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NUMERICAL SIMULATION OF INSTABILITY IN SUPERSONIC JET BOUNDARY

Masaru USAMI † **Koji TESHIMA** ‡

Abstract

The jet boundary in a supersonic free jet issuing from a circular orifice deforms for Re^* larger than several hundreds, where Re^* is the Reynolds number at the orifice divided by the square root of the pressure ratio p_0/p_1 between the stagnation pressure and the circumference pressure. The phenomenon occurs by the Taylor-Goertler instability due to the curved jet boundary, in which a large velocity gradient exists. We have tried to simulate it numerically by a continuum calculation and the DSMC method. A general-purpose flow solver, CFD2000 developed by Adaptive Research, is used in the continuum calculation. In the DSMC simulation, the new intermolecular collision scheme is developed in order to compensate for coarseness of the cell-network. Petal patterns of the jet boundary are simulated by the continuum calculation. The number of the petals is 12∼16, which is almost the same as that experimentally observed. The DSMC result also shows the deformation of the jet boundary, but due to the intrinsic and probabilistic fluctuation accompanying the method, the petal patterns are not positioned so neat as those by the continuum calculation.

Key Words: Supersonic free jet, Instability, Vorticity, Petal pattern, Continuum, DSMC

1 INTRODUCTION

Under-expansion jets at a large pressure ratio p_0/p_1 between the stagnation pressure p_0 and the circumference pressure p_1 have been widely studied theoretically and experimentally and the characteristics of the jet along the flow axis are almost understood. However, the three dimensional structure of the jet, especially the flow around jet boundary, which is important in gas-mixing or mass entrainment of the circumference gas into the expanding gas, still has to be studied. It is known that gas expansion from non-circular orifices yields a peculiar jet structure depending on the orifice shape [1] and even from a circular orifice the structure shows a non-axisymmetric nature. Novopashin and Perepelkin [2] have shown that the cross section of the jet has a 'petal' pattern around the jet boundary from density measurements and this axisymmetric loss starts at about $Re^* = 600$, where Re^* is the orifice Reynolds number Re divided by the square root of the pressure ratio, p_0/p_1. One of the authors has shown the deformation of the jet cross section by visualization using the laser-induced fluorescence method [1]. It is shown that even with a carefully polished orifice the jet cross section starts to deform at several hundreds of Re^* and the deformation becomes dominant with increasing Re^* as is shown in Fig.1. Krothapalli et al. [3] and Arnette et al. [4] have shown the existence of the streamwise vortices around the jet boundary in high Reynolds number under-expanding jets by flow visualization and Pitot pressure measurements. They explained the streamwise vortices as the result of the Taylor Goertler type instability of the curved shear layer surrounding the jet (see Fig.2). These vortices have streamwise vorticity of the opposite sign, so the action of adjacent vortices is to either pump jet fluid radially outward or entrain ambient fluid radially inward toward the jet. If the phenomena are physically intrinsic, the petal pattern must be simulated numerically.

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† Department of Mechanical Engineering, Mie University, Tsu, Mie JAPAN

‡ Department of Industrial Arts Education, Kyoto University of Education, Kyoto JAPAN