

Supersonic Pulse Jets Impinging on a Truncated Cylinder

by

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Abstract

A numerical investigation of the sound produced by an axisymmetric supersonic pulse jet impinging on a truncated cylinder is performed. The Euler equations in the axisymmetric coordinate system are used. Flow field around the body is investigated in detail with a TVD finite difference scheme. It is confirmed that strong sound pressure waves are generated due to strong interactions between shock waves and vortical structures. The detailed feed back mechanism of impinging tones is confirmed numerically, which are quite consistent with the previous experiments.

1. Introduction

The production of discrete frequency sound by the interaction of a supersonic jet and a normal flat plate was first reported by Marsh (1). Since then, many papers treating impinging tones have been reported, for example, by Ho and Nosseir (2), Didden and Ho,(3) Norum(4), Powell(5), Kuo and Dowling (6).

Powell's experiments with the supersonic impinging jet on a plate led to the realization that two different classes of tones existed: small plate tones and large plate tones. He found that there can exist a dominant and a minor with a different mode in the large plate tones for a large nozzle-plate distance. The small plate tones occurred when the plate was located in the pressure recovery region of the jet. This led to the suggestion that these tones were related to the

high harmonics of the Hartmann whistle.

As pointed out by Kuo and Doeling (6), these experimental investigations reveal two important sources of discrete-frequency perturbations in the jet-plate geometry. These are standoff shock oscillation and vortex shedding in the jet shear layer. Both self-excited oscillations rely on acoustic feedback to sustain the motion. The vortex shedding mechanism in the freejet involves jet disturbances excited at the nozzle exit and acoustic feedback between the plate and the nozzle lip. In the impinging jets on the plate, also large self-excited shock oscillations exist when the standoff shock lies in the downstream portion of each shock cell (7,8,9). In this case, however, Hendrson and Powell pointed out that, at least for some flow conditions, some feedback to the nozzle is required if the oscillation is to be self-sustained. The shock oscillation sound is found to dominate the vortex shedding sound when the plate size is less than two jet diameters.

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In the present paper, generation mechanism of the small plate tones is investigated numerically. Supersonic circular pulse jets impinging on a truncated cylinder are considered to simulate production of strong pressure waves due to interactions between vortices and a cylinder, between vortices and a shock wave, and between a pressure wave and a jet boundary. Numerically it was confirmed that these interactions play important roles in generation of strong pressure waves and then in construction of a feedback loop for discrete frequency pressure waves, a kind of impinging tones.

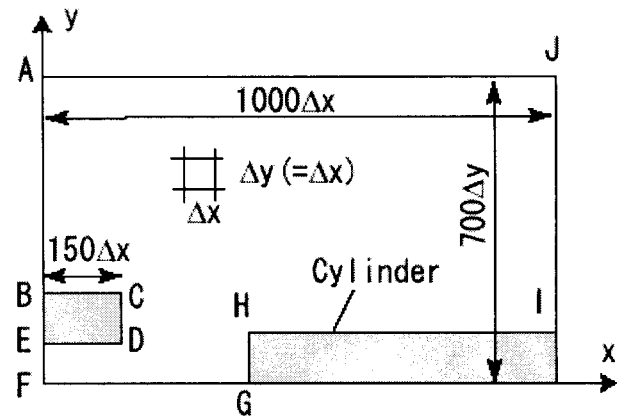
2. Numerical Simulation

2.1 Jet and boundary conditions

The computational domain and the nozzle-plate configuration are shown in Fig. 1, where the coordinates are normalized by the nozzle diameter D_S and square meshes ($\Delta x = \Delta y$) are employed. Wall conditions are applied on the body surfaces, BC, CD, DE, GH and HI, symmetric conditions are imposed on the centerline FG, ambient gas conditions are applied on the boundaries AB, AJ and IJ, and jet conditions are applied on the line EF. The jet conditions are specified as solutions of the shock tube problem for the pressure ratio $p_1/p_4 = 8.7$, where p_1 and p_4 are the initial pressures in the low- and high-pressure chambers. In this case, the constant jet conditions $M_j = 1$ and $p_j/p_1 = 1.79$ are realized at the nozzle exit at times greater than about 100 μsec after the jet blast for $D_S = 2.0$ cm (8).

2.2 Numerical Results

Here the results for $h/D_S = 2$ and $D_B/D_S = 1.25$ are shown, where h and D_B are the nozzle-plate distance and the cylinder diameter, respectively. For comparison with the previous experiments,



Euler equations (Axisymmetric)
 $C_{FL} = 0.2$, $\Delta x = 0.01$

BOUNDARY CONDITIONS

EF: Jet Condition

BC, CD, DE, GH, HI: Wall Condition

FG: Symmetric Condition

AB, AJ, IJ: Ambient Gas Condition

Figure 1: Schematic of computational domain.

the time $t = 0$ is taken as computational domain the time when the first shock arrives at the nozzle exit. Since the time evolution of this pulse jet without the cylinder (freejet) is presented in the previous paper (8), only the results at times after reflection of the first shock from the cylinder surface. Figs. 2-a and 2-b show the density contours of the jets at times from $t = 118 \mu\text{sec}$ to $t = 498 \mu\text{sec}$. At $t = 228 \mu\text{sec}$, convection of the first vortex is blocked by the cylinder edge and the vortex-induced shock in it cannot exist inside the vortex and then begins to propagate upstream to form a strong pulsed pressure wave as shown in the jets at $t = 268$ to $418 \mu\text{sec}$. On arriving at the nozzle lip, the pressure wave disturbs the unstable jet boundary and the coherent structure is produced during its convection as shown in the jets at $t = 418$ and $438 \mu\text{sec}$. When the reflected shock arrives at the nozzle lip, it disturbs the unstable shear layer (jet boundary) seen in the

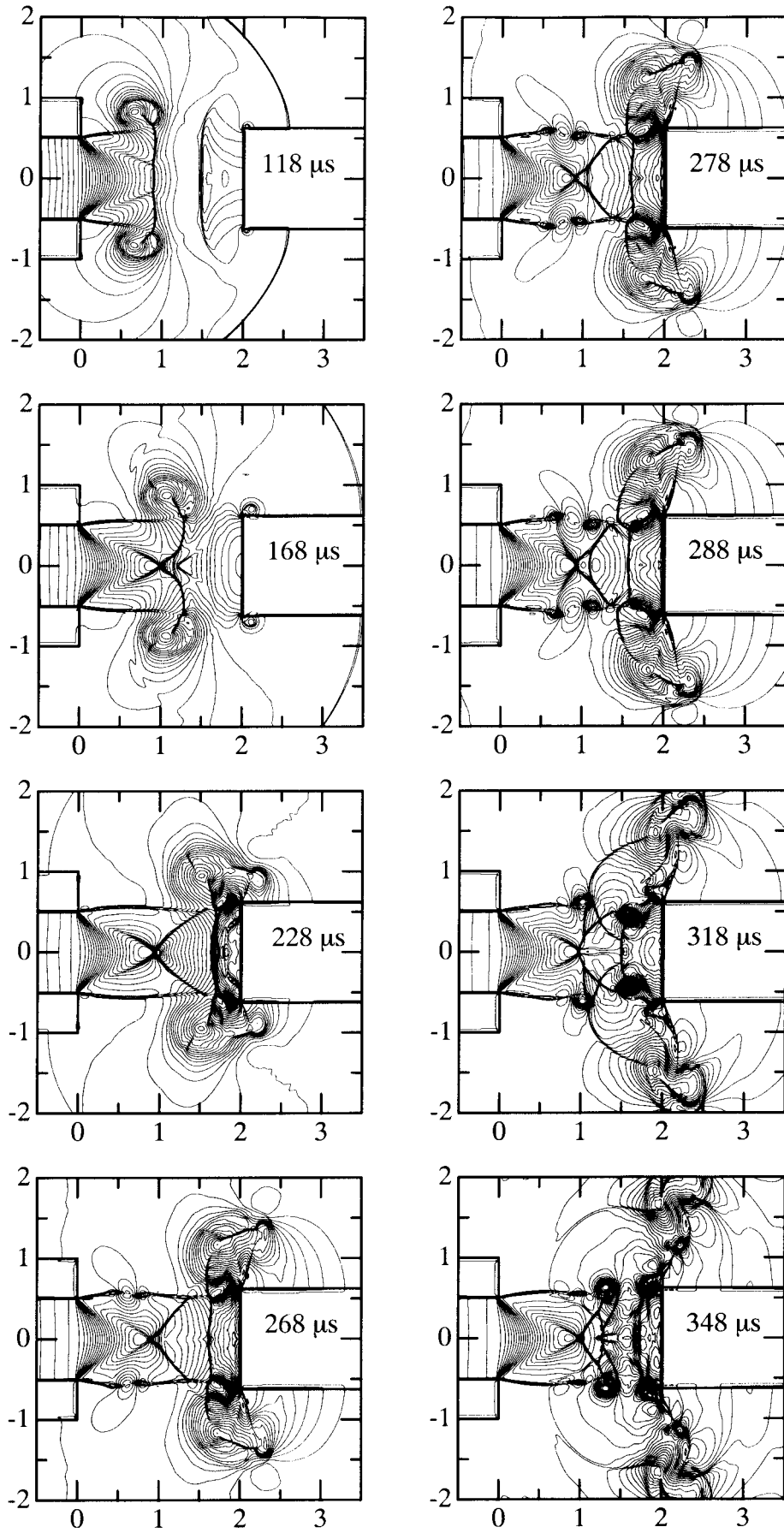


Figure 2a: Density contours of impinging jets

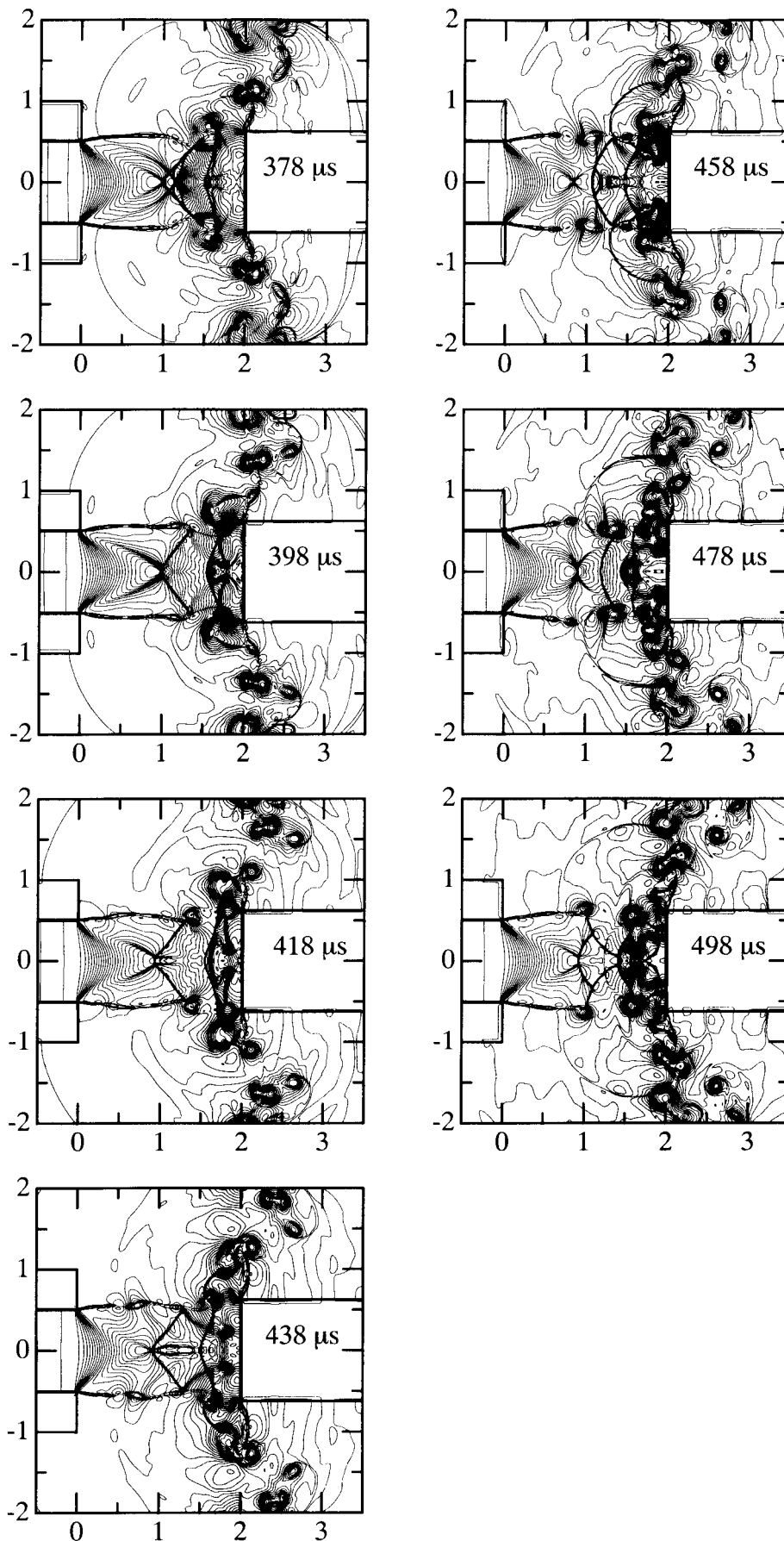


Figure 2b: Density contours of impinging jets

jets at $t = 228$ and $268 \mu\text{sec}$, and the coherent structure is produced and convected downstream. It interacts with the standoff shock in front of the

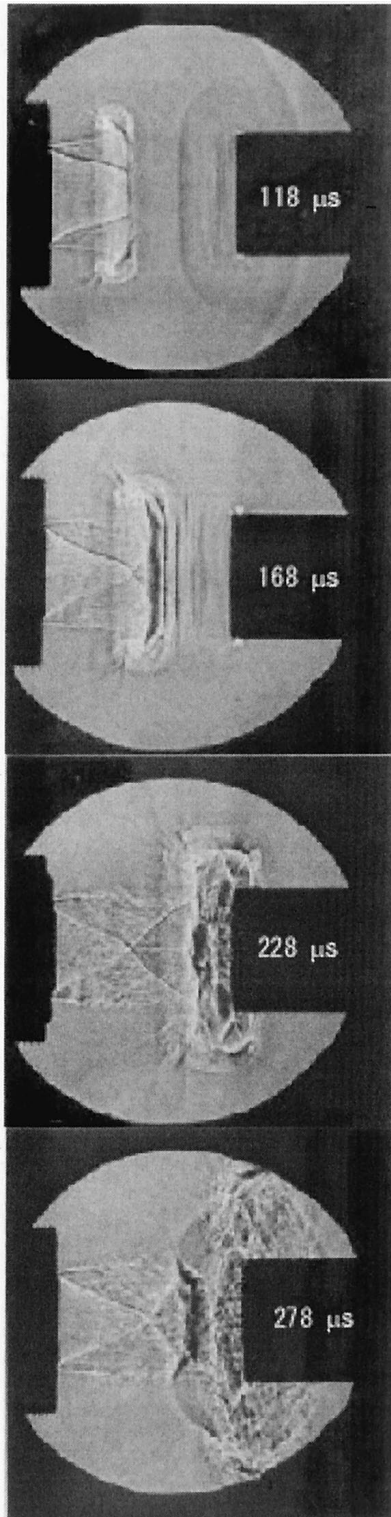


Figure 3: Comparison with experiment.

cylinder surface to produce the second pulsed wave as seen in the jets at $t = 438$ and $458 \mu\text{sec}$.

It is reasonably expected that the coherent structure produced by the interaction of the first pulsed wave and the unstable shear layer will interact with the standoff shock to produce a new pulsed-pressure wave. The pressure wave, unstable shear layer, coherent structure and standoff shock will constitute a feedback loop for generation of discrete frequency pressure wave, a small plate tone. This is quite consistent with Powell's experiments and his subsequent feedback model.

3. Comparison with experiments

Finally, the present numerical results are compared with our previous experiments. Fig.3 show the corresponding experimental results for $h/D_s = 2$ and $D_B/D_s = 1.25$ and $p_4/p_1 = 8.7$. Obviously, the numerical results well predict the flow fields. In the experiments, the flow field in front of the cylinder surface becomes significantly fluctuated and the vortical structure and the shock waves in front of the body surface cannot be identified. In the numerical jets, weak and small scales of fluctuations cannot be simulated but the larger and stronger flow structures can be well simulated (8). So the present numerical results are quite helpful to understand the generation mechanism of discrete frequency pressure waves, small plate tones.

4. Conclusion

A generation mechanism of pulsed pressure waves from the impinging jet was investigated numerically. The results were quite consistent with the previous experiments and the corresponding feedback model. Unfortunately, the self-sustained oscillation of the jet due to the

feedback loop could not be simulated. This is because the jet evolution at larger times simulated numerically is appreciably affected by the artificial boundary conditions specified on the upstream, downstream and outer boundaries. In spite of this, the numerical results gave us very useful and interesting information about the generation mechanism of small plate tones in the impinging jet.

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