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Aero-acoustics-I

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[1-B-01] Computational Estimation of the Drag on an Acoustic Liner in Three-Dimensional Turbulent Flow

*Hideaki Matsuura[1], Daisuke Sasaki[1], Shunji Enomoto[2], Junichi Oki[2] （1. Osaka Metropolitan University, 2. Japan Aerospace Exploration Agency）

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Computational Estimation of Drag on an Acoustic Liner under Three-Dimensional Turbulent Flow

Hideaki Matsuura*, Daisuke Sasaki*, Shunji Enomoto**, and Junichi Oki**
Corresponding author: sh24186d@st.omu.ac.jp
* Osaka Metropolitan University, Japan.
** Japan Aerospace Exploration Agency, Japan.

Abstract: Acoustic liner is essential for reducing noise in jet engines, but they also induce aerodynamic drag. This study examines the impact of hole shapes on the drag of acoustic liner used in jet engines. Using UPACS-LES for three-dimensional turbulent flow analysis, we compare the drag of three different hole shapes: a Square, a Z-slit, a Round. The simulations, conducted with an inflow Mach number of 0.3, reveal that the square hole generates the most drag, mainly due to vortices forming at the neck. The Z-slit hole, on the other hand, produces the least drag, thanks to its unique vortex formation inside the cell. These findings confirm that the shape of the holes significantly influences drag, with the Z-slit shape being the most efficient.

Keywords: Aeroacoustics, Acoustic liner, CFD, Drag

1 Introduction

Acoustic liners contribute to the reduction of noise in jet engines. They are composed of a surface with tiny holes and honeycomb structure cells. While these acoustic liners serve a critical function to reduce fan noise, they induce aerodynamic drag. The performance characteristics of acoustic liners vary depending on the shape of the holes. Noguchi et al. [1] conducted numerical simulations to investigate the impact of the shapes of hole on the sound absorption rate of acoustic liners under laminar flow conditions. The results show that the shorter the streamwise length of the holes, the higher the absorption rate is. In addition, Zheng et al. [2] and Oki et al. [3] find the same trend with respect to the drag. In their experiment, the shorter the length of the holes, lower the drag. In this study, we conduct a three-dimensional turbulent analysis of acoustic liner by Large-Eddy Simulation. We quantitatively compare the drag caused by different hole shapes and discuss the differences using visualization diagrams.

2 Methods

In this study, we employ UPACS-LES (Unified Platform for Aerospace Computational Simulation) [4] with a compact scheme for analysis of three-dimensional turbulent flow in single acoustic liner model depicted in Fig. 1. Inflow Mach number is 0.3 and the incidence of sound waves is not considered. The model is composed of duct, hole, and cell. A turbulent boundary layer is induced upstream of the hole by introducing tripping device. Computations are conducted for three different hole shapes: a Square, a Z-slit, a Round as illustrated in Fig. 1. We compute drag of these hole shapes by three methods: momentum conservation law analysis, Reynolds stress on the surface of the holes analysis, pressure difference inside hole. Momentum conservation law analysis is mainly used experimentally. Then, Reynolds stress analysis integrate the shear force on the surface of the holes. Pressure difference inside hole compute pressure on the neck and cell parts.

3 Results

Here, the drag force refers to the shear force on the hole surface. The drag is computed by the momentum conservation law, the integral value of the Reynolds stress on the surface of the holes, and pressure difference inside hole. From Table 1, it is apparent that the drag on the square hole is higher compared to the other holes. In addition, the drag due to pressure difference inside the hole is divided as shown in Table 2. This table show the breakdown of drag on the neck part and the cell part. From this table, we can see that most of the drag is generated in the neck part, while the cell part helps to reduce the drag. To investigate the causes, flow inside the hole is visualized as shown in Fig. 2. The figure provides Mach number contour and the streamlines inside the hole. The figure indicates that vortices are generated at the neck. Among them, Z-slit exhibits a characteristic vortex below the neck, which is thought to contribute to the reduction in drag. Next, visualizing the Reynolds stress on the surfaces of the three types of holes, the outcome is depicted in Fig. 3. The figure provides a graphical representation of the Reynolds stress distribution on the hole surface. The figure indicates that the Reynolds stress for the square hole is generally higher than that of the others, and it shows particularly large values near the sides. In addition, only square hole shows non-uniform distribution of Reynolds stress in the Z-direction. To clarify this phenomenon, vortices are also visualized using the Q-criterion as shown in Fig. 4. The figure illustrates the formation of vortices on both sides of the hole. The vortices descend along the wall and rotate. This occurs only in the square hole; thus, this is the reason of the high drag.

4 Conclusion

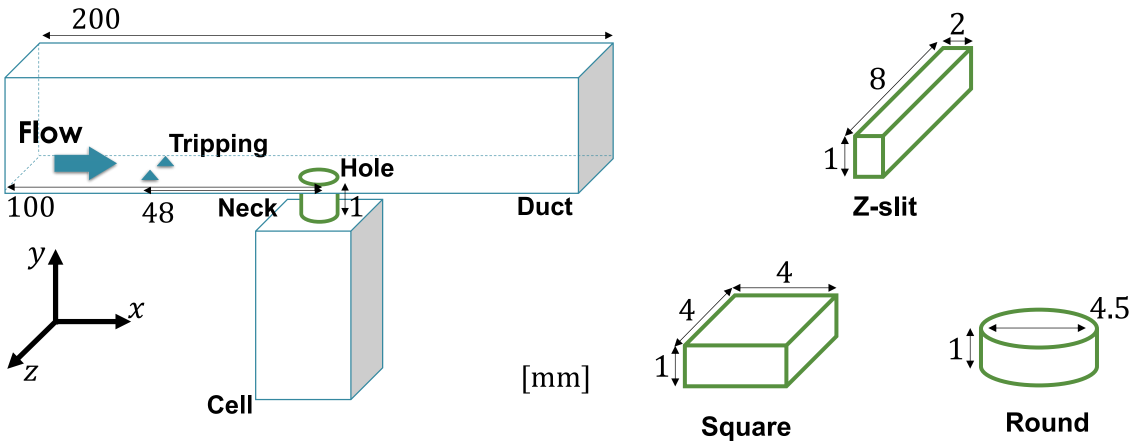
Large-Eddy Simulation was conducted to investigate the hole shape to drag on an acoustic liner. Results shows that Z-slit hole causes the least drag among the three holes. It was confirmed that most of the drag is generated at the neck of the hole. In addition, it is observed that vortices are formed on both sides of the square hole, which causes the large drag. This observation confirms that the relationship between vortices and drag.

Table 1 Drag of Various Hole Shapes (Unit: mN)

	Momentum conservation law	Reynolds stres	Pressure difference inside hole
Square	2.59	2.62	2.90
Z-slit	1.31	1.43	1.49
Round	1.41	1.57	1.58

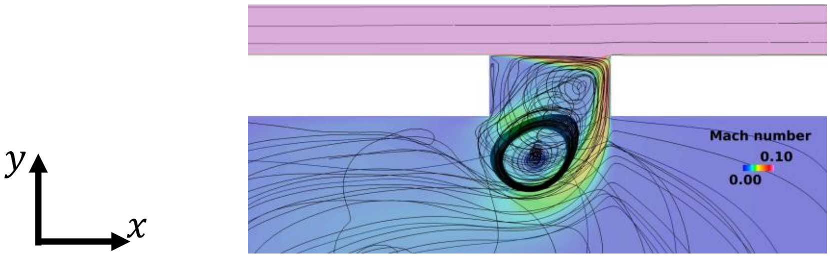
Table 2 Breakdown of Drag (Unit: mN)

	Neck	Cell
Square	3.02	-0.13
Z-slit	1.91	-0.42
Round	1.62	-0.05

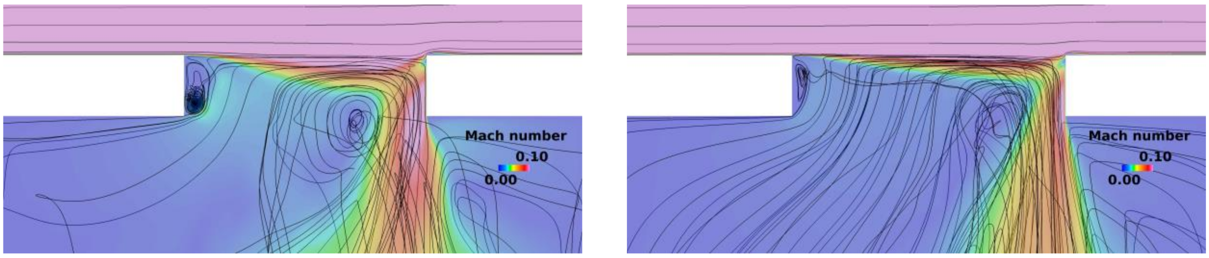


(a) Overview of the computational domain (b) Shape of holes

Fig. 1 Computational Domain



(b) Z-slit



(a) Square (c) Round

Fig. 2 Time-Average Mach Number Contour with Streamline

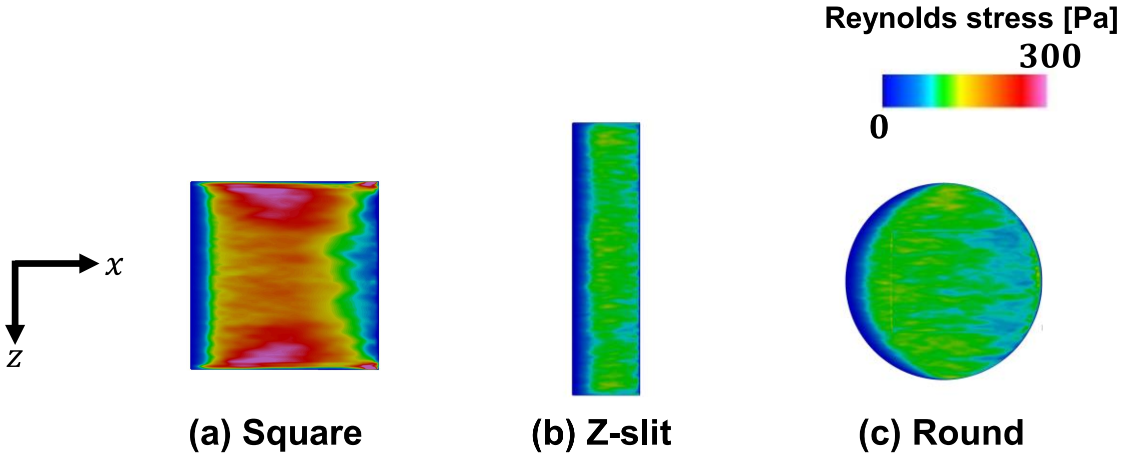


Fig. 3 Reynolds Stress Contours on Each Hole

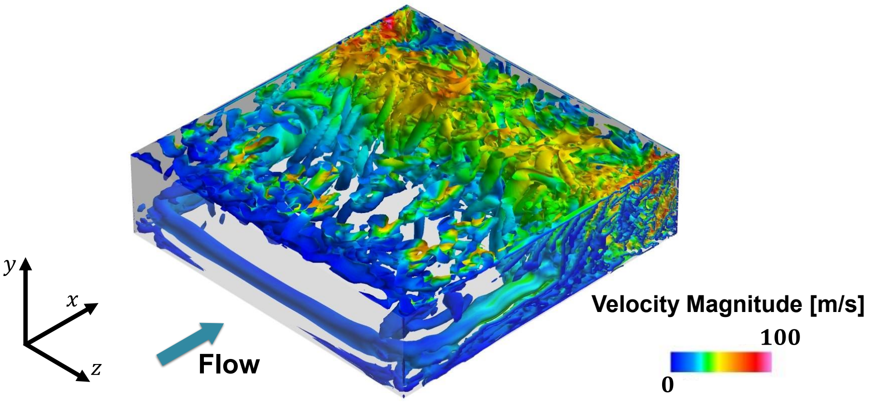


Fig. 4 Iso-Surface of the Q-criterion for Vortices of Square Hole

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