A study on supersonic mixing by circular nozzle with various injection angle

Shigeru Aso[a], Kei Inoue[a], Kohei Yamaguchi[a], and Yasuhiro Tani[a]

[a]*Department of Aero. and Astro.,Kyushu Univ., Fukuoka 812-8581,Japan*

Keywords : supersonic mixing, turbulence flow

1. Introduction

SCRAM-jet engine is considered one the useful system propulsion for super/hyper sonic transportation vehicle and various researches were made to develop the engine. However, these are a lot of problems to be solved to develop it and one of them is the problem of supersonic mixing. In the SCRAM-jet engine combustor, main airflow is supersonic and residence time of the air is very short (about 1ms). Hence rapid mixing of air and fuel is necessary. However, usually it is quite difficult to mix fuel with air in very short distance. Also total pressure loss occurs by flow interaction the air and fuel. Total pressure loss is not preferable because it causes the thrust loss. Therefore, supersonic mixing with very rapid mixing and lower total pressure loss is highly requested. In order to develop the supersonic mixing, it is very important to understanding the effect of injection angle. In present study, we investigate the effect of injection angle with circular sonic nozzle by changing the injection angle. Experimental and computational studies on supersonic mixing phenomena of two-dimensional slot injector with various injection angle were conducted.

Supersonic wind tunnel was used for the experiments. The free stream Mach number is 3.8, total pressure is 1.1MPa and total temperature is 287K on average. As a secondary gas, Helium gas was injected at sonic speed from the circular nozzle. The injection angle is 30deg, 60deg and 90deg. Its total pressure is 0.4MPa and total temperature is 287K on average.

The same flow field was also simulated by solving three-dimensional full Navier-Stokes equation with AUSM_PLUS scheme for convective terms and full implicit LU-ADI factorization method for time integration. Central difference was used for viscous terms and k- ω two-equation turbulence model was also employed. 30,90 and 150deg injection angle cases have been calcurated.

In the experiments, stream line on the wall surface was revealed by the oil flow picture and the flow field was visualized by the Shlieren photograph. The wall static pressure profile along the flow was obtained by the wall pressure measurements. Also volume fraction distribution measurements were conducted. Each one of those showed good agreement with computational ones. From the thorough investigation of the flow field by experiments and computations, various characteristics of the supersonic mixing with circular nozzle have been revealed.

2. Governing equations and methods

In this study, we consider three-dimensional full Navier-Stokes equation of two components (air, helium) of mixture. The equations are solved by using AUSM-DV scheme with MUSCL interpolation for convective terms and central difference for viscous terms. Also, full implicit LU-ADI factorization method is used for time integration. As the flow in this study will be turbulent, a turbulent model should be considered in numerical analyses. In this study, the k-ω model proposed by Wilcox is applied. Fig.1 shows the grid system used in this study. The number of grid points is 116 in x-direction, 42 in y-direction and 75 in z-direction.

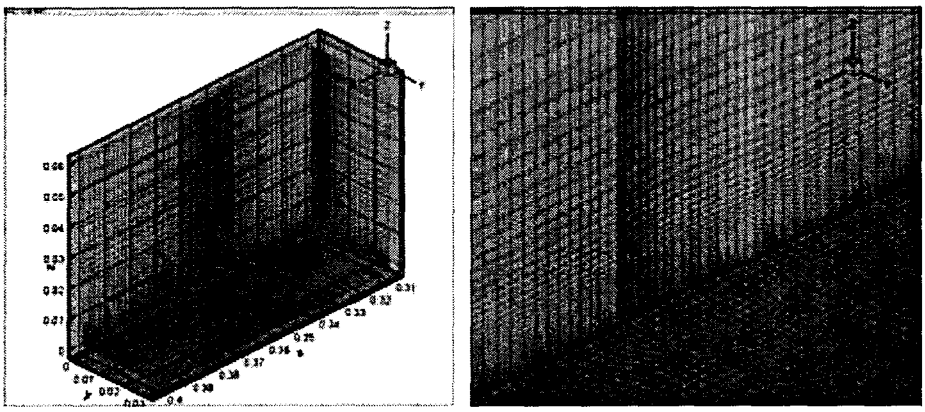

Fig.1 Grid system

3. Results

Free stream conditions and secondary gas conditions are set same value of experimental conditions shown in table1.

Free Stream	Gas	Air
	Mach Number	3.75
	Total Pressure	1.12MPa
	Total Temperature	286.9K
Secondary Gas	Gas	Helium
	Mach Number	1.0
	Total Pressure	0.40MPa
	Total Temperature	286.9K

Table.1 *Computational conditions*

The wall pressure distribution on the center line (y=0) are shown in Fig.2. It is normalized by the static pressure of the main flow. In this case, the injectioni angle is 90 degrees. The numerical result shows good agreement with the experimental result. The point where the pressure brings to increase agrees well.

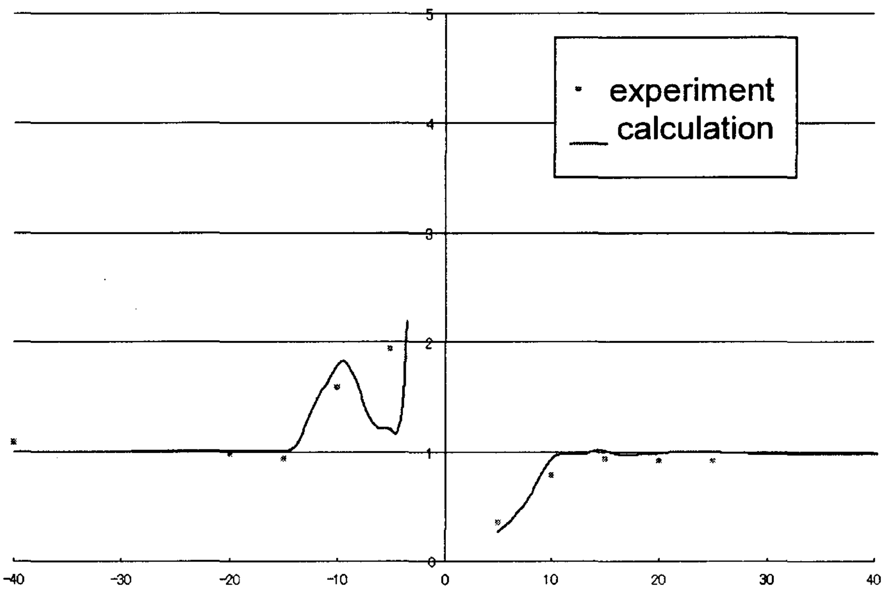

Fig.2 Wall pressure distribution (90 deg, y=0)

Volume fraction distribution is shown in Fig.3. In this case the injection angle is 90 degrees. The measurement plane is located at x=40. By comparison between the experimental and numerical result, almost same distribution is obtained

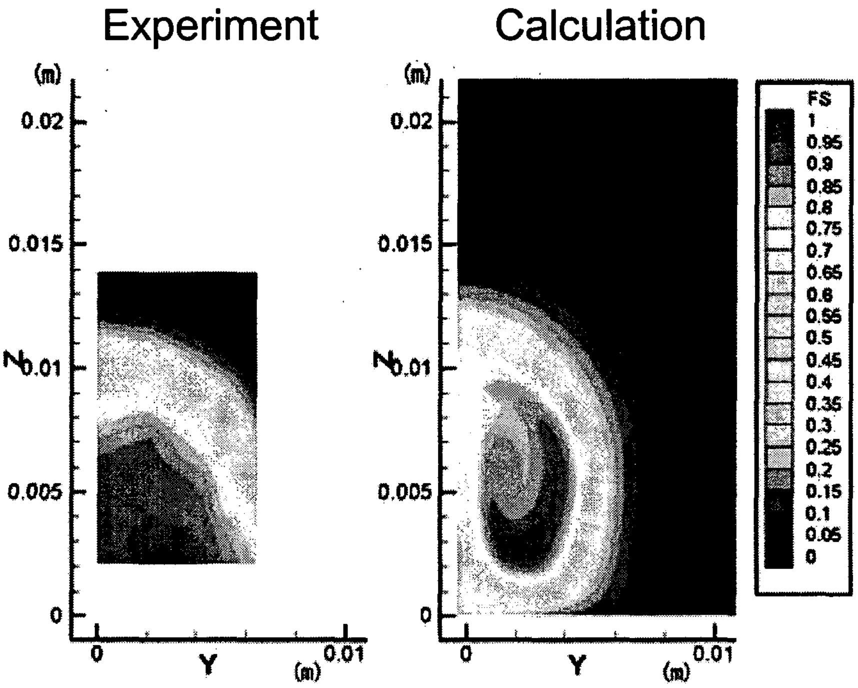

Fig.3 Volume fraction distribution (90deg)