SCRAMJET TESTING IN SHOCK TUNNELS

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Shock Tunnel Terminology

- No 4 - Driver Section (high pressure light gas-hydrogen, helium etc)
- No 1 - Driven Section (low pressure gas such as air)
- A - diaphragm
- B - diaphragm
- C - nozzle
- D - test section at very low pressure
- No 5 - nozzle stagnation condition (settling chamber)
- When A bursts shock wave travels at Mach No Ms from A towards B;
- An expansion wave travels from A towards driver section end;

How Shock Tunnel Works

Shock wave reaches diaphragm B and gets reflected and moves towards A; high pressure and temperature P5 and T5 created between shock wave and diaphragm B; diaphragm bursts and P5, T5 expands through nozzle to test section to desired Mach number;

* Expansion wave gets reflected from driver section end and travels towards B;
* Tunnel run time begins at instant of bursting of B and ends at instant expansion wave reaches B; this is usually about 1ms;
SHOCK TUNNEL TERMINOLOGY

CONNECTED PIPE TEST MODE

SEMIFREE JET MODE OF SCRAMJET TEST
Typical HRV Flight Conditions And Shock Tunnel Operating Parameters

<table>
<thead>
<tr>
<th>CASE</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alt (km)</td>
<td>25</td>
<td>30</td>
<td>35</td>
</tr>
<tr>
<td>Mach No</td>
<td>6</td>
<td>6.5</td>
<td>7</td>
</tr>
<tr>
<td>P inf(mb)</td>
<td>27</td>
<td>12.5</td>
<td>6</td>
</tr>
<tr>
<td>T inf(degK)</td>
<td>220</td>
<td>231</td>
<td>243</td>
</tr>
<tr>
<td>P5 (atm)</td>
<td>50</td>
<td>41</td>
<td>34</td>
</tr>
<tr>
<td>T5 (degK)</td>
<td>1624</td>
<td>1931</td>
<td>2258</td>
</tr>
<tr>
<td>M (shock)</td>
<td>3.5</td>
<td>3.9</td>
<td>4.3</td>
</tr>
<tr>
<td>P1 (mb)</td>
<td>600</td>
<td>350</td>
<td>250</td>
</tr>
<tr>
<td>P4(atm)</td>
<td>18</td>
<td>21</td>
<td>25</td>
</tr>
</tbody>
</table>

(For Hydrogen as driver gas)

Note: It is seen that the tunnel operating conditions are benign and feasible

Literature Survey

- Australia - complete scramjet model with intakes, burners, thrust surfaces, tested in T4 (Paulletal1995); thrust greater than drag recorded; stress wave balance used (from website of Univ. of Queensland)
- Japan - NAL proposed to test 2m long full configuration model at Minf=8 in Hiest free piston shock tunnel. A system of accelerometers to be used to measure forces. Model is freely suspended using fine wires (Takahashi etal-22ndInternational Symposium on shock waves)
- Russia-joint USA-Russia hypersonic combustion experiments in TsniimashPGU 11. Minf=10, P5=1000 bar, T5=4000 deg K. Hydrogen fuel (Orthand Kislykh-AIAA 96 -4584-CP)
- Italy - connected pipe supersonic combustion tests with hydrogen fuel; M=3 flow; rectangular cross section tunnel; multicasde compression
principle of PGU11 ; runtime ~ 10ms (Reggiorietal-8thIWSTT-Sept 2002-IISc)

Major Impulse Tunnels Worldwide

- Aachen, Germany-shock tunnel-1500 bar, 8000 degK, $M = 6$ to 20, nozzle .5m, 1.0m, 2.0m, .5 to 10ms test time;
- HEG, Germany-FPST -1500 bar, 10000 degK, $M = 8$ to 10, .8m diannoze, 1ms test time;
- T4, Australia-FPST -2000 bar, 8600 degK, $M = 6$, .25m diannoze, .4 ms runtime;
- CALSPAN, USA-shock tunnel, 1300 bar, 8000 degK, $M = 6.5$ to 20, 1.2m diannoze, .7 to 20 ms runtime;
- HIEST Japan-FPST -1500 bar, 9000 degK, 25MJ/kg, 1.2m diannoze, 1ms runtime;
- PGU 11 Russia-impulse facility-2500 bar, 10000 degK, 30MJ/kg, 1.0m nozzle dia, 500ms runtime;

Proposed Plan of Action

- Conduct preliminary combustion tests at IISc shock tunnels on a small scale during 2003;
- Set up large shock tunnel at DRDL by end of year 2003;
- Conduct tests at DRDL shock tunnel during 2004;
- Design large impulse tunnel by end 2003;
- Establish large impulse tunnel as a national facility by end 2006; conduct tests from end 2006;