Multisensory Analysis of Characteristic Noise from WW2 Aircraft

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ABSTRACT

The characteristic noise generated from a dive bomber used during World War II is computationally analyzed with the help of visualization and reproduction of generated noise. It is observed from the results of flow field analysis that the large separation occurs from the strut of the dive brake when it is deployed. This is the sound source of characteristic noise. From the results of aeroacoustic analysis, large sound pressure fluctuations are generated from the strut of the deployed dive brake. In addition, the frequency characteristics of the computed sound pressure fluctuations are compared with those of the recorded noise, where the agreement of the fundamental frequency was confirmed. The characteristics and loudness of generated noise can be understood intuitively by the reproduction of noise in addition to the visualization results.

Keywords: Virtual Reality, Aeroacoustics, CFD.

Index Terms: I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual reality; H.5.5 [Information Interfaces and Presentation]: Sound and Music Computing—Modeling; J.2 [Computer Applications]: Physical Sciences and Engineering—Aerospace

1 INTRODUCTION

A dive bomber used during World War II (Fig. 1) flies to targets at high Mach number to get the high bombing accuracy. When the dive bomber dives, the screaming noise like siren noise is observed at the ground. This noise is caused by several factors. The main factors are the dive brake and the non-retractable landing gear. However, the mechanism of the screaming noise is not clear.

The analysis of the noise generated from aircraft can be conducted in computational way with the support of supercomputer. However, it is difficult to understand the characteristic of generated noise only to visualize the sound field. A more intuitive way is needed. Therefore, the noise is reproduced from the computed frequency characteristic in this study. Auditory sense helps one to understand the characteristic and loudness of generated noise from aircraft.

The purpose of this research is the aeroacoustic analysis of the screaming noise generated from the dive bomber and the reproduction of the noise to comprehend the generated noise from aircraft in more intuitive manner. The aeroacoustic analysis method called stochastic noise generation and radiation (SNGR) approach is applied. The flow and sound fields are visualized to understand the mechanism of generated noise from aircraft. The frequency characteristics of generated noise are compared with that of recorded screaming noise on the ground. The characteristic and loudness are intuitively understood by the reproduction of generated noise in addition to the visualization results of the sound field.

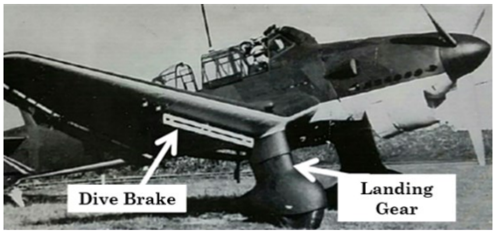

Figure 1: A dive bomber during World War II [1].

2 COMPUTATIONAL METHOD

The SNGR model is used as aeroacoustic analysis method [2]. The SNGR model can simulate the turbulent noise with lower computational cost in comparison with large eddy simulation. First, Reynolds-averaged Navier-Stokes (RANS) simulation with a turbulence model provides a time-averaged flow field. Second, turbulent velocity fields are generated by synthetic eddy method (SEM) using the flow information obtained from the RANS simulation. Third, linearized Euler equation (LEE) with unsteady source terms computed by SEM velocity fluctuations is solved to get the sound field.

A three-dimensional unstructured mesh flow solver named the Tohoku University aerodynamic simulation code is used to simulate a flow field. Compressible Navier-Stokes equations are solved by the cell-vertex finite-volume scheme. Convective fluxes are computed using an approximate Riemann solver of Harten-Lax-van Leer-Einfeldt-Wada. The lower/upper symmetric Gauss-Seidel implicit method is used for time integration. A turbulence model of Menter's shear stress transport model is used.

SEM is based on a superposition of a synthetic velocity signal which can be written as a sum of a finite number of eddies convecting with constant velocity.

LEE simulations are solved on the framework of block-structured Cartesian mesh method called Building-Cube Method. The spatial derivative is computed by fourth-order dispersion relation preserving scheme. Time integration is performed by fourth-order low dissipation and dispersion Runge-Kutta scheme. The outgoing wave is damped by the buffer zone boundary condition.

3 RESULT AND DISCUSSION

In this study, the target is the screaming noise generated from the dive bomber shown in Fig. 1. When the aircraft dives, the dive brake is deployed to reduce the speed by generated drag. Therefore, it is assumed the dive brake is the main sound source and three models are considered to compare the effect of the dive brake; the configuration without the dive brake, the configuration with the retracted dive brake and the configuration with the deployed dive brake.

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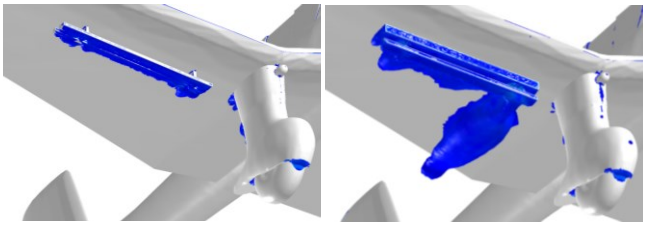
First, a steady flow field is computed. The free stream Mach number is $M_\infty = 0.5$, angle of attack is 0 deg and Reynolds number based on the chord length is $\mathrm{Re} = 2.9\times10^7$. In Fig. 2, zero contour of axial velocity is visualized to visualize the separated regions. The separation from the strut of the dive brake is confirmed. The configuration with the deployed dive brake shows the larger separation from the dive brake compared with the retracted dive brake. Figure 3 shows the axial velocity distribution near the deployed dive brake. Flow between boards of the dive brake is accelerated because of the narrowed flow path. This large separation can cause the screaming noise. On the other hand, there is no separation from the landing gear. Therefore, it is suspected the main sound source is the separation from the dive brake.



(a) Retracted (b) Deployed

Figure 2: Separated region.

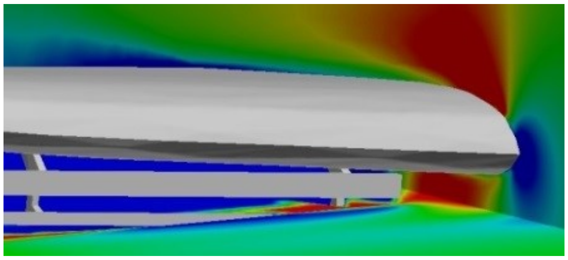
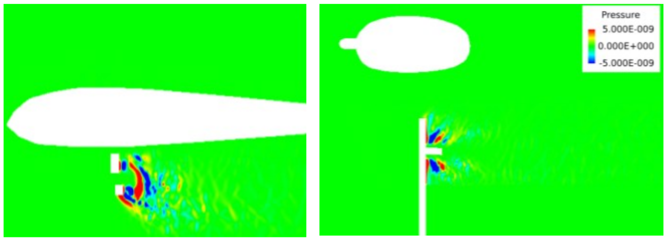


Figure 3: Axial velocity distribution near the deployed dive brake.

Next, the propagation of generated noise by SEM is computed. The aeroacoustic analysis takes longer computational time compared with flow field analysis. Thus, the computational domain is limited near the dive brake according to the visualization results of flow field. Figure 4 shows the sound pressure distribution of the configuration with the deployed dive brake. High pressure fluctuation is observed at the strut of the dive brake. It is confirmed the aerodynamic noise is generated from the strut of the dive brake because of the large separation. The pressure fluctuation is sampled below the main wing and the frequency characteristic are computed using fast Fourier transform. Figure 5 shows the sound pressure level (SPL) of three configurations. High peak near 410 Hz is observed in the configuration with the deployed dive brake. Frequency characteristic of recorded screaming noise of the dive bomber is analyzed to confirm this result [3]. The result is shown in Fig. 6. Recorded noise has the fundamental frequency of 480 Hz and peaks at the harmonic of 480 Hz. This sound is recorded at the ground and the frequency characteristic is shifted by the Doppler effect. In fact, the recorded noise in the aircraft has only the peak at 480 Hz. When the aircraft dives at $M_\infty = 0.5$, the peak frequency shifts to 820 Hz and this frequency is second harmonic. Therefore, it can be considered the peak of 410 Hz is the fundamental frequency as shown in Fig 6.

The noise was reproduced from the frequency characteristic of computational results and compared with the visualization of sound field. The characteristic and loudness of computed sound filed were directly sensed through the help of reproduced noise.



(a) Side view (b) Bottom view

Figure 4: Pressure distribution in LEE computation (Deployed).

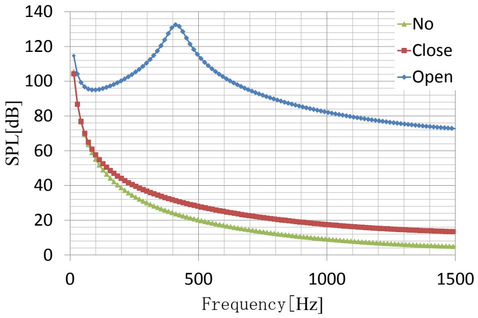


Figure 5: Frequency characteristic of computed noises.

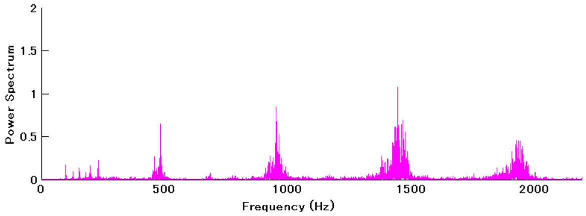


Figure 6: Frequency characteristic of recorded noise at the ground.

4 CONCLUSION

In this study, characteristic noise generated from a dive bomber is computationally analyzed and the generated noise is reproduced to understand the characteristic of noise sensuously. From the visualization of the flow field, it is confirmed the large separation from the deployed dive brake is the main sound source. The location and the size of sound source is clearly identified from the visualized flow field, and the computational domain of aeroacoustic analysis is able to be effectively chosen with the objective of computational cost. From the results of aeroacoustic analysis, large sound pressure fluctuation is generated from the strut of the dive brake when it is deployed. The relationship between flow field and sound field is able to be understood thanks to the visualization process. Frequency characteristic of the deployed dive brake shows the large peak near the fundamental frequency of characteristic noise. With the help the reproduction of noise with the visualization of sound field, the characteristic of computed noise is intuitively understood.

REFERENCES

[1] http://www.wwiiaircraftphotos.com/luftwaffephotos/lju8714.htm.

[2] Baily, C., and Juve, D., "A Stochastic Approach to Compute Subsonic-Noise Using Linearized Euler's Equations," AIAA Paper 1999-1872, 1999.

[3] http://www.youtube.com/watch?v=LCB8ZVxKqyI, (2014, 2, 3).