Japan Geoscience Union Meeting 2014
(28 April - 02 May 2014 at Pacifico YOKOHAMA, Kanagawa, Japan)
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PPS21-P01 Room:Poster Time:April 29 18:15-19:30

Sonic Boom Analysis of Meteorite at Hypersonic Speeds in Earth Atmosphere

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The sonic boom followed by the passage of shock waves may cause serious damage on the ground, when a meteorite falls at hypersonic speeds as experienced at the Chelyabinsk meteorite event in February 2013. Therefore, it is important to evaluate the sonic boom generated by the meteorite. In this study, the prediction method of the sonic boom developed in the aeronautical engineering is applied to the case of the meteorite. The nature of the sonic boom propagation in the earth atmosphere is evaluated by the whole-domain simulation technique, which is based on the computational fluid dynamics in the domain bounded by the flying object and the ground (R. Yamashita and K. Suzuki, APISAT2013, No. 02-05-3). The flowfield around the sphere with 20 m diameter is numerically obtained by solving the three dimensional Navier-Stokes equations with the gravity term. The earth ' s atmospheric model is based on the international standard atmosphere (ISO 2533:1975). The flight Mach number is 10 (about 3 km/s), the flight altitude is 10 km and the flight condition is the steady level flight. The computational grid is constructed by rotating the two dimensional grid about the body axis and the number of the grid points is about 5.5 million. After the numerical calculation is conducted by using the initial grid, the calculation is performed again with the adaptive grid reconstructed to align the bow shock wave to avoid the artificial smearing of the shock wave. For computational efficiency, the domain is divided into several sectors from the body to the ground. The shape of the meteorite is approximated as a sphere and the axi-symmetric flowfield is assumed in the sector near the body. The numerical fluxes are evaluated by SHUS scheme (E. Shima and T. Jounouchi, NAL SP, pp.7-12, 1997) with the third order accuracy by MUSCL interpolation technique. The time integration is conducted by MFGS (E. Shima, proceedings of 29th Fluid Dynamic Conference, pp.325-328, 1997) method. The gravity term is added to the governing equations as a source term.

The flowfield around the sphere is composed of the bow shock wave in front of the body and the trailing shock wave in the wake. Both the waves propagating downward are merged into a single wave at 8 km altitude. In such case, the sonic boom sounds only once, while the sonic boom generated by a supersonic airplane creates explosive sounds twice without merging of the shock waves. It is reported that Chelyabinsk meteorite has been broken into three big pieces and the sonic boom sounds three times at the ground (NHK COSMIC FRONT, June 2013). Hence, the number of the pieces is equal to that of the sound of explosion. This fact seems consistent with the present simulation result. The pressure rise across the shock wave decreases with the distance from the body because of the geometric spreading. In the actual earth's atmosphere, however, the rate of decrease becomes smaller near the ground, because the atmospheric pressure and temperature increase toward the ground. Assuming the pressure augmentation factor of 1.9 at the reflection of the shock wave at the ground, the peak pressure rise is estimated at about 1.5 kPa, which is 63 times as large as the maximum allowable pressure rise (24 Pa) determined in the environmental regulation for the supersonic airplane. In the case of the Chelyabinsk meteorite, the pressure rise is estimated at 3.2 ± 0.6 kPa (Nature 12741) from the observation of the damage of the glass windows there. Although the numerical condition is not the same as the actual flight condition of the meteorite, the pressure rise due to the passage of a meteorite at hypersonic speeds is expected to be in the order of 1 kPa or higher.

As mentioned above, the prediction method developed in the aeronautical engineering has a great potential to predict the flight condition, say, the size, altitude and Mach number, from the magnitude of the sonic boom measured on the ground by conducting the parametrical study.

Keywords: Sonic Boom, Meteorite, Hypersonic Flow, CFD, Shock Wave