Investigations Of Cyclic Pulsed Detonation Processes: Experiments and Calculations

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Pulse detonation engines (PDE) have come to the forefront of propulsion research because of their potential for high efficiency and low mechanical complexity as compared to conventional propulsion systems. One of the main potential advantages of PDE's is that the entropy rise across a detonation wave is lower than across the constant pressure combustion waves used in air-breathing propulsion devices such as gas turbines and ramjets [1]. Establishing whether PDEs can achieve higher operating efficiency than conventional propulsion systems is the focus of many research groups around the world [1,2,3,4]. Some of the major challenges to making PDE operation feasible include achieving uniform fuel-air mixing in a very short interval of time, obtaining repeated initiation of detonations within the detonation chamber and operation at higher frequencies.

A number of recent experimental studies have focused on quantifying the performance of a swinging pendulum-type, single-shot, idealized tube PDE [2,3], as well as multi-cycle, single tube and multi-tube PDEs [3,4]. Recent developments in laser diode sensors [5] have made it possible to monitor gas properties such as temperature, species concentrations and fuel mass fraction in the harsh operating environment of PDEs, with high temperatures, high pressure and highly transient operating conditions. Wavelength multiplexing has been used [3,5] to measure water mass fraction and temperature. Broad wavelength scanning has been used to measure C_2H_4 concentrations [5], thereby yielding a measure of fuel-air mixing in the unreacted mixture. These *in situ* measurements are needed for PDE development, validation of predictive methods and active control of PDE operation.

Purely computational studies of a single-shot, tube PDEs using ethylene-oxygen mixtures with multi-step mechanisms were reported by a number of investigators [6,7,8]. Predicted pressure and velocity distributions as a function of time at several locations of the tube were compared [6,8] against the experimentally measured values reported by Sanders *et al*. [5]. For the tube filled with a stoichiometric ethylene-oxygen mixture the fuel-based specific impulse was predicted [6,7,8] to be 715-740 s.

Experiments and analysis are being performed at General Electric Global Research Center to investigate detonation processes under cyclic operation of a tube PDE with hydrogen-air and hydrocarbon-air mixtures. This study explores how parameters such as tube geometry, operating frequency and fuel-air mixing influence detonation processes and resulting performance measures of thrust and fuel-based specific impulse. This paper aims to improve understanding of cyclic detonation processes through comparison of detailed measurements with high fidelity numerical simulations.

Detailed measurements are obtained from experiments performed on a bench-scale PDE (shown in Fig. 1). The test facility consists of a stainless steel tube PDE supplied with ports for *in situ* optical measurements. Air is supplied from a compressed air system and fuel and air are mixed within the PDE. Combustion is initiated via a spark igniter located near the fuel-air mixer. A Schlieren/shadowgraph imaging system permits high speed imaging of the blowdown processes at the exit of the PDE. A thrust stand permits characterization of the overall tube performance. Measurements from these tests include temperature, dynamic pressure measurements, thrust, as well as non-intrusive measurements of temperature, water concentration and C_2H_4 concentration obtained using IR laser diagnostics. This comprehensive set of measurements allows detailed comparison with numerical predictions of detonation and gasdynamic flow processes.

The results of numerical simulations are obtained using multidimensional computational fluid dynamics tools that invoke physics-based methods and multi-step chemical mechanisms. These computational models are being developed to predict (i) detonation properties such as gas temperature, pressure, velocity and species concentrations as a function of time, and (ii) the performance of a single or multiple cycle C_2H_4 based PDE. The comparisons of transient CFD predictions of multi-cycle PDE processes with test measurements of temperature, pressure, C_2H_4 concentration and water concentration are presented. Estimations of thrust obtained using a steady-state thrust stand and a transient thrust sensor are compared against the thrust predictions obtained using CFD simulations of a single cycle. Comparisons of the CFD predictions with the estimations obtained using an analytical model [9] are also presented.

REFERENCES

1. K. Kailasanath, "Recent Development in the Research on Pulsed Detonation Engines”, AIAA 2002-0470, 2002.

2. Cooper, M., Jackson, S., Austin, J.M., Wintenberger, E., and Shepherd, J.E., "Direct Experimental Impulse Measurements for Detonations and Deflagrations," AIAA 2001-3812, July 2001.

3. Schauer, F., Stutrud, J., and Bradley, R., “Detonation Initiation Studies and Performance Results for Pulsed Detonation Engines,” *AIAA, 2001-1129,* presented at 39th AIAA Aerospace Sciences Meeting and Exhibit, January 8-11, 2001, Reno, NV,

4. C. M. Brophy, LT S. Werner, and J. O. Sinibaldi, “Performance Characterization of a Valveless Pulse Detonation Engine,” *AIAA 2003-1344,* presented at *42nd Aerospace Sciences Meeting and Exhibit,* Reno, NV, January 2003.

5. S. T. Sanders, T. P. Jenkins, and R. K. Hanson, “Diode Laser System for Multi-parameter Measurements in Pulse Detonation Engine Flows,” *AIAA 2000-3592, 36th Joint Propulsion Conference*, Huntsville, Al, July 2000.

6. Kailasanath, K., Patnaik, G. and C. Li, "Performance Estimates of Pulsed Detonation Engines," Proc. of the Combust. Inst., Vol. 29, 2002.

7. V. E. Tangirala, B. Varatharajan, and A. J. Dean, “Numerical Simulations of Detonation Initiation,” *AIAA 2003-0716,* presented at *42nd Aerospace Sciences Meeting and Exhibit,* Reno, NV, January, 2003.

8. L. Povinelli and S. Youngster, “Real Gas Effects on Performance of Hydrocarbon-fueled Pulse Detonation Engines,” *AIAA 2003-0712,* presented at *42nd Aerospace Sciences Meeting and Exhibit,* Reno, NV, January, 2003.

9. Wintenberger, E., Austin, J .M., Cooper, M., Jackson, *S.,* and Shepherd, J.E., "An Analytical Model for the Impulse of a Single-cycle Pulse Detonation Engine," AIAA 2001-3811, July 2001.

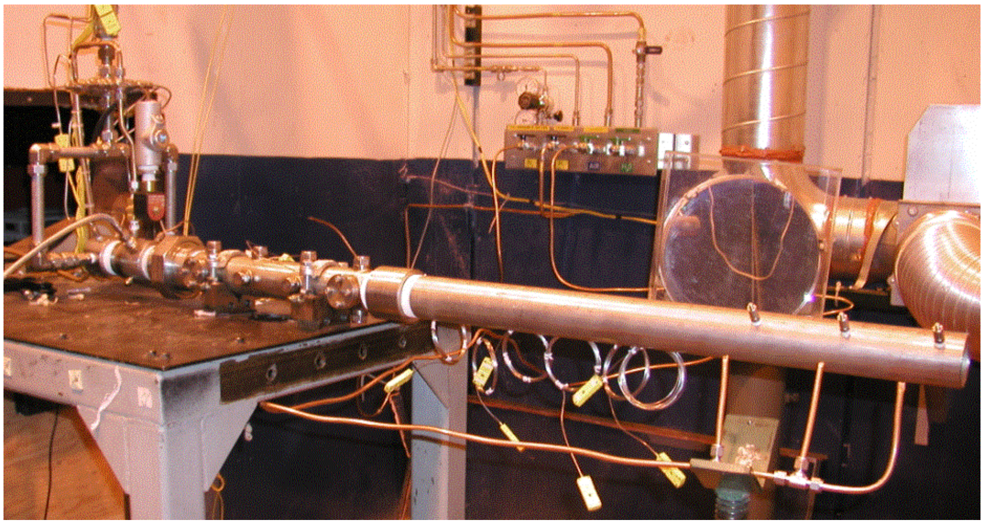

Fig. 1: The PDE tube used in the present study (Mixture: C_2H_4-air).