Introduction to the researches relative to gas turbines and aerodynamics conducted in Faculty of Science and Technology of Keio University

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1. Introduction to the faculty and the graduate school

Faculty of Science and Technology, Keio University is organized with 11 departments, which were reorganized or newly established in the past. The graduate school of Science and Technology was also reorganized from the structure directly connected with departments to the three school structure weakly connected with departments (School of Fundamental Science and Technology, School of Integrated Design Engineering and School of Science for Open and Environmental Systems). Each school has 6 courses of research according to the research fields, which are responsible for the inspection of the master thesis and doctor thesis.

In the four laboratories introduced at this report, researches on gas turbines and aerodynamics are conducted and the teaching staffs of the laboratories belong to Department of Mechanical Engineering and also to the School of Science for Open and Environmental Systems. The main research themes are mainly on high-energy conversion by fuel combustion and combustion technology to reduce pollutant emissions (Prof. Kawaguchi), flow instability and turbulence generation, control of turbulent flow (Prof. Masuda), prediction, measurement and control of turbulence phenomena (Prof. Obi), numerical simulation of compound problems of compressible flow and combustion (Prof. Matsuo). The research contents of several laboratories are introduced below.

2. Research review of Kawaguchi laboratory

In the Kawaguchi laboratory, various combustion problems occurring in the continuous combustion systems, such as gas turbine combustors, industrial burners, boiler burners and so on, are experimentally treated from various viewpoints. The treated problems are mainly on the combustion stability, the relation of combustion process and exhaust emission. All fossil fuels used in the practical systems are treated regardless of solid, liquid and gas. At present, experimental studies summarized below are conducted on the combustion problems of gas turbine combustors.

＊ The influences on the combustion performances caused by downsizing of gas turbine combustor

In a micro-size power generation plant using a gas turbine of several kW or less, some problems occur due to heat loss through the wall of combustor. To make clear the heat loss influence of a miniature size combustor on the combustion characteristics or exhaust emission characteristics, a small size annular combustor was manufactured and systematical experiments have been conducted.

＊ Examination of feasibility of a combustor for a ultra-micro gas turbine

An annular－disc type combustor (20 mm in outer diameter) for a button-shape ultra-micro gas turbine was produced and the combustion characteristics were experimentally examined. The gas flow and temperature distributions in the chamber and exhaust emission characteristics are predicted by numerical simulations. The experiments and numerical simulations made clear that the time shortage of fuel diffusion and wall quenching of chemical reaction caused by the size effect bring about serious influences on the combustion characteristics

＊ A study on the low NOx gas turbine combustor using a high swirling flow

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A study is conducted to develop a low NOx combustor introducing high－speed tangential air from several number of air slots and injecting gaseous fuel toward the air flow to achieve a rapid mixing and to control NOx emission. The relation between fuel hole position or hole size and emission characteristics were examined to obtain the optimum condition and the best combination. Numerical simulations and fundamental experiments are also conducted to make clear the process of diffusion and chemical reaction in the high shear flow.

＊ Ignition and combustion of a fuel droplet suspended in a hot and highly humid gas flow

Considering the spray combustion occuring in a steam injection gas turbine cycle, a fuel droplet suspended in a hot and highly humid combustion gas flow is examined on the evaporation rate, ignition delay and combustion time. In a hot and highly humid gas flow environment, water vapor condenses at the droplet surface and gives heat of condensation to the droplet. which promotes the evaporation rate. This study examines experimentally the effects of promotion of evaporation from droplet in a hot and humid gas flow on the ignition delay and combustion time of a fuel droplet.

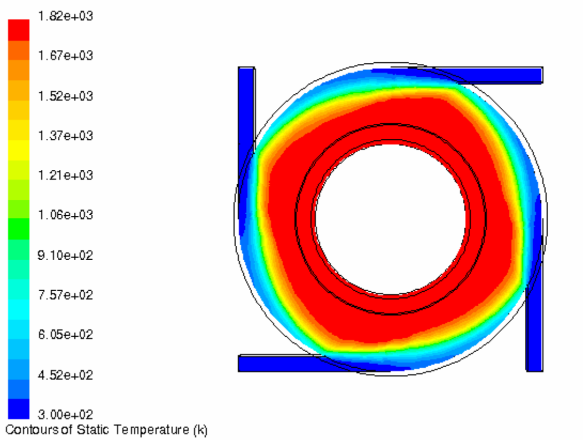

Fig. 1. Prediction of temperature distribution of premixed combustion in a UMGT

2. Research review of Masuda laboratory

Our interests lie in measurements and control of turbulent flows particularly in transitional and low-Reynolds number regime. Despite the extra difficulty both in numerical simulation and experiments due to high sensitivity to external disturbances, the research trend for micro-scale phenomena, biology, informatics and so on makes transitional and low Reynolds number turbulence increasingly important.

Our principal methods are hot-wire anemometry, Laser Doppler anemometry, particle image velocimetry, laser induced fluorescence, flow visualization and numerical simulation. Recent works include,

1) Heat transfer in rotating transitional boundary layer (application to cooling problem in rotating machinery) , Edo,Y. et al, *Int. J. Heat and Fluid Flow 21*(2000),684-692., Yamawaki, D. et al, *Int. J. Heat and Fluid Flow 23* (2002), 186-193

2) Flow instability and elastic vibration of corotating disk system (application to improvement of record density of harddisk drives),
Fukaya, R. et al., *Experiments in Fluids,* 33-3 (2002), 369-373, Kisaki,S. et al., *IIP/ISPS Joint Conf. on Micromechanics for Information and Precision Equipment,* Yokohama (2003), Yamamoto,Y., *ASME/ISPS Conference on Information Storage and Processing System,* Santa Clara(2004)

3) Control of separated flow by periodic disturbance
- Yoshioka, S. et al., Int. *J. of Heat and Fluid Flow 22*(2001) 301-307, and 393-401

4) Statistics of vertical gravitational flow impinging onto horizontal plate (Laboratory model of down burst)
- Nagata,T. et al, *Turbulence, Heat and Mass Transfer 4,* Antalya, Turkey (2003), 829-836.

5) Unsteady behavior of axisymmetric turbulent boundary layer (application to reactive control of separated flow)
- Masuda et al., *4th ASME/JSME Joint Fluids Eng. Conf.,* Honoluu, FEDSM 2003 - 45587 (2003), 1-7

6) Roll-cell instability in unstably stratified boundary layer (meteorology and transport of airborne pollutants)

7) Vortex ring generated by surface wave and its behavior in non-uniform density field (application to the water purification system using natural energy)

3. Research review of Obi laboratory

Our research activity is mainly related to measurement, modeling and prediction of incompressible turbulent flows. Particular efforts are made to improve performance of turbulence models based on Reynolds-averaged Navier-Stokes equation in predicting complex turbulent flows subject to massive separation and/or centrifugal force. A recent experiment on turbulent wake of a pair of bluff bodies set in tandem in uniform flow(1) has revealed the important role of correlation between instantaneous velocity and pressure gradient in determining the budget of Reynolds stress equation: The velocity field measured by a digital particle image velocimetry was used to solve the discrete Poisson equation to determine instantaneous pressure distribution, enabling the evaluation of the velocity-pressure gradient correlation. The comparison with the production rate of the individual Reynolds stress indicated that the velocity-pressure gradient term mostly contribute as a sink, having the opposite sign to that of the production rate, except for the equation of transverse normal stress component that exhibited an extraordinary strong magnitude as a consequence of the production due to interaction of velocity and pressure and not by the usual shear production. Another experiment on simultaneous measurement of fluctuating pressure and velocity in a plane mixing layer out of equilibrium(2) provided encouraging results to be utilized for development of turbulence models. Another recent topic is the development of vortex method aiming at its application to engineering problems. Because of its mesh-free nature, there is a great expectation on the applications of vortex method to unsteady flows with moving/deforming boundaries. The combination with a special purpose computer designed for molecular dynamics simulation, the computation speed is accelerated by an order of 100, which makes the vortex method an interesting alternative to conventional CFD.

(1) S. Obi, N. Tokai and K. Sakai, The role of pressure-velocity correlation in oscillatory flow between a pair of bluff bodies, to be presented at *ERCOFTAC International Symposium on Engineering Turbulence Modelling and Measurements,* Sardinia, Italy (2005).

(2) T. Omori, S. Obi and S. Masuda, Experimental study on velocity-pressure correlation in turbulent mixing layer, *4th Int. Symp. Turbulence, Heat and Mass transfer,* Anatalya, Turkey (2004), 253-260.

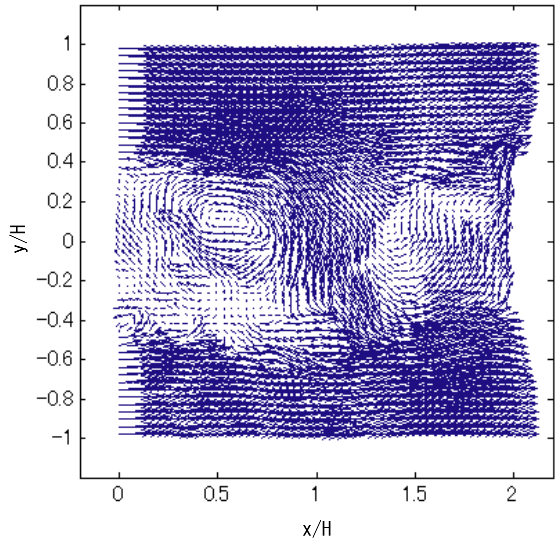

Fig.2 Instantaneous velocity vectors measured by PIV

4. Research review of Matsuo laboratory:

Research of our laboratory is focusing on Computational Fluid Dynamics (CFD) of compressible flows. Most of research projects are related to the compressible flows with the chemical reaction. One of our projects is the investigation of supersonic combustion process (detonation) in the premixed media. Moreover, the research of the next generation aerospace propulsion device, such as a Pulse Detonation Engine (PDE), is also one of our big projects. A pulse detonation engine (PDE) is a device that produces thrust by using repetitive detonation waves, and is regarded as a substitute of the existing jet engines. The PDE research is originally started in the USA, and currently there are many researchers in universities and engineers in the aircraft engine companies, such as GE and P&W, working for the investigation and development of PDE systems. Actually, the PDE system is available on the ground surface at zero velocity and the outer space, as the aerospace propulsion system. A number of experimental, numerical, and analytical studies have been conducted regarding the performance of PDE with our research collaborators in recent years. Figure 1 is one of the simulation results of PDE consisting of three tubes, and the intermittent detonation in three tubes makes the thrust. The detonation wave is ignited at the closed end of tube and propagates at supersonic velocity toward the open end of tube. Therefore, the PDE itself does not require a compressor or an additional combustor, and its simplicity has an advantage against the existing propulsion system.

Furthermore, we are extending our research activity to the safety engineering focusing on the explosion hazard, using the background of compressible flow analysis. Figure 2 shows the blast wave propagation in a two-story building with five rooms. The blast wave generated at point explosion propagates and reflects in the closed space, and sometimes, the reflected wave becomes much stronger than that in the open space. We have to try to reproduce quantitatively accurate simulations for the risk assessment of the explosion hazard. We believe that the CFD must be a useful tool for it.

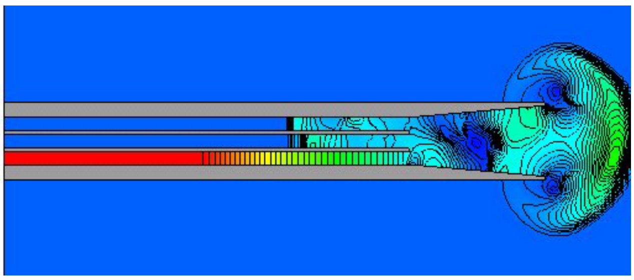

Fig. 3 Blast wave propagation in a two-story building with five rooms

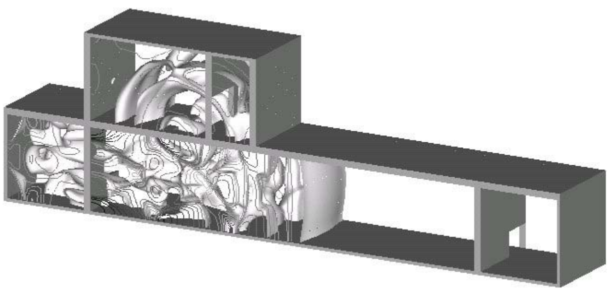

Fig. 4 Flow field around three tubes PDE