1. REPORT DATE (DD-MM-YYYY) | 2. REPORT TYPE | Technical Papers | 3. DATES COVERED (From - To) |
6. AUTHOR(S) | |
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) | |
Air Force Research Laboratory (AFMC) AFRL/PRS 5 Pollux Drive Edwards AFB CA 93524-7048 |
8. PERFORMING ORGANIZATION REPORT | |
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) | |
Air Force Research Laboratory (AFMC) AFRL/PRS 5 Pollux Drive Edwards AFB CA 93524-7048 |
10. SPONSOR/MONITOR'S ACRONYM(S) | |
11. SPONSOR/MONITOR'S NUMBER(S) | |
12. DISTRIBUTION / AVAILABILITY STATEMENT | |
Approved for public release; distribution unlimited. |
14. ABSTRACT | |
20030123 038 |
15. SUBJECT TERMS | |
16. SECURITY CLASSIFICATION OF: | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES |
a. REPORT | b. ABSTRACT | c. THIS PAGE | A |
Unclassified | Unclassified | Unclassified |
19a. NAME OF RESPONSIBLE PERSON | Leilani Richardson |
19b. TELEPHONE NUMBER (include area code) | (661) 275-5015 | 21 separate items enclosed
MEMORANDUM FOR PR (In-House Publication)

FROM: PROI (TI) (STINFO) 30 November 1999

Talley, D., "Overview of Pulse Detonation Engines" (BFI)

49th JANNAF Propulsion Meeting (Tucson, AZ, 14-16 Dec 1999) (Statement A)
Overview of Pulse Detonation Engines

Doug Talley
Air Force Research Laboratory\AFRL
AFRL/PRSA, 10 E. Saturn Blvd.
Edwards AFB, CA 93524-7660
(805)275-6174
Douglas.Talley@ple.af.mil

6.2 Objectives

Assess the technical merit of the pulsed detonation cycle and, if appropriate, develop pulsed detonation propulsion technology for Air Force applications.

<table>
<thead>
<tr>
<th>Funding ($1,000's)</th>
<th>FY98</th>
<th>FY99</th>
<th>FY00</th>
<th>FY01</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edwards</td>
<td>810</td>
<td>309</td>
<td>309</td>
<td>309</td>
</tr>
<tr>
<td>WPAFB</td>
<td>731</td>
<td>298</td>
<td>298</td>
<td></td>
</tr>
</tbody>
</table>
**The Pulsed Detonation Cycle**

- Fill with Air and Fuel (intake)
- Detonation (ignition & compression)
- Air Purge (exhaust)
- Expansion (power)

**The Potential**

- Better Isp
- Higher thrust/weight (reduced feed pressures lead to lighter pumps)
- Deeply throttleable and scalable (multiple tubes, operating frequency)
- Lower cost / more reliable (less complex)
- Wider applicable Mach number range

---

Const. vol. estimate of Isp in comparison to a CP device operating at the same fill pressure (compares equivalent feed systems).

\[
\frac{I_{CP}}{I_{CV}}
\]

Stoich. kerosine/air, 1 atm amb. pressure, 3 atm fill press.
The Issues

- Ignition energy
- Deflagration-to-detonation transition (minimize DDT length)
- Practical fuels (JP, RP)
- Multiphase ignitions
- Oxygen enrichment
- Preignitions
- Thermal loads
- Vibration and cycle fatigue
- Valves/injectors

Rocket - Specific Issues

- Filling in a vacuum
- Issues arising out of also having to inject an oxidizer
  - Different mixing regimes
  - Mixing and detonation of TWO condensed phases
- Different kinetic and rheological properties
  - Wide range of possible fuel/oxidants
  - Low/high temperature space environment
  - Lack of emphasis on emissions
- Higher rocket combustion temperatures
  - Hotter walls promote pre-detonation?
Technical Approach

- Develop/use/oversee models of pulsed detonation processes
  - Ideal cases; limiting cases
  - Cycle decks
  - High fidelity models
- Experimentally assess the performance of in-house and proprietary pulsed detonation systems.
  - State of the art facilities
- Conduct in house public domain research and development
  - ITAR restrictions could apply

Strategic Alliances

<table>
<thead>
<tr>
<th>Government</th>
<th>Industry</th>
<th>Academia</th>
</tr>
</thead>
<tbody>
<tr>
<td>NASA</td>
<td>APRI</td>
<td>Cal Tech</td>
</tr>
<tr>
<td>- Revcon</td>
<td>- ASI</td>
<td>- NPS</td>
</tr>
<tr>
<td>- MSFC programs</td>
<td>- Boeing</td>
<td>- Penn State</td>
</tr>
<tr>
<td>NAVY</td>
<td>- Enigmas</td>
<td>- Princeton</td>
</tr>
<tr>
<td>- MURI</td>
<td>- GE</td>
<td>- Stanford</td>
</tr>
<tr>
<td>- 6.2</td>
<td>- HyPerComp</td>
<td>- UCSD</td>
</tr>
<tr>
<td>SBIR funding</td>
<td>- Lockheed/Martin</td>
<td>- U. Florida</td>
</tr>
<tr>
<td></td>
<td>- MSE</td>
<td>- U. Texas</td>
</tr>
<tr>
<td></td>
<td>- RR/Allison</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- SAIC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- UTRC/P&amp;W</td>
<td></td>
</tr>
</tbody>
</table>
Hot fire facility for PDRE testing at Edwards AFB

Fuel: H2(g), CH4(g)
Oxidizer: O2(g)
Purge gas: N2(g), He(g)
H2 mass flow rate: 0.15 lbm/s (0.67 Kg/s)
CH4 mass flow rate: 0.25 lbm/s (0.11 Kg/s)
O2 mass flow rate: 1.0 lbm/s (0.45 Kg/s)
N2 mass flow rate: 0.1 lbm/s (0.23 Kg/s)
Water flow rate: 16 lbm/s (7 Kg/s)
Max. system press.: 2640 psi (179 atm)

128 ch, 200 kbs scanning A/D
16 ch, 2 MHz per ch A/D, independently controlled
Central laser/optics room
Fully instrumented PDRE DAQ and control system

PDE Research Engine at WPAFB
GM Quad 4 DOHC, 4 Cylinder Pulsed Detonation Engine

- Junkyard Technology - $2,000 Hardware Investment
- Pontiac Grand Am Cylinder head (formerly 150 BHP) produces up to 3,000 lbf theoretical thrust as PDE
- Test-bed for PDE Research, Benchmarking
- Pre-detonator/Initiator Development
- High Frequency Operation
- Multi-tube Effects/Pulsed Ejector Research

- Adapter Plate Mounts Detonation Tubes
  - 1-4 Tubes
  - 2' Diameter PDE Tubes for R&D
  - 3 1/2' Diameter PDE Tubes for Engine
- Electric Motor Driven Camshafts
  - 0.5-50 Hz currently (per tube)
  - 100 Hz possible
- Vapor Fuels: Hydrogen and Propane
- Liquid Fuels: Gasoline, Ethanol, JP, etc.

Stock Intake Manifold with Ball Valve Selection of 1-4 Detonation Tubes
(Purge Manifold Similar)
FY99 Accomplishments

• Demonstrated contractor capability to build a back pressure with multiple tubes discharging into a common nozzle
  - Joint effort with Adroit Systems, Inc, and NASA

• Developed constant volume limit model

• Initiated study on the use of condensed phases in PDRE's, including monopropellants

• Initiated efforts to establish a panel to develop a community-standard PDE/RE performance methodology

• PRS-East accomplishments
AFRL Constant Volume Code

Features

- Various propellants, variable mixture ratios
- Gaseous phase and liquid phase propellants
- Buffer gases and partial fills
- Nozzle options
  - Fixed area ratio nozzles
  - Area ratios continuously adjust to match pressure ratios during blowdown
  - Separated or non-separated flow
- Calculates ISP, average thrust, peak pressures, blow down times, area ratios, etc.

Effect of Ambient Pressure on Specific Impulse

GOx/HH2, MR=2.25
Complete expansion to ambient 5 atm fill pressure
Isentropic blow down

Theoretical result for expansion at infinite expansion ratio to a vacuum

\[ I_{sp,CP} = \frac{2}{\gamma} \left( \frac{T_{CP}}{T_{CV}} \right)^{1/2} \]

\[ < (T_{CV} / T_{CP}) < \gamma \]
Multi-cycle operation

\[ V_{\text{chamber}} = 10 \text{ cm}^3 \quad V_{\text{fuel}} = 1 \text{ cm}^3 \quad \text{frequency} = 100 \text{ Hz} \]
Successful Firing of 4-Tube AFRL Research PDE

Photo of firing

Pressure traces in a single tube

Signal (V) vs time
Planned for FY00

- Facilitate JANNAF panel to oversee the development of a community standard PDE/RE performance model
- Demonstrate vacuum start of a multi-tube, common nozzle PDRE
  - Continuation of Adroit/NASA work
- Determine the feasibility of a "constant-volume combustion" pulsed engine operating on condensed phase propellants
  - Monopropellants and bipropellants
- PRS-East plans

Videotapes

Have these been approved?
Air Force Research Laboratory|AFRL

Summary

- Significant facility upgrades have been installed at to support PDE/RE development and evaluation and demonstrated
  - PDRE development and firings at Edwards AFB
  - PDE development and firings at WPAFB
- Modeling efforts are underway in-house to support PDE/RE development
  - Constant volume code
  - Condensed phase code
  - DDT code
  - Other PRS-East codes
- AFRL is attempting to facilitate a panel to oversee the development of a community standard PDE/RE performance model