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Pressure, Ion Probe, and Flow-Visualization Measurements in Inside-injector Rotating Detonation Engines

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14. ABSTRACT
In this proposed study we investigated the more general detonation structure by using the Inside-injector Rotating Detonation Engines.
Using a hypersonic-propagation detonation wave, engines can have higher thermal efficiency cycle and specific thrust than conventional jet and rocket engines.
Particularly, a rotating detonation engine is now studied in the world. Since it has a simple double-cylinder structure with continuous detonation propagation, in which the detonation initiation is needed once only when the engine starts. Detailed visualization analysis experiments for the flow in a rotating detonation engine are needed immediately.

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Publications

Diverging RDE research period 2022to 2023 is progressing extremely well, leading to the publication of research results in three peer-reviewed and one conference papers.

1. K. Nakata, K. Ishihara, K. Goto, N. Itouyama, H. Watanabe, A. Kawasaki, K. Matsuoka, J. Kasahara, A. Matsuo, I. Funaki, K. Higashino, J. Braun, T. Meyer, G. Paniagua, “Experimental investigation of inner flow of a throat less diverging rotating detonation engine”, *Proceedings of the Combustion Institute*, Vol. 39, Issue 3, 2023, pp. 3073-3082, https://doi.org/10.1016/j.proci.2022.08.089
2. K. Nakata, K. Ota, S. Ito, K. Ishihara, K. Goto, N. Itouyama, H. Watanabe, A. Kawasaki, K. Matsuoka, J. Kasahara, A. Matsuo, I. Funaki, K. Higashino, J. Braun, T. Meyer, G. Paniagua, “Supersonic Exhaust from a Rotating Detonation Engine with Throatless Diverging Channel”, *AIAA Journal*, 2022, Vol. 60, Issue:7, pp.:4015-4023 https://doi.org/10.2514/1.J061300
3. K. Ishihara, K. Yoneyama, H. Watanabe, N. Itouyama, A. Kawasaki, K. Matsuoka, J. Kasahara, A. Matsuo, I. Funaki, K. Higashino, “Thrust Performance of Converging Rotating Detonation Engine Compared with Steady Rocket Engine”, *Journal of Propulsion and Power*, 2023, Vol.39, Issue: 3, pp.297-307, https://doi.org/10.2514/1.B38784
4. K. Nakata, K. Ota, S. Ito, K. Ishihara, K. Goto, N. Itouyama, H. Watanabe, A. Kawasaki, K. Matsuoka, J. Kasahara, A. Matsuo, I. Funaki, K. Higashino, J. Braun, T. Meyer, G. Paniagua, “Acceleration of Burned Gas to Supersonic in a Throat-less Rotating Detonation Engine”, *28th International Colloquium on the Dynamics of Explosion and Reactive Systems,* 19th-24th June, 2022, Napoli, Italy, http://www.icders.org/ICDERS2022/abstracts/ICDERS2022-160.pdf

Participants

(1) PI:

Prof. Yoshiyuki KAWAZOE, Tohoku University, supervise the project, verification of the numerical results and comparison with experimental data, ORCID=0000-0002-2369-7045

(2) Participants:

Dr. Kazuyuki HIGASHINO, Director of Technical Development Division, NETS, Ltd.,

Technical Report Document

1. Technologies or Techniques

In this research, a detonation engine in space flight has been successfully demonstrated. This is the world's first successful demonstration of a detonation engine in space. The detonation engine system developed in this basic study was loaded onto the mission section of the sounding rocket S-520-31 and launched from the JAXA Uchinoura Space Center at 5:30 a.m. on July 27, 2021. The rotating detonation engine was successfully operated in space, and photo images, pressure, temperature, and attitude data were acquired by telemetry. The fuel is methane, and the oxidizer is oxygen. The detonation engine generates detonation and compression waves at extremely high frequencies (1-100 kHz), rocket engine weights and high performance by easy generation of thrust.

The success of this space flight demonstration will bring the detonation engine much closer to practical use for deep space exploration and so on.

2. Accomplishments

1. Fig.1 shows a schematic of the structure of flow phenomena in the two-parallel-plane RDC proposed in the previous study. Larger and smaller circles show the outer edge of the combustion chamber and the inner boundary of visible area, respectively. Continuous lines in the combustion chamber were drawn based on images from experiments. Dashes lines drawn in outside of the combustion chamber show injectors. A detonation wave is in the region 1 and propagates counterclockwise. In region 2, which is behind the detonation wave, high pressure and temperature burned gas is generated. The high pressure burned gas stops the injection of ethylene and oxygen and flow back to the injector at the direction OB. As a result, contact surface of oxygen and burned gas and contact surface of ethylene and burned gas are generated in the injectors.

2. The well mixed area develops between the flesh oxygen and ethylene, and become a medium of next cycle detonation wave. As shown above, since ethylene and oxygen re-injection have phase lag and they are injected in parallel, a certain distance is needed to be mixed sufficiently. Consequently, the well mixed area is keeping a certain distance from the outer edge of the combustion chamber. Therefore, the detonation wave propagates keeping the distance from the outer edge of the combustion chamber.

3. In this study we investigated the more general detonation structure by using the Inside-injector Rotating Detonation Engines.

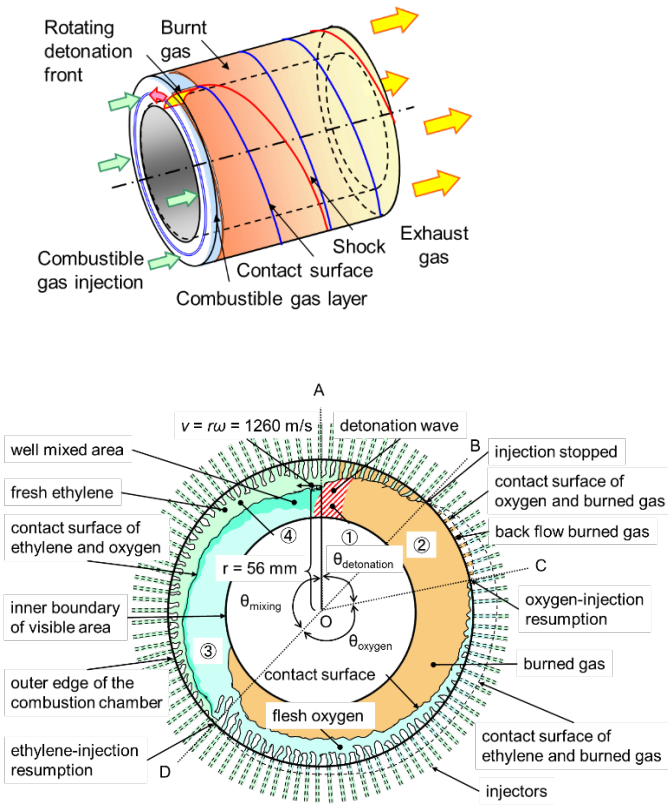

Fig.1 Rotating Detonation Engine

3. Impacts

Development of the principal discipline(s) of the project

Using a hypersonic-propagation-velocity detonation wave, engines can have higher thermal-efficiency cycle and specific thrust than conventional jet and rocket engines. Particularly, a rotating detonation engine is now studied in the world. Since it has a simple double-cylinder structure with continuous detonation propagation, in which the detonation initiation is needed once only when the engine starts.

Detailed visualization analysis experiments for the flow in a rotating detonation engine are needed immediately.

Other disciplines:

Detailed visualization analysis experiments for the flow in a rotating detonation engine are needed immediately. In the present project research, experimentally, we try to visualize the flow field in the disc-shaped RDE including the coreless RDE to analyze detonation wave and flow structures.

The pressure amplitude and this propagation velocities in the experiments cannot be explained by the existent theories. Detailed visualization analysis experiments for the flow are needed immediately. In the present project research, experimentally, we try to visualize the flow field in the disc-shaped RDE including the coreless RDE to analyse detonation wave and flow structures.

Describe the impact in this reporting period on the development of human resources

We treat young researchers by tutorial course of Aerospace Division periodically. This activity will be continued.

Describe the impact on teaching and educational experiences

We have given lectures for graduate course students and young researchers in the occasion of real high level study.

Describe the impact in this reporting period on physical, institutional, and information resources that form infrastructure.

Detonation engines interest many researches because of its potentials for a next generation aerospace propulsion engine.

We published many times at AIAA meetings, etc.

Impact on society beyond science and technology:

Detonation engines interest much research because of its potentials for a next generation aerospace propulsion engine. Using a hypersonic-propagation-velocity detonation wave, engines can have higher thermal-efficiency cycle and specific thrust than conventional jet and rocket engines. Particularly, a rotating detonation engine RDE is now studied much in every country in the world since it has a simple double-cylinder structure with continuous detonation propagation, in which the detonation initiation is needed once only when the engine starts. Although many researchers confirmed the wave propagation at near detonation propagation velocities in the engines by pressure and self-emission measurements,

4. Changes

Basically, there are no fundamental change in this project research.

5. Technical Update

Hypersonic-propagation-velocity detonation wave, engines can have higher thermal-efficiency cycle and specific thrust than conventional jet and rocket engines. Particularly, a rotating detonation engine is now studied in the world since it has a simple double-cylinder structure with continuous detonation propagation, in which the detonation initiation is needed once only when the engine starts.

Detailed visualization analysis experiments for the flow in a rotating detonation engine were needed immediately. In the present project research, experimentally, we tried and succeeded to visualize the flow field in the disc-shaped RDE including the coreless RDE to analyse detonation wave and flow structures.

References

1. H. Nakayama, J. Kasahara, A. Matsuo, and I. Funaki, "Front shock behavior of stable curved detonation waves in rectangular-cross-section curved channels", *Proceedings of the Combustion Institute*, Vol. 34, Issue 2, pp.1939-1947.
2. S. Maeda, S. Sumiya, J. Kasahara, A. Matsuo, "Initiation and Sustaining Mechanisms of Stabilized Oblique Detonation Waves around Projectiles", *Proceedings of the Combustion Institute*, Vol. 34, Issue 2, pp.1973-1980.
3. H. Yamashita, J. Kasahara, Y. Sugiyama, and A. Matsuo, "Visualization Study of Ignition Modes Behind Bifurcated-Reflected Shock Waves", *Combustion and Flame*, 2012, Vol. 159, Issue 9, pp.2954-2966.

4. H. Nakayama, T. Moriya, J. Kasahara, A. Matsuo, Y. Sasamoto, and I. Funaki, "Propagation of Curved Detonation Waves Stabilized in Annular Channels with a Rectangular Cross-section", *The ISTS Special Issue of Transaction of JSASS Aerospace Technology Japan,* 2012, Vol.10, Issueists28, pp. Pe 7-14.
5. K. Matsuoka, M. Esumi, K. B. Ikeguchi, J. Kasahara, A. Matsuo, and I. Funaki, "Experimental Investigation of a Multi-Cycle Single Tube Pulse Detonation Rocket Engine with a Coaxial Rotary Valve", *The ISTS Special Issue of Transaction of JSASS Aerospace Technology Japan*, 2012, Vol.10, Issue ists28, pp.Te 1-4.
6. S. Maeda, J. Kasahara, A. Matsuo, "Unsteady Propagation Process of Oblique Detonation Waves Initiated by Hypersonic Projectiles", *The ISTS Special Issue of Transaction of JSASS Aerospace Technology Japan*, 2012, Vol.10, No. ists28, pp.Pe 1-6.