the chevrons of various configurations were used to suppress acoustic noises. Mehmed et al. [4] also used chevrons and eight micro jets as generators of longitudinal vortices. Experiments of Zapryagaev et al. [5] demonstrated the significant efficiency of water injection for changing the acoustic spectrum supersonic jets radiation. It was showed that increasing the injection rate of water jets reduces the magnitude of the main supersonic jet acoustic noise. James B et al. [6] showed that the use of the lobed mixers allows one to reduce the jet acoustic noise by 10 dB. Zapryagaev et al. [7, 8] also studied the chevrons influence on the main features of the supersonic jet flow both experimentally and numerically. Sipatov et al. [9] developed a numerical method for supersonic jet noise modeling using the ANSYS Fluent software package. Using this approach, influence of the various geometric nozzles characteristics on the acoustic radiation intensity analyzed.

The present study shows the influence of the longitudinal cutout length in tube on parameters of a supersonic flow. The study is carried out on the basis of the numerical simulation. The theoretical and
analytical equations determining the jet power were shown to be valid for the values of the Mach numbers between 1.5 and 2 [10, 11].

2. Conditions of computations
Three-dimensional modeling of the supersonic jet flow into the quiescent air was performed. Modeling took into account the gas viscosity, both molecular and turbulent. For the numerical simulation, the commercial ANSYS Fluent software package was used. The general approach is to use the Reynolds-averaged Navier-Stokes equations (RANS) with a suitable turbulence model (SST k-ω) to close the system of equations.

Figure 1 shows a scheme of the computational domain indicating the main dimensions. At the inlet boundary, the static temperature and pressure drop were set. The flow passed through the profiled nozzle reaching the Mach number value M = 2. The flow enters from the nozzle into the tube 300 mm long. Several cases were considered with different lengths of symmetrically located slit cutout at the tip end l = 3 cm, 6 cm, and 9 cm. In all cases, the slit cutout had a constant width of 1 mm. The flow exhausted from the tube into the still air.

![Figure 1. Scheme of the computational domain.](image)

This type of flows require highly accurate computations, because even small changes in environmental parameters affect the flow pattern. Therefore, in the calculation, a mesh with a high density and good quality should be used. To ensure an appropriate grid structure, the area of the nozzle, tube, and jet core was divided into cubic elements 0.4 mm in size. The area near the jet core was divided into 0.8 mm elements. The maximum grid elements size at the remote boundary was 24 mm. The computational domain was divided into 12 000 000 elements, most of which were concentrated in the jet flowfield.

3. Results
Figure 2 shows the pressure contours of the jet exhausting from the tube for all cases considered. An increase in the slit cutout length at the discharge channel cut leads to a decrease in the jet plume length and to a decrease in the pressure drop intensity. The 3 cm slit cutout reduces the jet plume length by about 17%. Each subsequent increase in the length of the slit cutout by 3 cm reduced the length jet plume by about 3%.

Figure 3 shows the turbulence kinetic energy contours during the jet expiration from the tube for all cases considered. An increase in the length of the slit cutout leads to an increase in the mixing zone at the outflowing jet boundaries and to a decrease in the gradient of the mixing intensity in the near outflow field. This flow picture in the mixing zone is somewhat similar to the case of chevrons use.
Figure 2. Pressure contours in the plane of symmetry for the case of blowing out from tube without slit cutout (a) and with slit cutout length: 3 cm (b); 6 cm (c); 9 cm (d).

Figure 3. Turbulence kinetic energy contours in the plane of symmetry for the case of blowing out from tube without slit cutout (a) and with slit cutout length: 3 cm (b); 6 cm (c); 9 cm (d).
4. Conclusion
A study by numerical simulation showed that the use of a slit cutout on the expiration tube of a supersonic jet leads to a decrease in pressure in the outflowing jet, a decrease in the mixing zone intensity and a decrease in the jet plume length. All these factors should lead to more rapid jet attenuation in space, and, as a result, a decrease in the acoustic effect from the jet outflow. An increase in the slit cutout length leads to a more efficient attenuation of the outflowing jet, which means a more efficient reduction of acoustic noise.

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