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MEMORANDUM FOR PRS (In-House Publication)

FROM: PROI (STINFO)  

24 January 2002

Doug Talley (PRSA), "Progress in Pulsed Detonation Rocket Engines at AFRL-West"

ONR Mid-Year PDE MURI Review
(St. Augustine, FLA, 11-12 February 2002) (Deadline: 11 Feb 2002)

1. This request has been reviewed by the Foreign Disclosure Office for: a.) appropriateness of distribution statement, b.) military/national critical technology, c.) export controls or distribution restrictions, d.) appropriateness for release to a foreign nation, and e.) technical sensitivity and/or economic sensitivity. Comments: ____________________________

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PHILIP A. KESSEL Date
Technical Advisor
Space and Missile Propulsion Division
Progress in Pulsed Detonation *Rocket* Engines at AFRL-West

Doug Talley
6.1 Condensed Phase Detonations for PDRE

- Start with low P LOX/Hydrogen
- Evolve to increased P and liq. loadings
  - GHC and LHC fuels
- 10,000 psi design pressure
- Status: still under construction, operational 3Q02

6.2 Pulse Combustion Rocket Demo

- Monopropellants and bipropellants
- Constant-Volume Combustion – not attempting detonations.
- Immediate objective: demonstrate average chamber pressure higher than feed pressure.
- Status: version 1 unable to sustain pulses. Version 2 under construction.
Space Payoffs for PDRE's

Background

- Previous estimates have shown potential Isp advantages at sea level and even up to significant altitudes.
  - Potential boost, combined cycle advantages
- However, there appeared to be little or no Isp advantage in a vacuum.
  - But comparisons were performed only for ideally expanded nozzles
- When practical considerations governing real nozzles are considered, there now appears to potentially be an Isp advantage
  - Isp advantages can be traded for other advantages, such as thrust, weight, etc.
Space Payoffs for PDRE’s

Practical Considerations Governing Real Nozzles

- Although 300:1 and higher expansion ratio thrusters are available, spacecraft manufacturers are often forced to live with much lower expansion ratios (down to 50:1)
  - Larger nozzles may not fit on the launcher
  - Larger nozzles may couple unfavorably with spacecraft vibration modes.
  - Larger nozzles may change the CG unacceptably

Potentially better PDRE Isp comes from being able to package a larger expansion ratio into a smaller nozzle

Marquart Radiation cooled Apogee Engine (MMH/N2O4)

<table>
<thead>
<tr>
<th>Engine</th>
<th>Chamber</th>
<th>Thrust (lbf)</th>
<th>Expansion ratio</th>
<th>Dt</th>
<th>Engine length</th>
<th>Engine mass</th>
<th>Isp (sec)</th>
<th>Pc (psia)</th>
<th>P proof</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-4D-11</td>
<td>Columbium</td>
<td>100-110</td>
<td>164 &amp; 300:1</td>
<td>0.85 inch</td>
<td>14, &amp; 23 inch</td>
<td>11 lbm</td>
<td>310 &amp; 315</td>
<td>115-120</td>
<td>600 psia</td>
</tr>
<tr>
<td>R-4D-15</td>
<td>Iridium/rhenium</td>
<td>100-110</td>
<td>260, 300 &amp; 375:1</td>
<td>0.76 inch</td>
<td>19 to 29 inch</td>
<td>12.5 lbm @ 300:1</td>
<td>318, 323, &amp;327</td>
<td>135-150</td>
<td>600 psia</td>
</tr>
</tbody>
</table>
Space Payoffs for PDRE's

**Approach**

- Space payoffs for PDRE's will ultimately be determined by comparing an optimized PDRE system with optimized conventional and other systems.

**But**

- It is not currently known how to optimize a PDRE
  - Optimization requires an investment of resources

**So**

- Perform sensitivity analyses to determine whether there is enough potential payoff to warrant further investment.
Space Payoffs for PDRE's

Scenario #1
A spacecraft manufacturer wishes to increase the Isp of the spacecraft thrusters, but cannot live with a bigger nozzle. The manufacturer does not wish to change anything about the spacecraft, including the tankage and feed system, which means they must remain at the same pressures and flow rates.

(Trade PDRE advantages for Isp)

Scenario #2
The spacecraft manufacturer is willing to consider using PDRE's to lower feed pressures, thereby reducing tankage and feed system weights

(Trade PDRE advantages for weight)
## Space Payoffs for PDRE's

<table>
<thead>
<tr>
<th></th>
<th>R-4D-11</th>
<th>Scen.1</th>
<th>Scen. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thrust (lbf)</strong></td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td><strong>P_{C, \text{MINIMUM}} (psia)</strong></td>
<td>100</td>
<td>100</td>
<td>37</td>
</tr>
<tr>
<td><strong>P_{C, \text{MAXIMUM}} (psia)</strong></td>
<td>100</td>
<td>440</td>
<td>160</td>
</tr>
<tr>
<td><strong>(lbf/s)</strong></td>
<td>0.316</td>
<td>0.310</td>
<td>0.316</td>
</tr>
<tr>
<td><strong>\frac{A_{\text{EXIT}}}{A_{\text{THROAT}}</strong></td>
<td>164</td>
<td>375</td>
<td>164</td>
</tr>
<tr>
<td><strong>D_{\text{throat}} (inch)</strong></td>
<td>0.752</td>
<td>0.497</td>
<td>.752</td>
</tr>
<tr>
<td><strong>D_{\text{exit}} (inch)</strong></td>
<td>9.63</td>
<td>9.63</td>
<td>9.63</td>
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<tr>
<td><strong>D_{\text{chamber}} (inch)</strong></td>
<td>2.0</td>
<td>1.30</td>
<td>2.0</td>
</tr>
<tr>
<td><strong>L_{\text{motor}} (inch)</strong></td>
<td>23.8</td>
<td>22.5</td>
<td>23.8</td>
</tr>
<tr>
<td><strong>I_{SP}</strong></td>
<td>316</td>
<td>322</td>
<td>316</td>
</tr>
<tr>
<td><strong>Motor Wt. (lbf)</strong></td>
<td>8.8</td>
<td>11.7</td>
<td>8.8</td>
</tr>
<tr>
<td><strong>Tank Wt. (lbf)</strong></td>
<td>49</td>
<td>49</td>
<td>35</td>
</tr>
</tbody>
</table>

*Coy pulsed combustion model*

*AIAA weight model*

*A 6 sec potential gain in lsp for scenario #1.*

*14 lb weight savings for scenario #2*

*How significant are these?*
Space Payoffs for PDRE’s

Satellite Economics*

- For each second of Isp, enough fuel is saved to support approximately 50 days worth of station keeping.
- 1 year’s worth of station keeping in geo requires 50-60 lb propellants.
- Each month on station is worth several millions of dollars of revenue.

6 sec of Isp buys propellants for almost a year on station
15 lb buys propellants for several months on station

Potential for $$ tens of millions in payoff

- Spacecraft manufacturers are also willing to pay hundreds of thousands of dollars more for large expansion ratio thrusters, and are willing to pay a million dollars or so to flight qualify them.

*Maj Abdi Nejad (res), former director of engineering at Marquart
Space Payoffs for PDRE's


### Table 5.1 Specific impulse for operational engines

<table>
<thead>
<tr>
<th>Engine</th>
<th>Thrust (lbf)</th>
<th>Fuel</th>
<th>Oxidizer</th>
<th>$I_{sp}$ (Vac)</th>
<th>Expansion ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rocketdyne RS-27 (Delta)</td>
<td>207,000 lbf</td>
<td>RP-1</td>
<td>Liquid oxygen</td>
<td>262 (S.L.)</td>
<td>8:1</td>
</tr>
<tr>
<td>Atlantic Research Corp. 8096-39 (Agena)</td>
<td>17,000 lbf</td>
<td>UDMH</td>
<td>H.P. nitric acid</td>
<td>300 (Vac)</td>
<td>45:1</td>
</tr>
<tr>
<td>Aerojet AJ110</td>
<td>9,800 lbf</td>
<td>UDMH/N$_2$H$_4$</td>
<td>N$_2$O$_4$</td>
<td>320 (Vac)</td>
<td>65:1</td>
</tr>
<tr>
<td>TRW TR-201 (Delta)</td>
<td>9,900 lbf</td>
<td>UDMH/N$_2$H$_4$</td>
<td>N$_2$O$_4$</td>
<td>303 (Vac)</td>
<td>50:1</td>
</tr>
<tr>
<td>TRW MMPS (Spacecraft)</td>
<td>88 lbf</td>
<td>MMH</td>
<td>N$_2$O$_4$</td>
<td>305 (Vac)</td>
<td>180:1</td>
</tr>
<tr>
<td>TRW MRE-5</td>
<td>4 lbf</td>
<td>N$_2$H$_4$</td>
<td></td>
<td>226 (Vac)</td>
<td>?</td>
</tr>
<tr>
<td>Rocket Research</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MR 104C</td>
<td>129 lbf</td>
<td>N$_2$H$_4$</td>
<td></td>
<td>239 (Vac)</td>
<td>53:1</td>
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<tr>
<td>MR 50L</td>
<td>5 lbf</td>
<td>N$_2$H$_4$</td>
<td></td>
<td>225 (Vac)</td>
<td>40:1</td>
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<tr>
<td>MR 103A</td>
<td>0.18 lbf</td>
<td>N$_2$H$_4$</td>
<td></td>
<td>223 (Vac)</td>
<td>100:1</td>
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<tr>
<td>United Technologies</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orbis 6</td>
<td>23,800 lbf</td>
<td>Solid</td>
<td></td>
<td>290 (Vac)</td>
<td>47:1</td>
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<tr>
<td>Orbis 21</td>
<td>58,560 lbf</td>
<td>Solid</td>
<td></td>
<td>296 (Vac)</td>
<td>64:1</td>
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<tr>
<td>Morton Thiokol</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>STAR 48</td>
<td>17,210 lbf</td>
<td>Solid</td>
<td></td>
<td>293 (Vac)</td>
<td>55:1</td>
</tr>
<tr>
<td>STAR 37F</td>
<td>14,139 lbf</td>
<td>Solid</td>
<td></td>
<td>286 (Vac)</td>
<td>41:1</td>
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<tr>
<td>Pratt &amp; Whitney RL-10</td>
<td>16,500 lbf</td>
<td>Liq. H$_2$</td>
<td>Liq. O$_2$</td>
<td>444 (Vac)</td>
<td>?</td>
</tr>
</tbody>
</table>

- Other space thrusters start with even smaller expansion ratios
  - Bigger potential payoffs
Summary

- The numbers above are still rough, but appear to show payoff for further PDRE development.