3rd International Workshop on Detonation/ Detonation Engine

November 19, 2011

Program for 3rd International Workshop on Detonation/Detonation Engine

Sponsored by MSI, Tokyo Institute of Technology and Aoyama Gakuin University

and

Cosponsored by EMI Inc.

November 19, 2011

Room E306, Sagamihara Campus, Aoyama Gakuin University

10:30-10:45 **Introduction** A. Koichi Hayashi, Aoyama Gakuin University, Japan
and Piotr Wolanski, Warsaw University of Technology, Poland

Chair: P. Wolanski

10:45-11:15 **Ignition in the boundary layer driven by shock-boundary layer interaction**

E. Dzieminska, A.K. Hayashi, E. Yamada, and N. Tsuboi
Dept of Mechanical Engineering, Aoyama Gakuin University

11:15-11:45 **Bio Fuel and its Pulse Detonation Engine**

A. Koichi Hayashi: Aoyama Gakuin University
Tatsuya Aoki: Aoyama Gakuin University
Eisuke Yamada: Aoyama Gakuin University
Nobuyuki Tsuboi: Kyushu Institute of Technology

11:45-13:00 **Lunch**

Chair: J-P Wang

13:00-13:30 **Presence of single bubble in water hammer due to axial impact loading**

Kazaki Inaba: Tokyo Institute of Technology

13:30-14:00 **Numerical Simulation on Detonation for CH_4/O_2 Gas Mixture : Effects of Chemical Reaction Model**

Nobuyuki Tsuboi: Kyushu Institute of Technology
Youhi Morii: The Graduate University of Advanced Studies
Hiroyuki Ogawa: Institute of Space and Astronautical Science / Japan Aerospace Exploration Agency
A.Koichi Hayashi: Aoyama Gakuin University

14:00-14:15 **Intermission**

Chair: J-Y Choi

14:15-14:45 **Recent Research on Rotating Detonation Engine**

Piotr Wolanski: Institute of Aviation and Warsaw University of Technology

14:45-15:15 **Three-Dimensional Numerical Simulation of Rotating Detonation Engines**

Jian-Ping Wang, Meng Liu, Rui Zhou
State Key Laboratory of Turbulence and Complex System, Department of Mechanics and Aerospace Engineering, College of Engineering, Peking University

15:15-15:30 **Intermission**

Chair: K. Inaba

15:30-16:00 **Understanding Unsteady Flow Processes in a Pulse detonation Engine**

Venkat Tangirala

Combustion Systems Organization, Aero Thermal Mechanical Systems Technologies, General Electric Global Research Center

16:00-16:30 **Computational Studies of Detonation for Propulsion in PNU**

Jeong-Yeol Choi

Pusan National University, Busan 609-735, Korea

16:00-16:45 **Intermission**

16:45-17:15 **Explosion and Shock Wave Simulations**

Masatake Yoshida: Explosion Research Institute Inc

Chair: V. Tangirala

17:15-17:45 **Discussion on Detonation/Detonation Engine and Closing**

17:45-18:30 **Laboratory Tour**

18:30-19:00 **Move to Banquet**

19:00-21:00 **Banquet at Hotel the Ellcy, Machida**

Exhibition: Explosion Research Institute Inc.

- **This workshop is sponsored under the program of Materials and Structures Laboratory, Tokyo Institute of Technology.**

Ignition Process in the Boundary Layer triggered by shock-boundary layer interaction

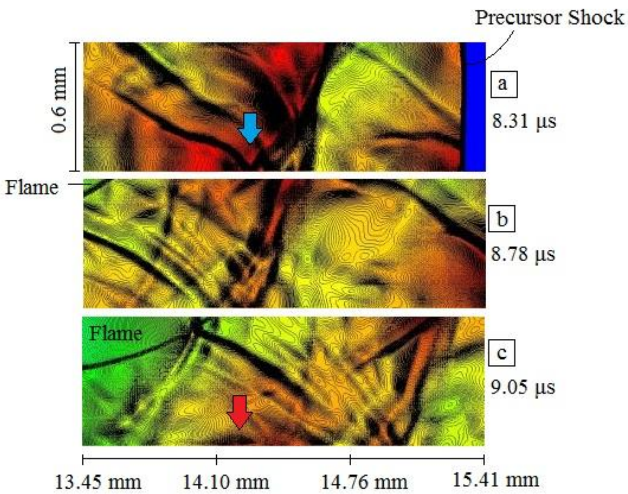
E. Dzieminska*, A.K. Hayashi*, E. Yamada*, and N. Tsuboi**
* Aoyama Gakuin University
** Kyushu Institute of Technology

Even though detonation process is known for over a century many questions become unsolved. Problems like deflagration-to-detonation transition or a fast flame are not fully explained yet. Because computers are more powerful now we are able to observe phenomena which cannot be seen in detail in experiments. One of those is shock-boundary layer interactions, which were postulated a long time ago but only numerical calculations makes it possible to observe each microsecond of the process.

In our case calculation domain is divided into three regions: Ignition Source (IS), Shock Region (SR) and Ambient. SR simulates a precursor shock that travels at some distance in front of the flame front and its pressure is 23 times higher than in the ambient region. IS carries even higher pressure. This model allows simulating flam propagation from any point in time skipping the very beginning of flame development.

The Figure below shows pressure record for a zoomed part of the tube. Due to strong shock-boundary layer interaction, boundary layer is heated up and ignition occurs. Blue arrow points very strong compression wave interacting with the boundary layer. At the point boundary layer is heated up. Later on weaker compression waves are also passing.

Even though most of them are weak, it provides enough energy for auto-ignition to begin (red arrow). We do not see an explosion on the wall. In this case explosion is only observed in the center of the tube when flames collide. It causes DDT and detonation.



Bio Fuel and its Pulse Detonation Engine

A. Koichi Hayashi*, Tatsuya Aoki*, Takashi Shimada*, Eisuke Yamada*,
and Nobuyuki Tsuboi**
* Aoyama Gakuin University
** Kyushu Institute of Technology

Bio fuel becomes one of potential fuel for future propulsion. Ethanol is one of such fuels. In the present talk a detailed ethanol reaction mechanism is firstly discussed to show its property for detonation. A ethanol/air reaction mechanism is developed to simulate detonation where the numerical results performed by a STANJAN code are compared with the experimental ones obtained by Smeets. This comparison gave a good agreement between them. Moreover the combination of droplet diameter (2-8μm) and initial evaporation rate (20-60 %) are studied for detonation propagation. As far as detonation velocity, detonation velocity decreases when the initial evaporation rate decreases or droplet diameter increases. The simulation of cell structure shows that the larger diameter of droplet gives the larger detonation cell width and that the higher initial evaporation rate provides the smaller detonation cell width.

Then the ethanol/air pulse detonation engine is simulated for a converging-diverging nozzle case and a straight nozzle case. As far as the CD nozzle case, the fuel based specific impulse is lower than that of hydrogen/air PDE. Especially the cycle time of ethanol/air PDE is longer than that of hydrogen/air one. And especially the low purge fraction for ethanol/air PDE causes the ignition on the refilling phase because of high temperature for ethanol fuel. On the other hand the high refill fraction causes the ignition a choke at the throat. The refilling fraction is found not to affect the fuel based specific impulse. Then the PDE with the straight nozzle is simulated to show the partial refilling effect for ethanol/air PDE is not seen comparing with hydrogen/air PDE in this case too.

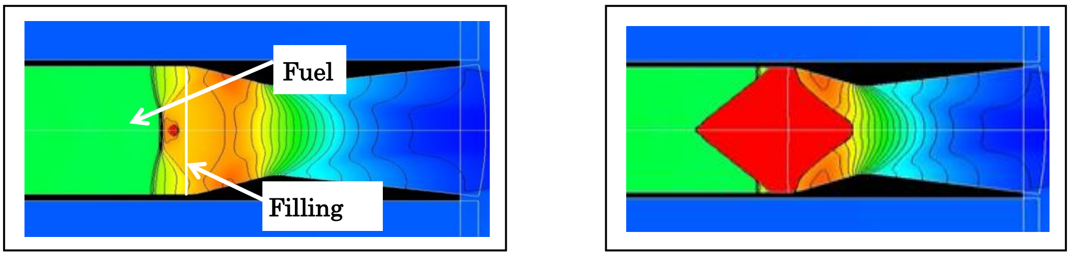


Fig.1 Pressure distribution at the time when purge gas reached the throat (β_f=1.0, β_p=0.2)

Presence of single bubble in water hammer due to axial impact loading

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Two-phase bubble flow appears in many industrial fields such as plants, power plants and gas pipelines. For safety design, it is important to consider water hammer phenomena in two-phase flow due to detonations or explosions in pipes. Though many researchers have conducted experiments and numerical simulations of water hammer through bubbly liquid, there are few laboratory scale experiments taking into account of fluid–structure interaction (FSI) in two-phase flow. In the Korteweg–Joukowski model for FSI, the wave speed is determined by fluid–structure coupling parameter derived from geometry and modulus of fluid and structure. Besides FSI problems, bubble effect becomes dominant for tube distortion. Bubbles instantaneously deform and collapse due to the water hammer and strongly affect the wave propagation.

We examined the relation between a single bubble oscillation and tube response in the water hammer event. A free-falling projectile hit the buffer on the top surface of the water in the vertical mounting tube and a compression wave propagated downward along with the tube deformation. In this manner, buffer motion reproduces pressure history of detonations and explosions as to the impact axial loading in water. A single balloon which was a rubber spherical membrane including air was arranged in the horizontal center of the tube. We tried to measure gas pressure in the balloon by pressure transducer set at the bottom of the balloon. We compared the gas pressure with calculated values derived from the Rayleigh–Plesset equation. The tube deformation was measured by strain gages mounted on the external surface of the tube and the water pressure was calculated by Tijsseling's thick-tube equation.

We found that the speed of water hammer and the maximum pressure in the tube and the bubble decreased with increasing bubble radius. The wave speed is constant immediately before the bubble though it suddenly decreases due to the presence of the bubble increasing the void fraction of the mixture. Bubble pressure is generally equal to the surrounding pressure inside the tube when the bubble diameter is large. Bubble pressure, however, becomes higher than water pressure around the bubble when the bubble size is enough small to the tube inner diameter. We found the possibility of tube strains becoming higher than those in water case when the bubble is small and dramatically compressed.

Numerical Simulation on Detonation for CH4/O2 Gas Mixture: Effects of Chemical Reaction Model

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Methane has been studied as aerospace propulsions and electric power plants because it is better storage, low cost, and clean burning. However, methane also causes explosions and detonations because mixture gas of methane and oxygen or air is easy to ignite. Therefore, the studies about ignition, deflagration, and detonation for methane are important for safety problems. The present research is to estimate the effects of chemical reaction models on one- and two-dimensional CH4/O2 detonations under low-pressure environments. Three reduction models such as DRG30, Petersen & Hanson model, and Soetrisno model are estimated in this study. DRG30 model is reduced from the detailed reaction model k3l1 proposed by Miyoshi. The results for one-dimensional simulations show that Soetrisno model cannot simulate detonations; however, the other two models can predict unstable one-dimensional detonations as shown in Fig. 1. Two-dimensional simulations with DRG30 model are simulated under initial pressure of 0.01 MPa. The propagation of detonation significantly depends on the channel width because the large unburned gas pockets appear behind the detonation front due to long induction length foe CH4/O2 gas mixture.

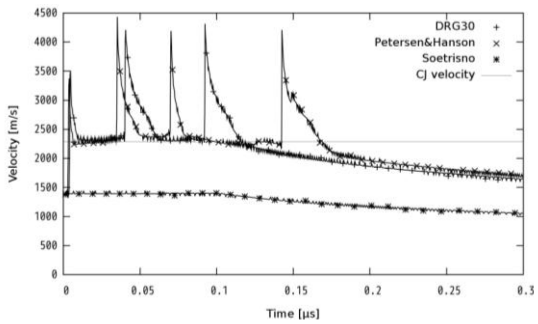

Figure 1 Comparison of instantaneous detonation velocities for various reaction models.

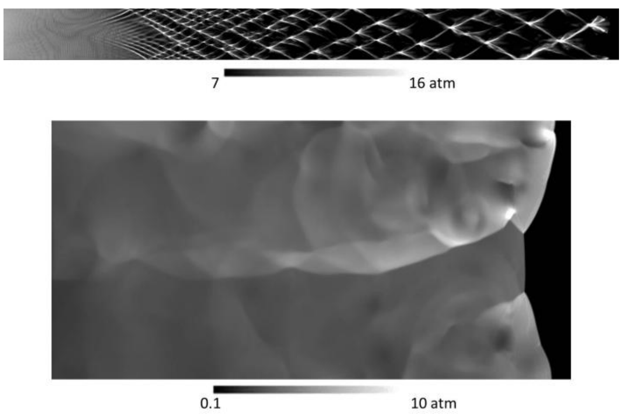

Figure 2 Results of two-dimensional simulation with DRG30. Upper figure is maximum pressure history and lower figure is instantaneous pressure contours, respectively.

Recent Research on Rotating Detonation Engine

Piotr Wolanski
Institute of Aviation and Warsaw University of Technology, Poland

Recent research carried out at the Institute of Aviation and the Warsaw University of Technology, are focused on evaluation of the conditions at which rotating detonation is propagating in cylindrical channels for different fuel-air mixtures. Hydrogen-air as well as kerosene-air mixtures are tested. Tests of of the initiation of detonation for kerosene-air mixtures at elevated pressures and temperatures, as well as test of hydrogen infected into air in relatively large cylindrical chamber will be presented. Also preparation for tests of chamber designed for the turbine engine will be discussed.

Additionally, numerical 3-D simulations of mixture formation as well as simulations of detonation propagation in cylindrical chambers are carried out at the Institute of Aviation.

Three-Dimensional Numerical Simulation of Rotating Detonation Engines

Jian-Ping Wang, Meng Liu, Rui Zhou

State Key Laboratory of Turbulence and Complex System, Department of Mechanics and Aerospace Engineering, College of Engineering, Peking University, Beijing, 100871, China

The three-dimensional simulation of different fuel injection patterns reveals the detailed evolution of detonation waves, which comply with the experimental observation. It shows that multiple detonation waves will be formed, and can possibly propagate in both directions along or opposite the initiation detonation. Fuel injection patterns may change the wave's shape and distribution. Interactions of the fuel and combustion products are likely improve or undermine the performance of the engine, depending on the specific pattern that is utilized. According to the numerical results, the total number of shockwave fronts has inherent relationships with the pattern of the injection and the size of the chamber.

The three dimensional phenomenon of detonation flow field is investigated in the annulus combustions. The effect of annulus channel width on the detonation flow field is discussed. The inner radius is 3cm, and outer radius is 3.4cm, 4cm, and 4.4cm, respectively. The results demonstrate that the radial dimension is not obvious when the annulus channel width is small. However when the annulus channel width is 10mm or 14mm, the radial dimensional phenomenon is more and more obviously. At the head wall, reflecting shock waves repeatedly reflect between the inner wall and outer wall. Regular reflection and Mach reflection all exist at the head wall. The Mach stem and maximum pressure all increase as the annulus channel width is increased.

Understanding Unsteady Flow Processes in a Pulse detonation Engine

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Unsteady flow investigations of a pulse detonation engine (PDE) play a key role in the PDE technology development for performing trade studies, evaluating different implementations of the PDE applications and conceptual designs. Time-resolved simulations and test measurements of a pure thrust-producing PDE are needed to understand the operability and to estimate thrust generated by PDE operating as a pure propulsion system. Simulation of all PDE processes was found to be necessary for estimating the performance using a limit cycle model of a PDE. Comparisons of the predicted Ispf of a PDE with the estimated Ispf for a ramjet operating with the same inlet conditions show a PDE performance advantage of 16%, and this is in agreement with a recently disclosed study on PDE performance.

A key application that benefits from Pulse Detonation Engine (PDE) concept is a hybrid engine, where a Pulse Detonation Combustor (PDC) replaces the combustor in a conventional gas turbine. A systems level performance estimation model for a PDC-based hybrid engine cycle was presented. A variable property formulation was used to estimate the cycle performance parameters namely the thermal efficiency and the net specific work. Performance estimations were obtained using a one-step finite-rate chemistry to simulate reactions, and the frozen reactions assumption to model the products of combustion.

Computational Studies of Detonation for Propulsion in PNU

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An introduction to the computational research activities on detonation for aerospace propulsion will be presented. The early works on detonation for aerospace propulsion applications begins with the numerical simulation of the ram accelerator operating at super-detonative mode where the combustion flow physics is governed by oblique detonation wave and boundary layer interactions. After that, it had been further extended to the thermally choked mode ram accelerator and laser-driven in-tube accelerator, in collaboration with Prof. Sasoh of Tohoku University at that time. However, more attention was given to the fundamental structure of oblique detonation wave and its stability. Capturing the cell structures of an oblique detonation wave and the instability of oblique detonation wave and/or oblique shock-induced combustion over wedges of flow turning angles greater than the attaching condition are the noticeable results among that. Recently further studies on oblique detonation waves have been done for the new experimental results from Prof. J. Kasahara's group using a spherical projectile and from Prof. A. Higgins group with conical projectiles. Studies on the ordinary normal detonation waves had been started during the stay at Pennsylvania State University where the author was involved for the pulse detonation engines studies. Well-known detonation wave structures have been reproduced and numerical issues were further investigated. Multiple cell structures in three dimensional square tubes and circular tube has been studied in this regards. Interests have been further extended to rotating detonation engines, and two- and three- dimensional simulation of RDE has been performed in international collaboration. A unique concept for the studies on the effect of the radius of curvature has been done in PNU to investigate the critical radius for the self-sustained detonation wave propagation in annular channel as shown in the next figure.

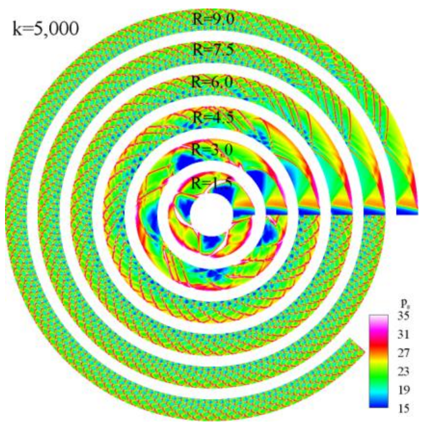

Figure 1 Effect of radius of curvature on the detonation wave propagation in annular channels.

Explosion and Shock Wave Simulations

Masatake Yoshida
Explosion Research Institute Inc.

I report about capabilities of various (propriety and open-source) softwares in simulating explosion and shock wave phenomena.
Simulations include hydrogen-air ignition and explosion (FLACS), LPG BLEVE (CFD++), explosion of natural gas (FLACS), internal ballistics of firework launch (CFD++) blast wave propagation (CFD++ and OpenFOAM), and so on.
Capabilities of these softwares for simulating explosions and shock waves are summarized and compared.