MEMS-Based Pulse Detonation Engine for Small-Scale Propulsion Applications

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A small-thrust, flight-weight, pulse detonation engine (PDE) is being developed by the General Electric Company as part of a small-scale propulsion systems program. This engine will incorporate mesoscopic- and micro-electro-mechanical systems (MEMS) to allow for integrated, large volume manufacturing at reduced cost. The engine development is a joint effort led by GE with Caltech and Stanford University aiding in the engine design, and Arizona State University and University of Cincinnati assisting with the MEMS design. These abstract details the progress made during the Phase-1 program. The pulse detonation engine is a potentially inexpensive engine capable of high-speed flight that does not require the multistage compressors and turbines of modern jet engines. Harnessing gaseous detonations, which offer extremely high power density, enables the simplicity. The key uncertainties of the engine design are the minimum combustor size, which is associated with the properties of the desired fuel (JP 8), and the detonation initiation process, which may require too much energy, power, or both.

To address these concerns, a series of tasks were undertaken to determine the viability of the PDE concept for small scale propulsive devices and were successfully completed. Numerical models were used to better understand the importance of geometric features, and showed that optimal performance occurred when the ratio of the effective areas of the inlet valve/turbulence enhancing system to the nozzle throat was near unity. Experiments demonstrated detonative performance with liquid fuels (Butane and JP-8) in a flowing system with the assistance of a conical initiator with a 70 mJ spark and a stoichiometric C_2H_4-O_2 mixture. This experimental set up is illustrated in figure 1. The primary airflow (up to 8 kg/sec at 1100 K) was supplied by a series of compressors located in an adjacent building, allowing for steady-state testing of the prototype engines at equivalent free-stream Mach numbers greater than 2.5 at sea level. Liquid jet fuel (JP-8) was supplied by either a high pressure pump or a N2-filled reservoir, depending on the test duration. The engine was housed in a 15 cm pressure vessel with three high-pressure, rectangular windows for optical access.

Figure 2 shows a typical pressure trace for a detonation in this system. In comparison to the peak pressure measured during deflagration, which was about 1.8 atm (barely larger than the initial pressure of 1.5 atm) the peak pressure measured during detonation was about 6.0 atm. The temporal resolution of the transducers was limited by the delay and attenuation induced by the standoffs (15 cm). The standoffs were required because, even with the cooling bypass air, transducers mounted directly to the engine were very short lived.

The influence of tube diameter, length, and internal and external obstructions on the thrust was determined using single-shot devices. The reduction of thrust due to the obstacles and various nozzle geometries was measured and it was demonstrated that the induced drag of internal flow obstructions invalidates the common practice of measuring wall pressure to infer thrust. Diagnostic tools were developed to allow full characterization of the flow field during transient operation. Real time diagnostics for soot, temperature, and H_2O, JP-8 and O_2 concentrations were demonstrated in a PDE and shown to be applicable to the flowfield of the small scale PDE. MEMS valves were designed which were capable of accurate control of the fuel flow. The MEMS substrate and metallizing technologies were evaluated at the conditions expected during the PDE cycle. Finally, compact circuits were designed that were capable of directing the necessary power to the valves and ignition system with the required timing.

Phase II of this program in currently underway. The initiation strategy and PDE design for liquid fuel systems will be optimized. Free-form manufacturing techniques will also be employed to build these new designs. The high-speed, small-scale propulsion device discussed here will cost-effectively enable supersonic reconnaissance vehicles, high-speed munitions, miniature cruise missiles, long-range sensor platforms, mother vehicles, and launch vehicles for mini satellites. Mission cost is expected to be an order of magnitude cheaper than manned reconnaissance missions.

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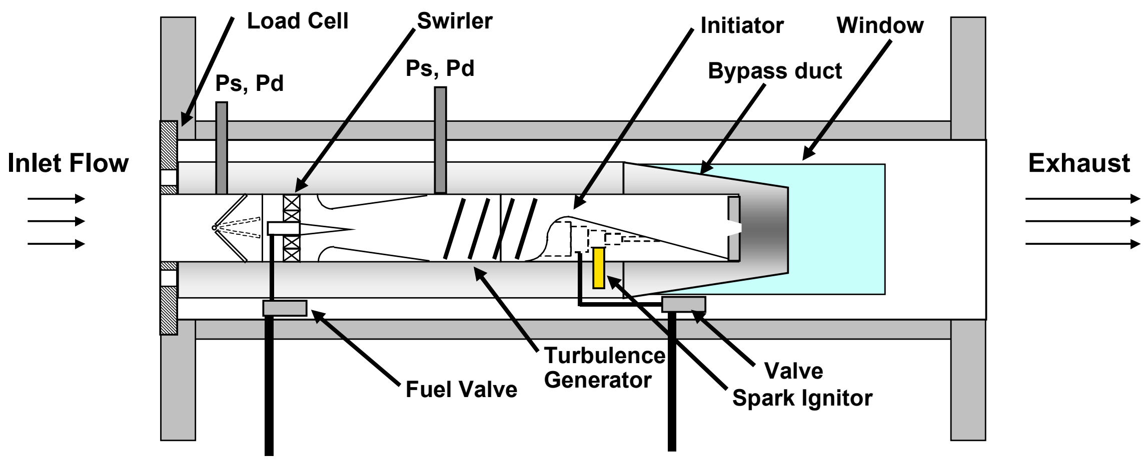

Figure 1. Schematic Arrangement of the PDE test facility at GE Corporate Research and Development.

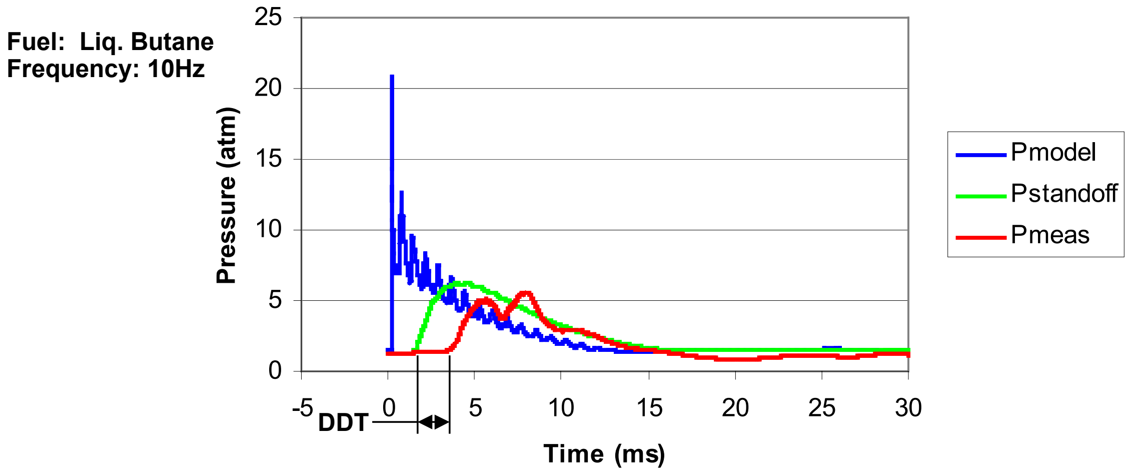

Figure 2. Measured pressure time history (red) compared with the numerical model at the wall (blue) and at the measured location (green).