Mechanical Engineering Annual National Seminar (SNTTM)
organized by Indonesian Consortium of Higher Education in Mechanical Engineering (BKSTM)
18th Oct., 2012 at Gadja Mada University, Jogjakarta, Indonesia

A Study on Pulse Detonation Engine in Japan

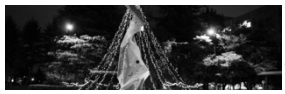
Shigeharu Ohyagi
Saitama University
Japan

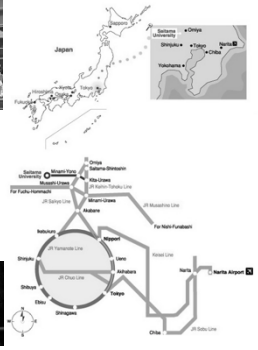
Outline

- About Saitama University
- What is a Detonation Wave?
- What is a Pulse Detonation Engine
- Studies on PDE/PDTE in Japan
- Concluding remarks

Saitama University

- Founded by Japanese Government at 1949 in Urawa, Saitama
- 5 Faculties (Culture, Education, Economics, Science and Engineering)
- 8,000 undergraduate students, 1,000 graduate students
- Foreign students; 170 undergraduates, 280 graduates
- From Indonesia, only 2 graduate students(2012)





http://www.saitama-u.ac.jp/en/index.html

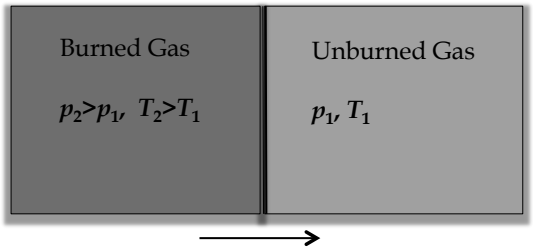
What is a Detonation?

- Premixed Combustion
  - Deflagration
    - Spark Ignition Engine
    - Bunsen Burner
  - Detonation
- Diffusive Combustion (Non premixed combustion)
  - Diesel Engine
  - Gas Turbine
  - Candle

What is a Detonation?

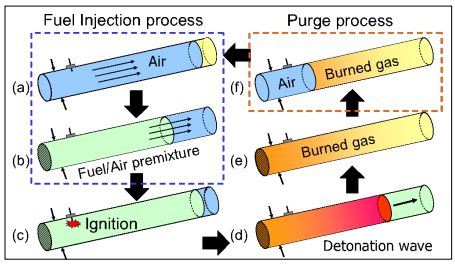
- It is a combustion wave.
- It propagates through combustible mixtures like hydrogen/air.
- It propagates at a velocity 2000-3000 m/s, i.e., supersonic velocity.
- It consists of a shock wave and a combustion wave.
- It compresses a medium 10 to 20 times a initial pressure.

Detonation Wave
= Shock Wave + Combustion



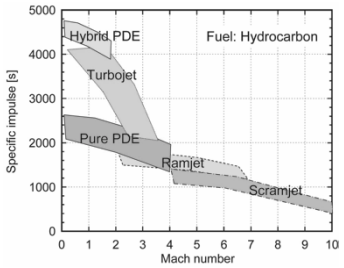
Supersonic Propagation Velocity

Processes of
Pulse Detonation Engine



courtesy of Dr. Sakurai

Specific Impulse of Various Propulsion System



First Experimental Study

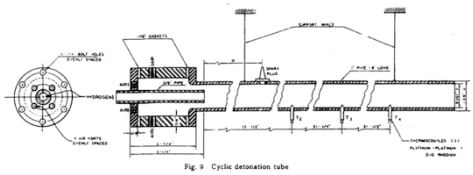


Fig. 9 Cyclic detonation tube

Nicholls, J. A., Wilkinson, H. R. and Morrison, R. B.,
Thrust-Producing Mechanism, Jet Propulsion, 27, 5, pp.534-541, 1957.

Review Papers

- Kailasanath, K.,
  Detonation Waves, AIAA J. 38, 9, pp. 1698-1708, 2000.
- Roy G.D., Frolov S.M., Borisov A.A., Netzer D.W.,
  Pulse detonation propulsion: challenges, current status, and future perspective, Progress in Energy and Combustion Science, 30, pp. 545-672, 2004.

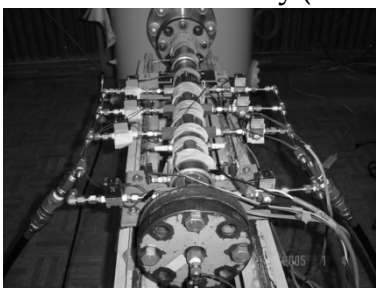
Studies in World

- Dr. K. Kailasanath ; US Naval Research Laboratory
- Dr. Venkat Tangirala ; US General Electric
- Dr. John Hoke and Dr. Fred Schauer ; US Air Force Research Laboratory
- Prof. Ming-Hsun Wu; Republic of China National Cheng-Kung University
- Prof. Piotr Wolanski ; Poland Warsaw University of Technology
- Prof. Sergey Frolov ; Russia Semenov Institute of Chemical Physics
- Dr. Ratiba Zitoun ; France Institute PPRIME, CNRS
- Prof. Longxi Zheng ; China Northwestern Polytechnical University
- Prof. Mike Kuznetsov ; Germany Kalsruhe Institute of Technology

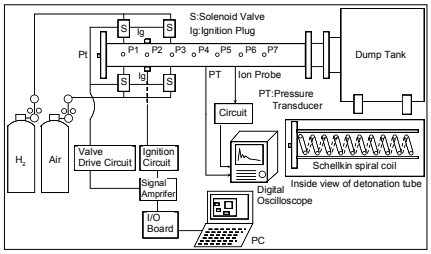
Studies in Japan

- Aoyama Gakuin University; Prof. Koichi Hayashi
- Hiroshima University; Prof. Takuma Endo
- Hokkaido University; Prof. Masashi Wakita
- Keio University; Prof. Akiko Matsuo
- Tokyo Metropolitan University; Dr. Takashi Sakurai
- Tsukuba University; Prof. Jiro Kasahara
- Yokohama National University; Kazuhiro Ishii
- Saitama University; Prof. Shigeharu Ohyagi

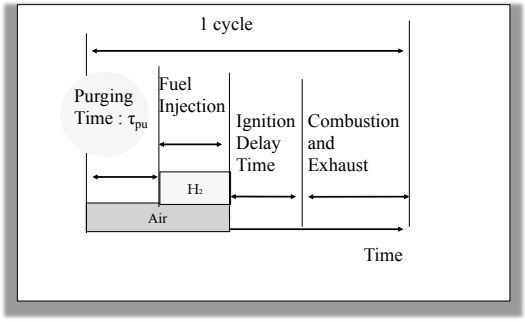
First PDE of Saitama University(2005)



Schematics of Experimental PDE



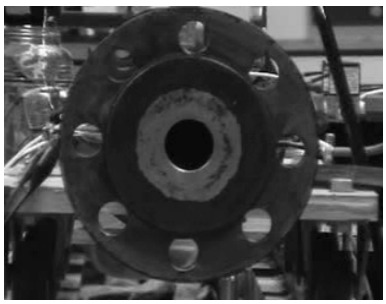
Time Sequence of a Cycle



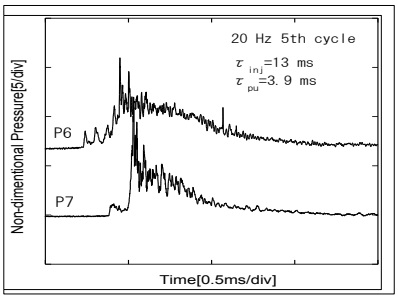
Experimental Condition

Fuel/Oxidizer	H2/Air		
Initial Pressure	Atmospheric Pressure		
H2/Air Injection Time [ms]	13	11	8
H2/Air Injection Volume [cc]	820	700	700
Equivalence Ratio : ϕ	2.5	1.3～3.5	2.0～3.5
Ignition Delay Time : τ ig	0.1		
Ignition Position [mm]	150		
Purging Time [ms] : τ pu	1.9～12.9		1.9～14.9

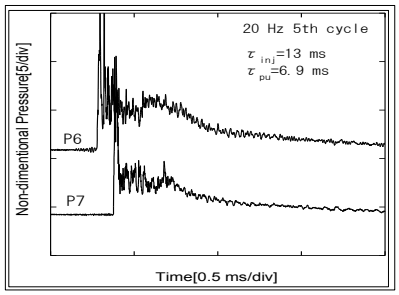
Outlet of PDE



Pressure Profile on the Wall



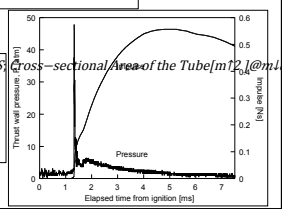
Pressure Profile on the Wall



Impulse on Thrust Wall

■*Impulse[Ns]; I=S∫cyclef≡p(t)dt @Specific Impulse[s]; Isp,f =I/mcycle ,fg*

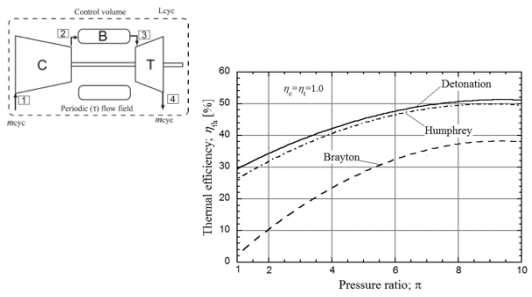
■*p; Thrust Wall Pressure[Pa]@t; time[s]@S; Cross−sectional Area of the Tube[m^2],@m*



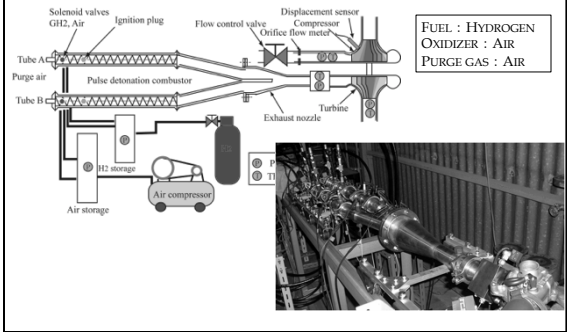
Comparison with Theory
H_2-Air (ϕ=1, p_0=101 kPa)

	I [Ns]	I_{sp} [s]	I_{spf} [s]
Experiment	0.493	104.7	1965
Nicholls Theory	0.266	65.1	2511
Shepherd Theory	0.633	155.0	5980
1D Numerical	0.669	132.6	6320

Thermodynamic Cycles of Pulse Detonation Turbine Engine

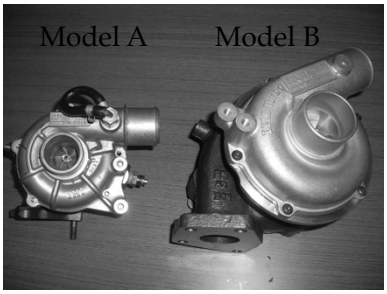


TWO CYLINDER PULSE DETONATION TURBINE ENGINE

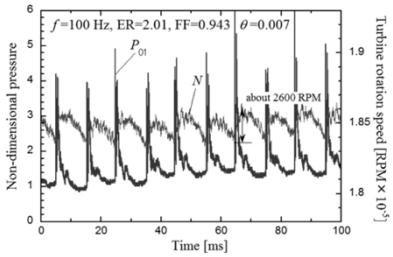


USED TURBO-CHARGERS

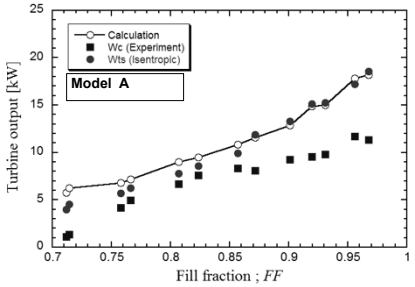
THANKS FOR MOTOHIDE MURAYAMA (IHI)



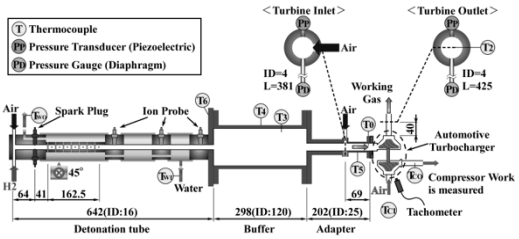
Turbine Inlet Pressure and Rotation Speed



Turbine Output



PDTE of Hiroshima University



Courtesy of Prof. Endo

Hiroshima University

Courtesy of Prof. Endo

Demonstration Experiment

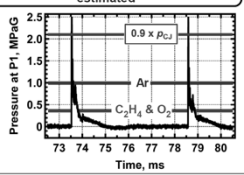
The PDC was operated at 200 Hz for 75 cycles in the valveless mode

Experimental conditions

Operation frequency:	200 Hz
Operation cycle:	75 cycles (0.375 s)
Composition of the detonable gas:	1.1~1.2C_2H_4+3(O_2+2.5Ar)
Fill-fraction of the detonable gas:	97 % of the PD combustor estimated

Gas	Supply pressure
C_2H_4	0.36 MPaG
O_2	0.36 MPaG
Ar	0.99 MPaG

Peak pressures higher than 90% of the Chapman-Jouguet value were regarded as successful detonations.



Hiroshima University

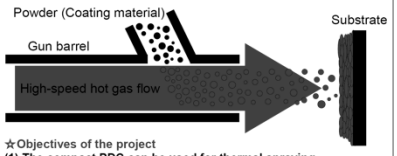
Courtesy of Prof. Endo

Compact PDC for Thermal Spraying

We recently started to develop a more compact PDC for thermal spraying

☆Thermal spraying

A technology for thick surface coating in which melted or highly heated materials are sprayed onto a surface with high speed.



☆Objectives of the project

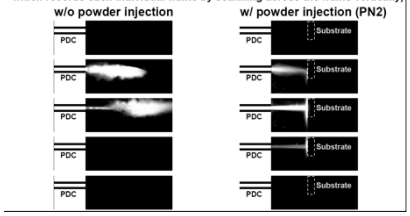
(1) The compact PDC can be used for thermal spraying.
(2) The compact PDC can be operated for more than 10 minutes.
(3) The compact PDC can be manipulated by a robot arm.

Hiroshima University
Courtesy of Prof. Endo

Compact PDC for Thermal Spraying

Powder flow lasted longer than the hot-gas flow w/o powder injection

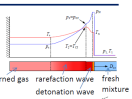
Self-emission images
(Frame rate: 1200 fps by a rolling-shutter CMOS sensor which records each individual frame by scanning across the frame vertically)



University of Tsukuba
Courtesy of Prof. Kasahara

Background : Fundamental and application studies of PDE (reviewed by Roy et al., Kailasanath), and evolution to very high frequency PDE operation

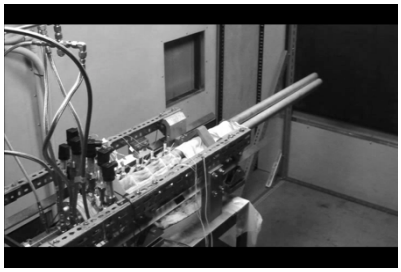
Pulse detonation engine (PDE) - simplified PDE
specific impulse 4200sec (air-breathing jet engine (H_2-air))
190sec (rocket engine (H_2-O_2))
Endo et al., JPP, 2004, Cooper et al., JPP, 2002,
Wintenberger et al., JPP, 2003
Specific impulse increases if partial fill fraction decrease
Sato et al., JPP 2006, Cooper et al., JPP, 2004
Kasahara et al., AIAA Journal, 2008
If the ambient pressure is sufficiently low, burned gas in PDE tube can be accelerated by a convergent-divergent nozzle.
Morris, JPP, 2005, Cooper and Shepherd, JPP, 2008
The first PDRE system is demonstrated by pulse detonation rocket Todoroki.
Kasahara et al., JPP, 2009-1
The first manned PDE flight test was conducted by AFRL-ISSI.
Hoke et al., Japanese Shock wave Sym., Jan 2008.
Specific impulse of 305 sec was achieved using multi-cycle partial-fill effect
Kasahara et al., JPP, 2009-2
Most recent interests are flight demonstration by rocket system with high frequency operation and to put this system in practical use.




University of Tsukuba, ISE, JAXA


ISSI-AFRL

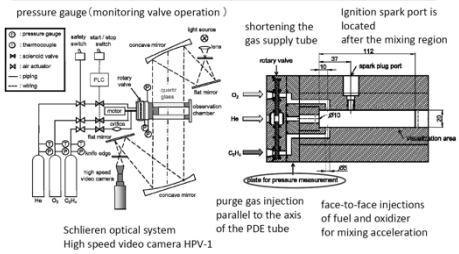
PDE of Tsukuba University



Courtesy of Prof. Kasahara

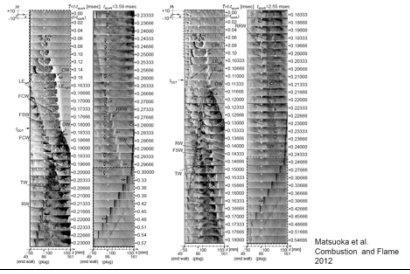
University of Tsukuba
Courtesy of Prof. Kasahara

Optical observation of gas supply jets and detonation initiation in the PDE tube (combustor) attached with the rotary valve was conducted. These monitorings brought stable PDE operations.



University of Tsukuba
Courtesy of Prof. Kasahara

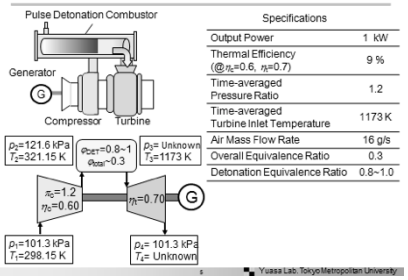
Detonation wave was initiated at the distance of 5 times as long as the tube diameter from the closed end.



Matsuoka et al. Combustion and Flame 2012

Tokyo Metropolitan University
Courtesy of Dr. Sakurai

Schematic of the proposed 1kW-class micro gas turbine

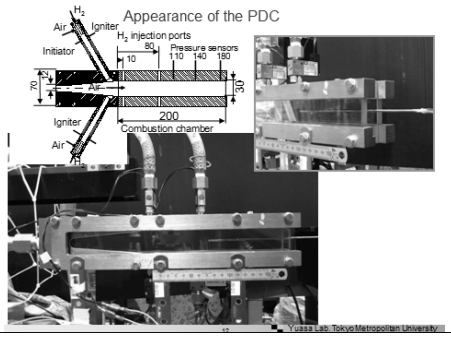


Specifications	
Output Power	1 kW
Thermal Efficiency ($@\eta_c$=0.6, η_t=0.7)	9 %
Time-averaged Pressure Ratio	1.2
Time-averaged Turbine Inlet Temperature	1173 K
Air Mass Flow Rate	16 g/s
Overall Equivalence Ratio	0.3
Detonation Equivalence Ratio	0.8~1.0

Yuasa Lab. Tokyo Metropolitan University

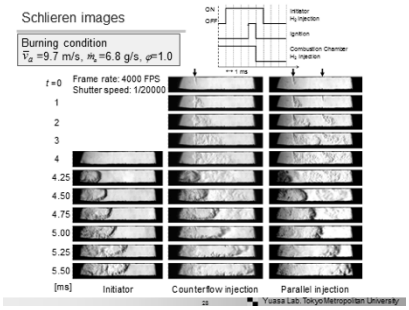
Tokyo Metropolitan University

Courtesy of Dr. Sakurai



Tokyo Metropolitan University

Courtesy of Dr. Sakurai



Concluding Remarks

- A pulse detonation engine (PDE) is a propulsion system utilizing detonative combustion of combustible gas.
- It is very attractive because of its rapid completion of combustion and of its high pressure release.
- However, in the present stage, the development of PDE is not complete so that it is necessary to perform a fundamental study on detonation phenomena.

Thank you for your kind attention.

Shigeharu Ohyagi