論 文 の 内 容 の 要 旨

論文題目　Sound source characteristics in compressible turbulent flows
（圧縮性乱流中の音源特性に関する研究）

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It is known that the Mach number and temperature ratio affects the characteristics of supersonic jet noise significantly. Toward the accurate prediction and reduction of the supersonic jet noise, it is necessary to understand those effects correctly. Regardless of the importance of the parameter dependence, however, the systematic explanation with detail underling physics has not been achieved so far.

In the present study, the direct numerical simulations (DNS) of the isotropic compressible turbulence and the temporally evolving compressible mixing layer were conducted to understand the Mach number and the temperature ratio dependence on supersonic jet noise. In the isotropic compressible turbulent simulation, the effects of the turbulent Mach number which is highly related with the smaller turbulent fluctuation were analyzed. In the temporally evolving compressible mixing layer simulation, on the other hand, the effects of two important parameters determining the large scale of turbulence were investigated. In the computation, the convective Mach number and the density (temperature) ratio dependence on the noise characteristics were analyzed. One unique point in the present study is that the source terms of the Lighthill equation which are numerically obtained by DNS results were analyzed to understand the relationship between change in flows and sound sources.

In the isotropic compressible turbulent simulation, it was shown that the sound generation mechanism is highly depending on the turbulent Mach number. For the lower turbulent Mach numbers, the important sound sources are only vortices. For the higher turbulent Mach numbers, on the other hand, eddy shocklets become the other important sound sources in addition to vortices. The relationship between the Reynolds stress term and the entropy term is changed depending on the turbulent Mach number due to the different sound generation mechanism (vortices and shocklets) between the lower and higher turbulent Mach numbers. For the lower turbulent Mach number flows, the Reynolds stress term and the entropy term are intensified each other around vortices, whereas those are canceled out each other across shocklets for the higher turbulent Mach numbers. Note, however, that the contribution of the entropy term for the lower turbulent Mach numbers would become smaller, because the entropy term is generated by the diffusion process around vortices, so that it would become smaller in the higher Reynolds number flows, though the trend was not observed in the present range of the Reynolds number.

In the temporally evolving compressible mixing layer computation, the results showed that the convective Mach number has two important effects. One is that the acoustic waves are weakened with increasing the convective Mach number. This is due to the suppression of vortices because of the compressibility effects. The other important effect is that shocklets in flows affects the acoustic wave characteristics for the higher convective Mach number cases. For those cases, the turbulent Mach number becomes high enough to generate shocklets and the acoustic waves show smaller (based on the scale of vortices), random, and non-linear (but still small) characteristics.

For the density ratio dependence, the strength of acoustic waves becomes weaker with increasing the density (temperature) ratio. There are two possible reasons. One is that the vortices (as sound sources) are weakened with increasing the density ratio. The other reason is that the source terms of the Reynolds stress term and the entropy term are canceled out each other. This is because the mean profile of density affects the Reynolds stress term and the entropy term significantly. Then, it leads to the similar mean profiles of the Reynolds stress term and the entropy term. In addition, the randomness of the Mach angle increases with increasing the density ratio. The results of the Mach angle would suggest the existence of various modes of instability wave moving with different convective Mach number which generates different Mach wave for the higher density ratio cases. The mean temperature difference over the mixing layer leads to locally different speed of sound, so that it would cause the locally different Mach numbers. The other possibility affecting the Mach angle is that the appearance of a lot of different scale structures over the mixing layer for the higher density ratio cases. This is also due to the mean temperature difference across the mixing layer. The temperature difference makes the Reynolds number locally different over the mixing layer and creates many different scales of turbulence. Note, however, that the effect is expected to be smaller at sufficiently high Reynolds number flows, because the Reynolds number difference between upper and lower streams becomes relatively smaller (based on the Reynolds number of the mixing layer) than that of the low Reynolds number flows. Also, at least in the present range of the density ratio and the convective Mach number, the non-linearity of acoustic waves is not changed significantly depending on the density ratio, regardless of the different sound source characteristics between cases.