Investigating Reentry Plasmas using Sounding Rockets

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Presentation Overview

- History of Hypersonic Flight
- Sounding Rocket Trajectory
- Reentry Plasma Formation
- Mitigation of Reentry Plasma Effects
- Previous Hypersonic Plasma Diagnostics
- Plasma Impedance Probes
- Preliminary Simulation
- Conclusions
History of Hypersonic Flight

1949
Bumper Rocket Program
V2 / WAC Corporal
(Anderson, 2006)

1967
Scout Vehicle
RAM C-I
(Akey, 1970)

1970
Scout Vehicle
RAM C-III Payload
(Dunn, 1973)

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Recent History of Hypersonic Test Flights

2005
DLR SHEFEX

2010-2011
DARPA HTV-1/2

2012
DLR SHEFEX II

2012
NASA Langley IRVE-3

2009-2017
AFRL, NASA, Australian DSTO
HIFiRE

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Comparison to Shuttle & Exploration

Space Shuttle
7.8 km/s (17,500 mph)

Exploration Flight Test 1
8.9 km/s (20,000 mph)
Compression of air between shock front and vehicle causes a dense highly collisional plasma to form

Why care about the plasma formed?
- RF Communications Blackout (NASA Technology Roadmap – TA 5.2)
- Boundary Layer Flow Analysis
- Atmospheric Composition Determination

Hartunian, 2007

Rybak, 1971
Mitigation of Reentry Plasma Effects

- Electrophilics / Ablatives
- Sharp Tip
- $E \times B$ Drift
- Matching Plasma Impedance
- Higher Frequencies / TDRSS

Belov, 2001

Kim, 2008

Akey, 1970

Davis, 2011

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Previous Hypersonic Plasma Diagnostics

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<thead>
<tr>
<th>Index</th>
<th>Band</th>
<th>Frequency [MHz]</th>
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<tbody>
<tr>
<td>10</td>
<td>VHF</td>
<td>225.7</td>
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<tr>
<td>4, 5</td>
<td>VHF</td>
<td>259.7</td>
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<tr>
<td>11</td>
<td>C</td>
<td>5700 (5800*)</td>
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<td>6, 7, 8, 9</td>
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<td>9210</td>
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</table>

Reentry Plasma Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min Value</th>
<th>Max Value</th>
<th>Unit</th>
<th>Source</th>
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</thead>
<tbody>
<tr>
<td>Electron Density</td>
<td>$3 \times 10^{14}$</td>
<td>$6 \times 10^{17}$</td>
<td>m$^3$</td>
<td>Dunn, 1973</td>
</tr>
<tr>
<td>Collision Frequency</td>
<td>$6.3 \times 10^7$</td>
<td>$1.3 \times 10^{11}$</td>
<td>s$^{-1}$</td>
<td>Hartunian, 2007</td>
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<tr>
<td>*Peak Plasma Layer Distance</td>
<td>0</td>
<td>11</td>
<td>cm</td>
<td>Dunn, 1973</td>
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<tr>
<td>Electron Temperature</td>
<td>4000</td>
<td>10000</td>
<td>K</td>
<td>Dunn, 1973</td>
</tr>
</tbody>
</table>

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Plasma Impedance Probes

- RF stimulus to Probe (Antenna) with the excitation signal swept in frequency.
- The reflected magnitude and phase response provides the plasma impedance.
- The plasma impedance determines the plasma parameters:
  - Electron Plasma Density
  - Electron-Neutral Collision Frequency
  - Electron Temperature (Under Investigation)
  - Plasma Layer Thickness (Under Investigation)
- Space Lab and Penn State investigating new methods to determine these plasma parameters.
Preliminary Impedance Simulations

Reentry Plasma Effects
- Negligible geomagnetic field effects
- Decreased from ideal 50 $\Omega$
- Wide BW (real)
- Resonance not at peak real impedance
Conclusions

- **Why care about reentry plasma formation?**
  - RF Communication Blackout (NASA Technology Roadmap)
  - Boundary Layer Flow Analysis
  - Atmospheric Composition

- **Sounding rockets can provide a low-cost test platform for reentry plasma studies.**

- **Needs for further understanding of reentry dynamics:**
  - New Sounding Rocket trajectory required utilizing high thrust configurations and attitude adjustments prior to motor burn phases (i.e. Black Brant XII-A or similar)
  - Partnerships in investigation of multiple reentry technology areas

- **Needs for further understanding of the reentry plasma environment:**
  - New Theory Development & Simulation
  - Wind Tunnel Verification
  - Sounding Rocket Flight Verification
References


