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# PULSE DETONATION PHYSIOCHEMICAL AND EXHAUST RELAXATION PROCESSES

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## SUMMARY/OVERVIEW:

The objective of this program is to establish the scientific knowledge of detonation initiation, propagation, and blow-down needed to develop a pulse detonation engine (PDE) that will operate on hydrocarbon fuels. Detonation tube exhaust blow-down conditions, which are predicted to have a significant impact upon performance, will be explored in order to achieve basic understanding of the relationships between detonations, nozzles, and multiple detonation tube interactions.

## TECHNICAL DISCUSSION

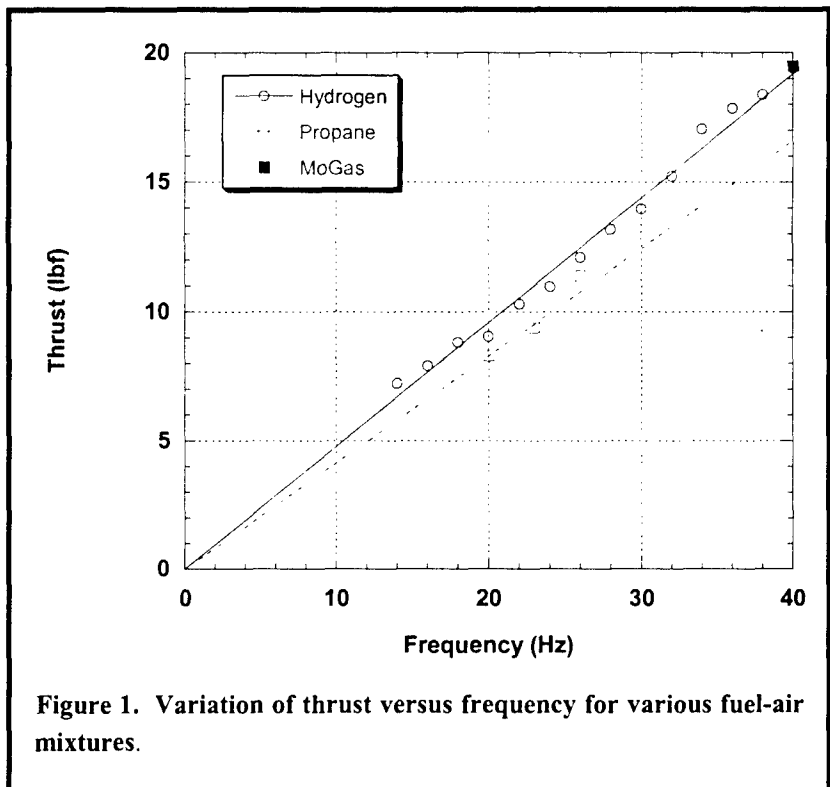
The technological motivation for this program is the need to develop low-cost high-performance PDE's that can operate on hydrocarbon fuels. PDE's rely upon detonation combustion to produce a pressure rise in the combustion chamber instead of the expensive rotating machinery used in gas turbine engines. Consequently, the most expensive and maintenance-intensive components of a conventional turbine engine, namely the compressor and turbine stages, will not be necessary in PDE's. PDE's operates on a near-constant-volume heat addition cycle as opposed to the constant-pressure cycle employed in nearly all conventional aero-propulsion systems. The constant volume cycle offers improvements to specific thrust, specific fuel consumption, and specific impulse at a greatly reduced cost. In theory, the PDE can efficiently operate at Mach numbers from zero to above four without using a combined cycle/rocket approach. However, there are some major technical problems that must be resolved before the full potential of PDE's can be realized.

Foremost among the hurdles for a practical PDE system are the requirements for initiation and successful propagation of a detonation with hydrocarbon fuels in air. Although this has not been achieved in 60 years of PDE research, modern computational fluid mechanics (CFD), laser diagnostics, and high-speed instrumentation have not been applied to this challenge until recently. CFD and experimental studies of deflagration-to-detonation transition (DDT) and propagation are being carried out in order to explore the

parameters controlling detonation initiation including: geometry effects, plasma ignition, hybrid fueled pre-detonators, and endothermic fuels. In addition to existing high-frequency instrumentation, an optically accessible test section will be coupled with our high-framing rate cameras to observe the deflagration to detonation transition processes and compare with models. The imaging and laser diagnostics experience obtained from our AFOSR Combustion Research program will also be used to study the detonator tube blow down. High-frequency Schlieren, PLIF, and/or planar Raman imaging will be used to investigate the exit boundary conditions influence on thrust. Two-dimensional nozzles are used in these investigations, and an optical test section will be employed to study both the nozzle flow conditions and multi-tube interactions. CFD calculations are used to gain an understanding of the mechanisms whereby the thrust is influenced by the conditions established when the detonation wave reaches the exit plane. For example, our Chin detonation spiral was developed recently because modeling of the detonation initiation processes indicated a new mechanism for starting detonations. The insight gained from discovering these phenomena resulted in propane/air detonations with no oxygen enrichment.

This research couples the Combustion Science Branch's extensive basic combustion research experience with the pulse detonation engine in-house research program and high-fidelity detonation modeling capabilities in order to gain the understanding required to overcome the fundamental technological hurdles bracketing the PDE tube: detonation initiation and blow down conditions. Prior 6.2 studies conducted by AFRL/PRTS have made tremendous progress, but we lack understanding of the mechanisms enabling this progress. The techniques developed under this research effort are producing this understanding and then applied to the challenges of detonation initiation and tube blow down.

Computational modeling and experiments have been conducted in order to understand the mechanisms required for deflagration-to-detonation-transition (DDT). The complex interaction of chemistry, gas dynamics, and geometry was found to play a key role in the generation of coalescing compression waves that were ultimately responsible for the creation of 'hot



spots' required for successful DDT. Mechanisms studied by this research for DDT include: obstructions such as classical Shelkin spirals which create compression wave reflections while increasing flame speed through turbulence and flame mixing enhancement; 'Smirnov' type cavities which generate compression waves that subsequently interact with the flame front; and flame propagation in small detonator tube to cell width ratios which result in increased transverse wave reflection events.

The understanding gained of these complex mechanisms through CFD, DDT is experimentally achieved in complex hydrocarbon-air mixtures that did not previously achieve DDT in a practical configuration. Furthermore this work has been extended from detonation of vapor fuel/air mixtures, to the detonation of liquid fuel/air mixtures. Sample results of thrust versus detonation frequency are shown in figure 1 with hydrogen, propane, and liquid gasoline fuels. The mechanisms described above have subsequently been applied towards successful detonation initiation in motor gasoline, av-gas, JP4, JP8, and ethanol with stoichiometries ranging from 0.7 to over 4.

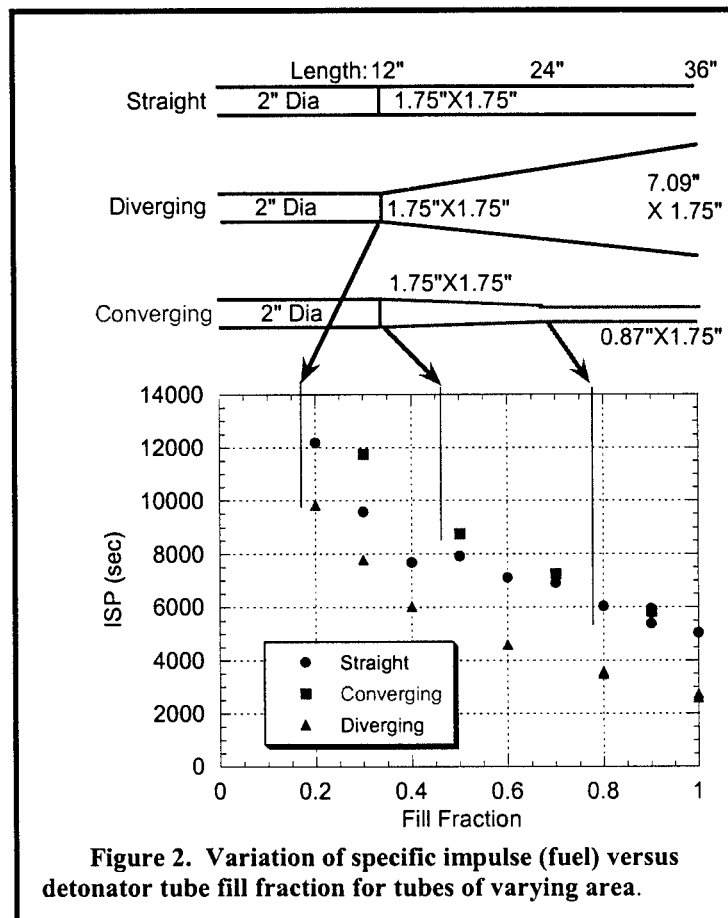


Figure 2. Variation of specific impulse (fuel) versus detonator tube fill fraction for tubes of varying area.

Exhaust relaxation processes have also been studied both numerically and experimentally. The detonator tube blow down process had previously been found to have a significant impact on the resulting PDE performance and is also the source of much controversy as small changes in the exit conditions may impact the pressure relaxation portion of each detonation cycle. The effects of nozzles, bleeding off detonation pressure, ejectors, and other detonator geometry's which impact the sensitive tube exit boundary conditions are being examined. Some sample results depicting the impact of changing detonator tube shape are contained in figure 2. Axial variations in tube area were found to produce variations in efficiency as high as 50%. Details and similar effects will be reported for other changes in exit boundary conditions.

Background information and further details on this program and will be presented at the Contractor's Review meeting.