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# Influence of shear layer control on mixing enhancement

**An shear layer control**

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***Abstract:*** This paper reports an investigation into the shear layer control of impulse jets by comparing different types of nozzles that were used as injectors in detonation experiments. Experiments were carried out to visualize the non-reactive air flow from the injectors. Preliminary whistler nozzle and sonic generator flows were visualized and evaluated. The acoustic wave frequency was measured on the basis of schlieren pictures to be 27 kHz for the whistler nozzle, and 17 kHz for the sonic generator. Image processing was applied to calculate the contact surface area. Under the same initial parameters the contact surface areas from the two different configurations differ strongly.

***Keywords:*** Visualization, impulse jets, mixing enhancement

# 1. Introduction

The existence of large structures in a shear layer and the relation of these structures to flow instability make it possible to control the development of the shear layer and thus affect its mixing characteristics. Mixing enhancement techniques are arranged in two categories: passive and active techniques of shear layers.

To enhance the mixing due to using a passive technique, a fully expanded Mach 2 circular jet using open rectangular and semicircular cavities was mounted adjacent to the jet exit plane [1]. The observed forcing frequencies can be explained by either a convective-acoustic feedback mechanism or normal mode resonance of the cavity. The efficiency of external acoustic excitation (active control) of a high subsonic jet has been demonstrated using an acoustic generator [2].

The aim of this paper is to investigate the shear layer control of impulsive jets from different types of nozzles that were used as injectors in detonation experiments. Experiments were carried out to visualize the non-reactive air flow from the injectors.

# 2. Experiments

## *2.1 The experimental setup*

The experimental equipment consisted of a square section shock tube connected to a vacuum chamber (fig. 1). This vacuum chamber is equipped with optical windows. At the end of the shock tube, different nozzles were mounted in turn. The post-shock flow was visualized by an IAB-451 schlieren device. The schlieren pictures show the time evolution of the process at intervals of 5 - 10 μs with an exposure of 1 μs. To obtain 72 images in one experiment, a high-speed optical-mechanical device VSK-5, with a frame size of 16 x 22 $mm^2$ was used. In the visualization experiments, the initial ambient pressure $P_0$ and the incident shock wave Mach number $M_0$ were defined as parameters. The mass flux through the nozzles was equal to the calculated value in detonation experiments. The incident shock wave Mach number was set so that parameters behind reflected shock wave ensure the same mass flow rate as in detonation experiments. The pressure ratios were 3.5-17. The ambient conditions and mass flux were the same in visualization and detonation experiments

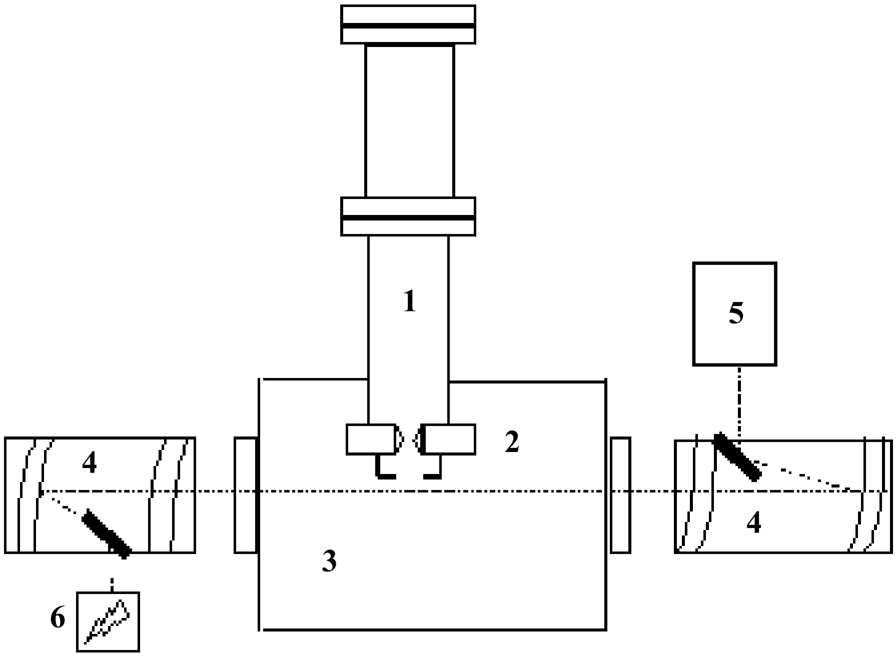


Fig. 1 The experimental setup. 1- shock tube; 2- nozzle; 3- vacuum chamber; 4- shadow device IAB-451; 5- high speed camera VSK-5; 6- light source

## *2.2 Flow visualization of injected gas*

The whistler nozzle consists of a nozzle and a resonator (annular cavity) (fig. 2a.). The supersonic jet from nozzle can interact with the cavity excited the instability modes in the jet. The modes depend on the jet velocity and the dimensions of the collar. The acoustic driver (fig. 2b) consists of the sonic nozzle and resonator (the tube with closed end). The nozzle and resonator are connected with a screw to adjust distance between them.

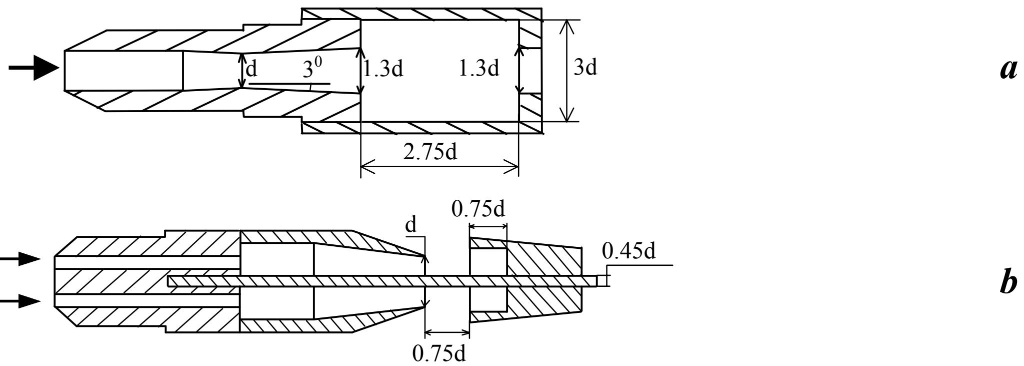


Fig. 2. Whistler nozzle (a) and acoustic driver (b). Dimensions are presented terms of the critical area.

Preliminary whistler nozzle and sonic generator flows were visualized and evaluated. The flow injection through the whistler nozzle is presented in fig. 3a. The acoustic driver was investigated as an injector (fig. 3b) and as an external sound field generator (fig. 3c.). The distance between sonic nozzle and the resonator (fig2.b) was chosen using experimental flow visualization schlieren pictures the sound field frequency was close value to whistler nozzle one. The acoustic wave frequency was determined using schlieren pictures to be 27 kHz for the whistler nozzle, and 17 kHz for the sonic generator. The incident shock wave increased the sound velocity that was measured using the known time between frames in high-speed imaging and corresponded $380^0$K. . The whistler nozzle (Fig. 3a) and external sonic generator produced a surrounding sound field (Fig. 3b) and can excite the shear layer perturbations of the supersonic jet (fig. 3c).

In detonation experiments the injectors were installed in a disk of 83 mm diameter. The reactants were injected through six injectors: three for oxygen and three for hydrogen. In the detonation tube, the surrounding acoustic field disturbs the neighborhood jets. In the conditions investigated, there was a mutual, simultaneous excitation between the neighboring reactant flows. To visualize the mixing characteristics, the situation was simplified. Only the flow from a single injector was visualized. The contact surface was considered as a mixing surface of the injected flow and surrounding gas. In this case, the contact surface can be considered as one of the mixing characteristics. Image processing was applied to calculate the contact surface. The surrounding sound field produced by the sonic generator (fig. 3b) influences the supersonic flow and the starting vortex injected from supersonic nozzle without resonator (fig. 3c).

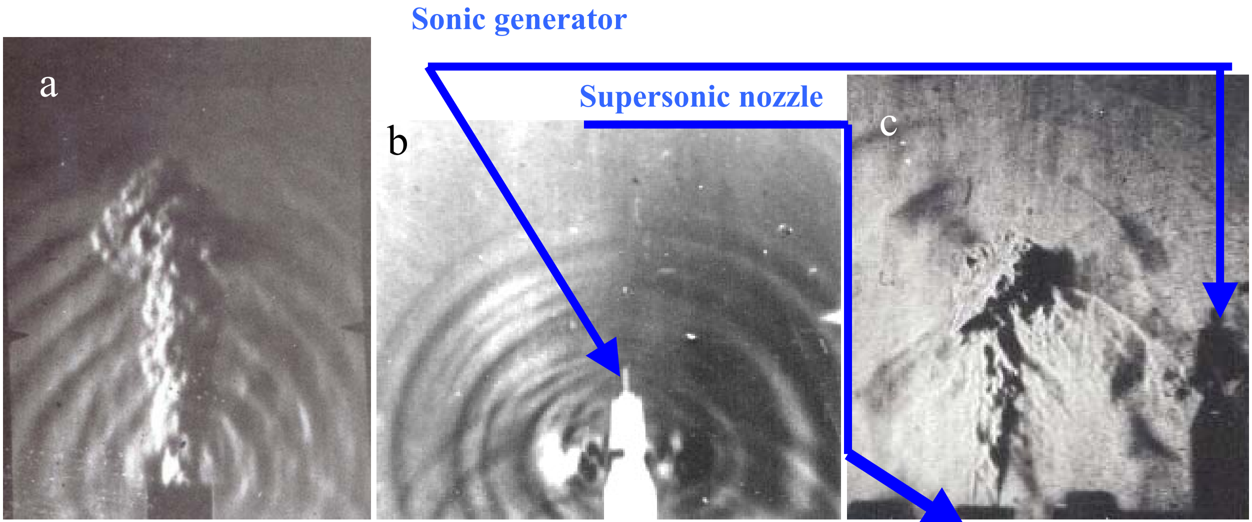

Fig.3 Schlieren pictures of (a) whistler nozzle producing passive shear layer control due to the resonator; (b) acoustic driver performance; (c) perturbations in the shear layer of the supersonic jet due to the acoustic driver

# 3. Results

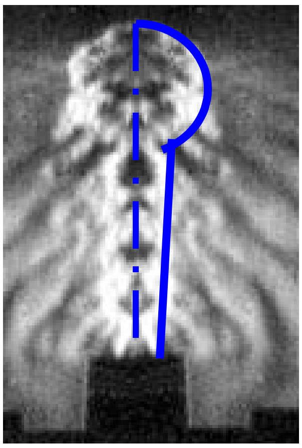
Fig.4. Image processing that reveals the contact surface

## *3.1 Image data processing*

The pictures were scanned into computer memory. The image was processed using Adobe Photoshop to reveal the boundaries. Since the schlieren knife-edge was installed orthogonally to the flow direction, the boundaries were of different shades on the left and right sides of the picture. The better quality side was chosen for future calculation of the contact surface area. The picture split along the line of symmetry and the better half was reflected to form the image shown in fig. 4. The boundary curve is shown as a solid blue line in the figure. This curve forms three-dimensional surface by rotating around the axis. The curve was divided into small length segments that can be approximated by different mathematical curves. The area for every segment can be calculated. The surface area was then calculated as the sum of the areas of the segments.

Additional problems were connected with the frequency regime of the sonic generator. In fig. 5, the schlieren pictures are presented in time sequence. The contact surface was revealed in the initial frames only, see figs. 5a, b. Later the contact surface cannot be detected, see figs .5c, d. The injected gas propagated contact surface due to extension has the same parameters like ambient gas therefore it disappear in pictures set. The measurements of sonic generator contact surface area were produced at the beginning of propagation (fig. 6, curve 3).

## *3.2 Contact surface area measurements*

According to the described technique, the contact surface areas were calculated for supersonic nozzle (whistler nozzle without resonator), whistler nozzle and sonic generator. Under the same initial parameters, the contact surface areas from the jets strongly differ for the whistler nozzle and supersonic nozzle (fig. 6, curves 1 and 2 correspondingly). This difference is increases with time. The areas of the sonic generator flow (curve 3) appear to considerably exceed those of whistler and supersonic nozzles for the same test conditions (curve 1 and 2). The disturbed jet contact surface area was measured for whistler nozzle flow with less mass flux and pressure ratio (curve 4). This parameter is close to one of an undisturbed jet from the supersonic nozzle of the more mass flux and pressure ratio (curve 2).

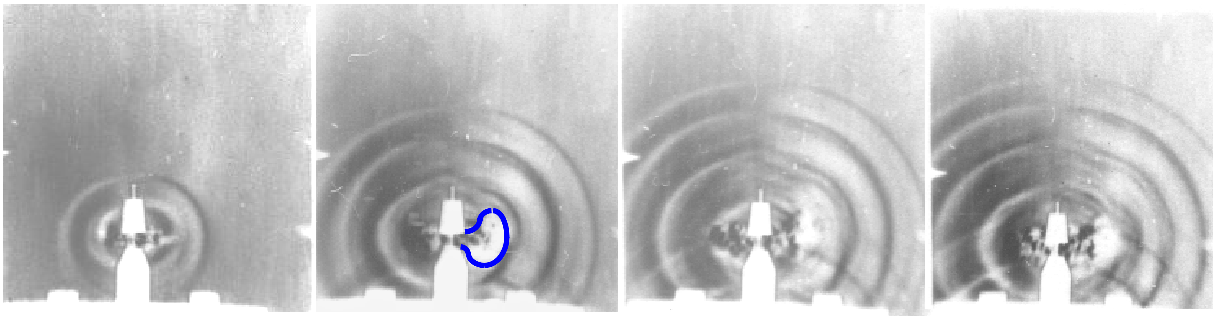

Fig.5 High speed schlieren pictures of sonic generator performance. The ambient pressure is 1 atm, the pressure supply is 6.15 atm. The time moments from the start of the process are 72 μs, 156 μs, 192μs, 228 μs.

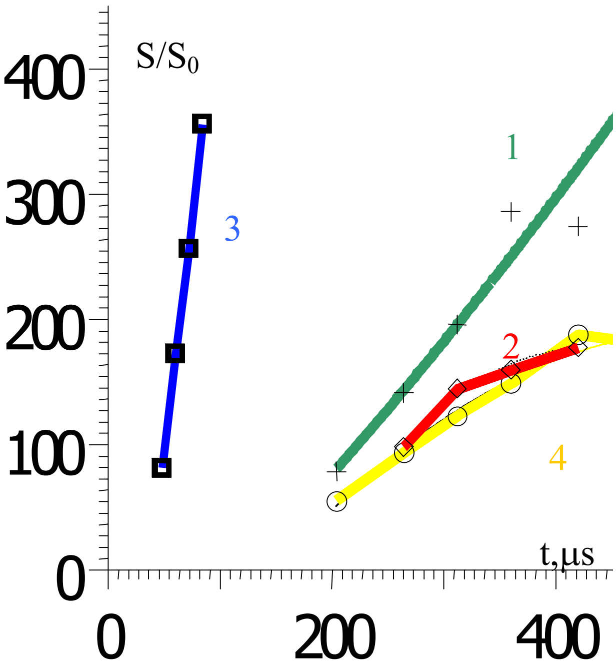


Fig.6 Dependence of the contact surface area of formed jets following from nozzles of the same critical area as function of time; the pressure ratio = 6.6 and mass flux of 33.1 gram/s: curve 1 – from the whistler nozzle (green), curve 2 – from circular supersonic nozzle (red), curve 3 – from sonic generator (blue), the pressure ratio = 4.05 and total mass flux = 21.1 gram/s: curve 4 – from the whistler nozzle (yellow)

# 4. Conclusions

1. The acoustic wave frequency was measured using schlieren pictures
2. Image processing can be applied to obtain the contact surface area
3. Under the same initial parameters the contact surface areas strongly differ for the whistler nozzle and supersonic nozzle.
4. The areas of the sonic generator flow appear to be considerably exceeded at the same initial parameters of jets

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