Plasma Sheathing Control Using Boundary Layer Stabilization and Additives

Hartmut H. Legner, John F. Cronin and W. Terry Rawlins
Physical Sciences, Inc., Andover, MA
Substitute Speaker: Dr. Robert F. Weiss, Physical Sciences Inc.

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Acknowledgment and Note

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- **This Phase I SBIR effort was sponsored by two AFRL organizations: SNHE and VAAC, with additional interest from a third organization: VSBXT**

- **The technical monitor is Dr. James Ernstmeyer of AFRL/SNHE at Hanscom AFB, MA**

- **<u>Special note</u>: This presentation provides a general overview of potential sheathing solutions. Specific results and designs have SBIR rights and ITAR restrictions. The detailed report can be obtained from Dr. Ernstmeyer.**

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Outline

- **Plasma sheathing control objectives**
- **Three techniques**
  - Boundary layer stabilization by extreme cooling
  - Liquid injection into boundary layer flow
  - Electrophilic material in heat shield material
- **Application to hypersonic vehicles**
- **Summary**

Plasma Sheathing Control Objectives

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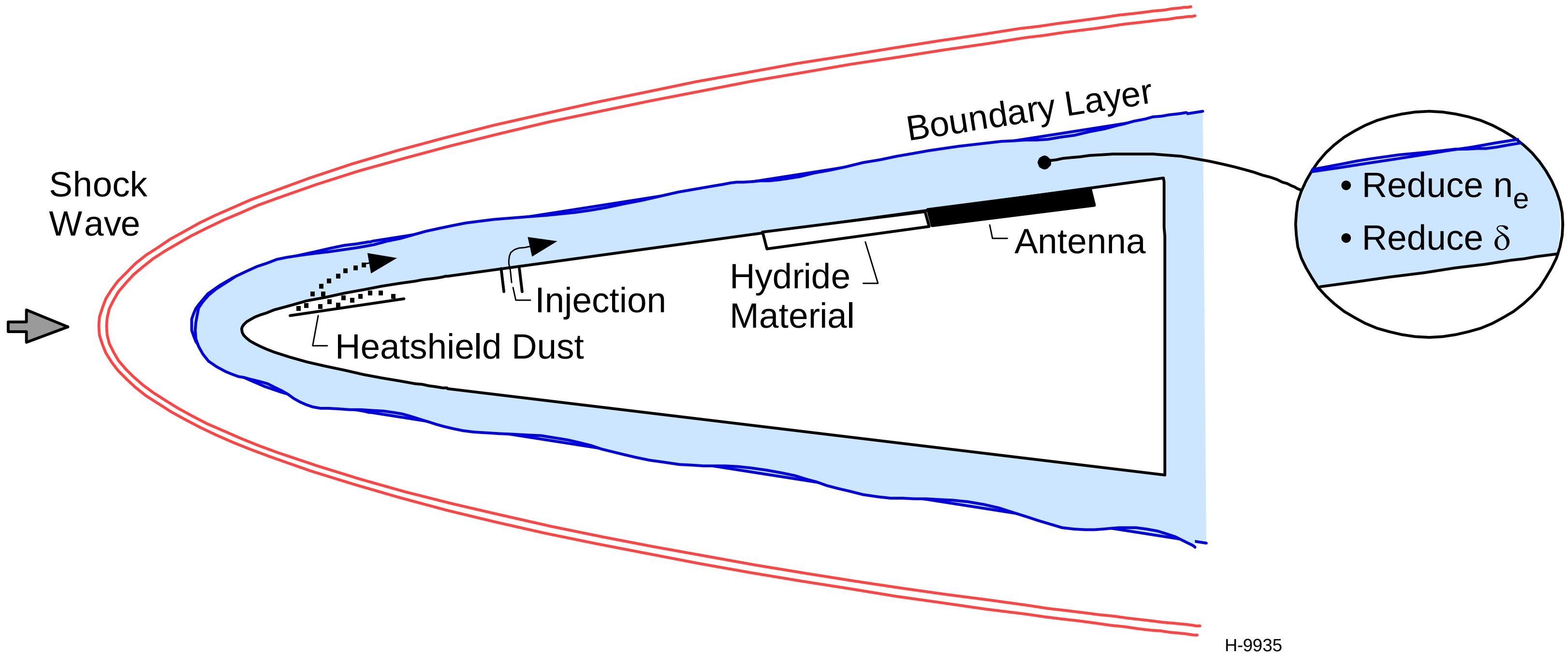

- **Control sheathing via temperature and chemistry**
- **Reduce electron density, n_e**
- **Reduce boundary layer thickness, δ**

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Plasma Sheath Attenuation Reduction
BRV, 50 kft, n_e = 1.8 x $10^{12}/cm^3$, 0.130 atm, ν_c = 1.3x10^{10} S^{-1}

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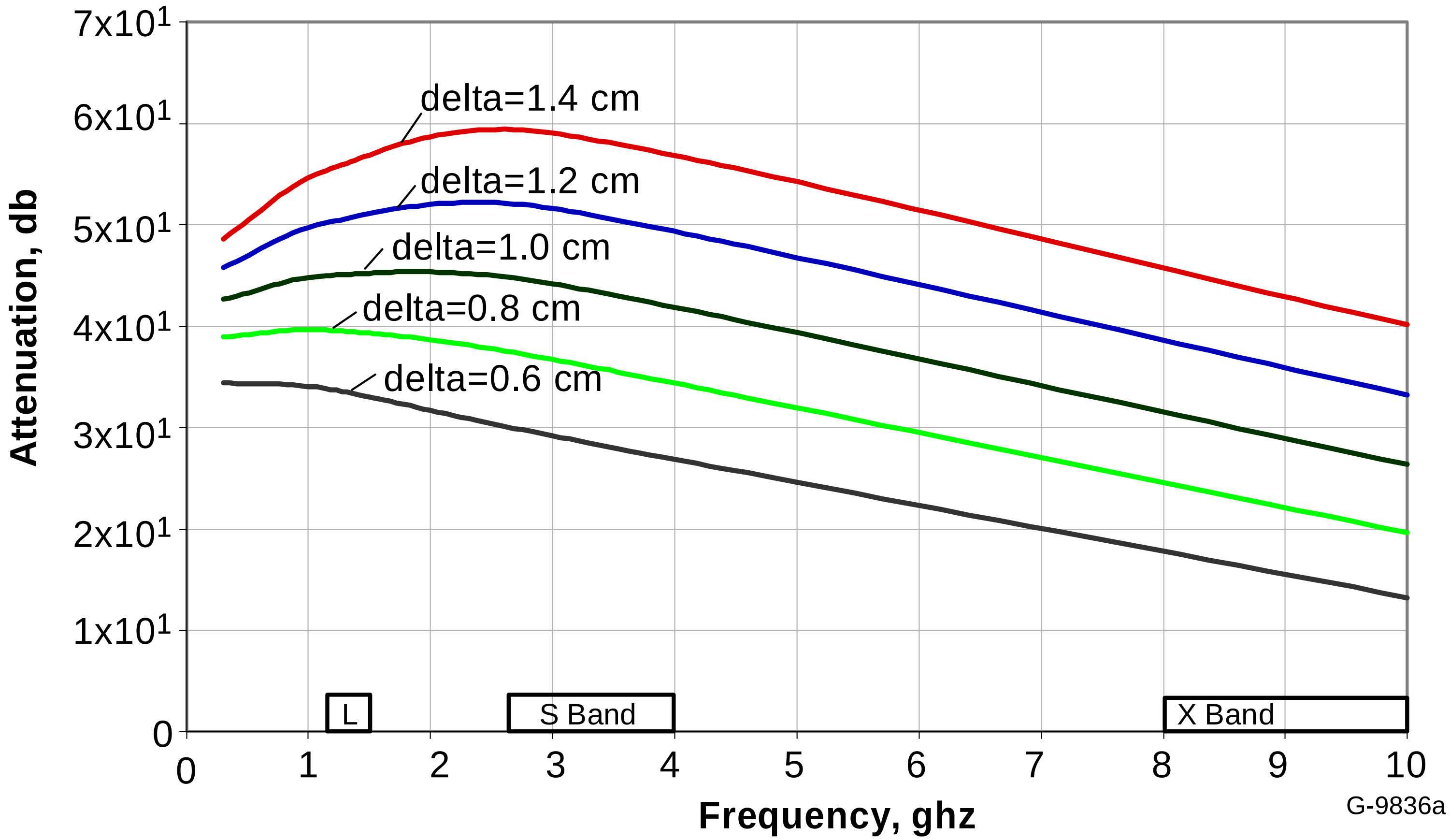
Boundary Layer Thickness Reduction



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Plasma Sheath Attenuation Reduction
BRV, 50 kft, Delta = 1.4 cm, 0.130 atm, ν_c = 1.3x10^{10} S^{-1}

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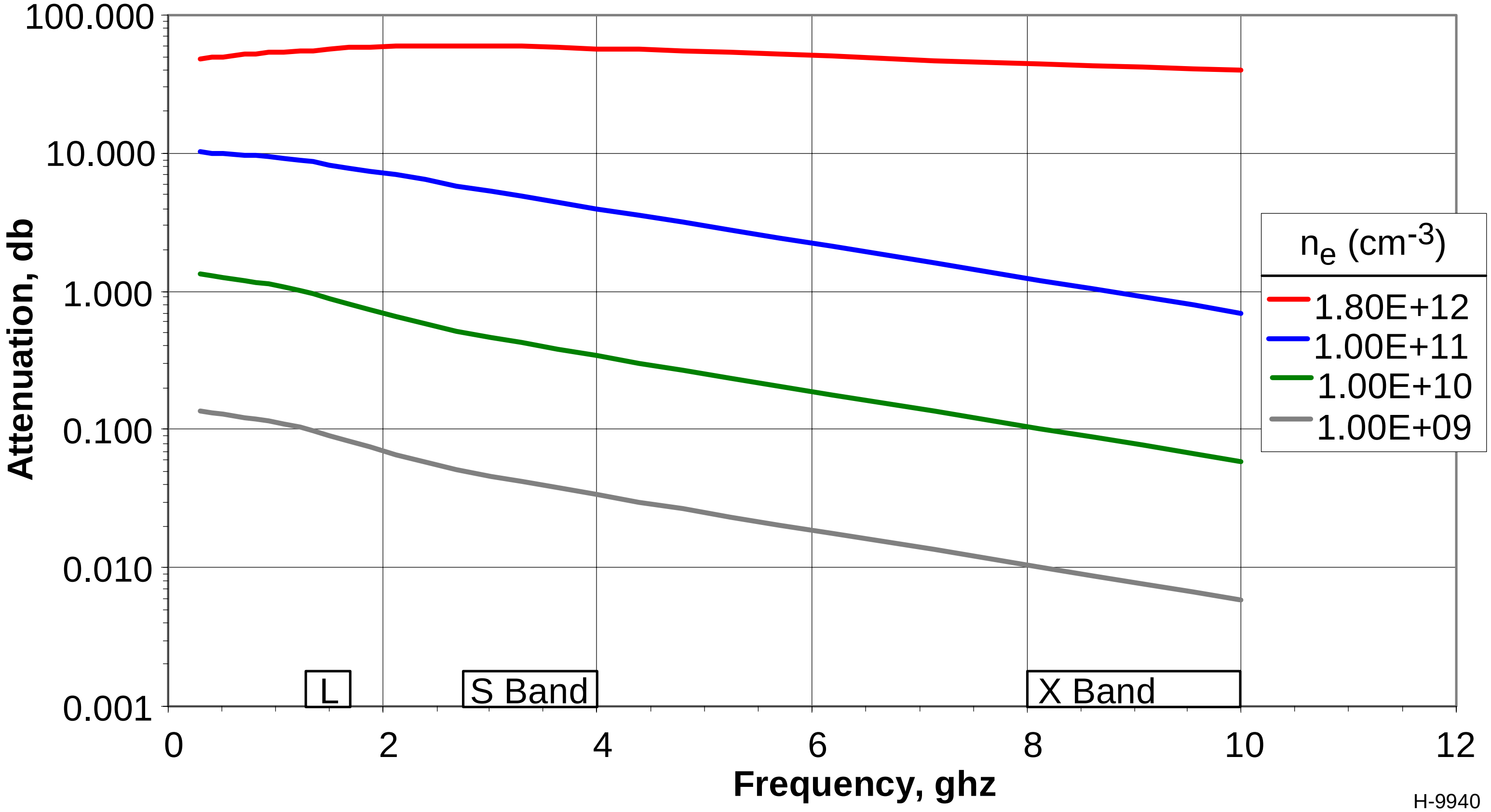
Electron Density Reduction



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Extreme Surface Cooling Using Hydride Materials

- **Extreme cooling stabilizes hypersonic boundary layer**
  - Secondary mode unstable at high edge mach number
  - Remain below $M_{e_{2nd\ mode}}$ for laminar flow
- **Hydride cooling works over a large range of heating conditions**
  - Amount of hydride (material thickness) controls "cool time"
- **Hydrogen gas released during low-temperature ablation process**
  - 15-20 kJ/gm H_2 , heat of desorption (and adsorption)

Hydride cooling works over wide range of trans-atmospheric flight conditions

Hydride Cooling for Typical Surface Heating Flux
50 W/cm²

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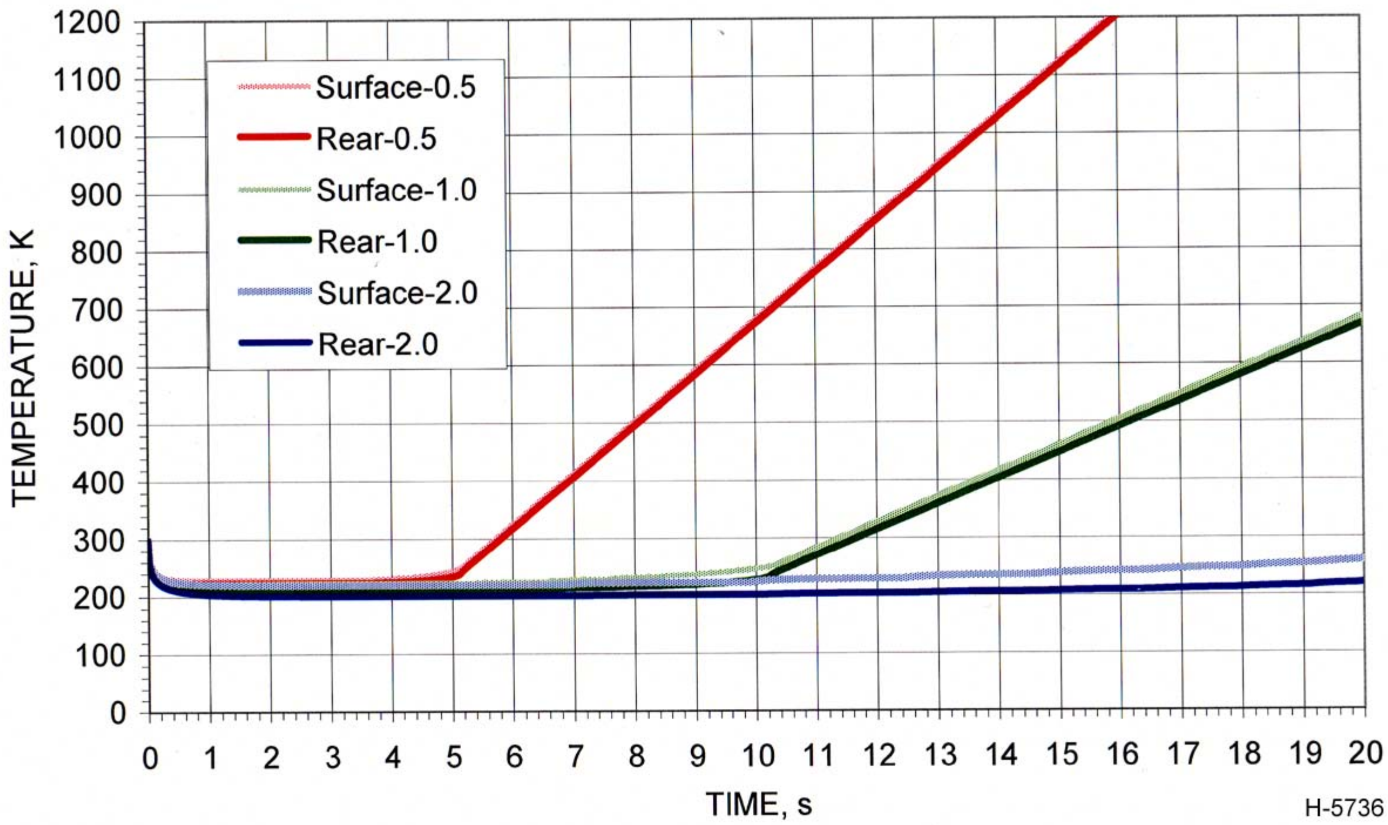

Computations performed using PSI's validated thermal response code

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Cooling Stabilization Boundary for Trans-atmospheric Trajectory Points

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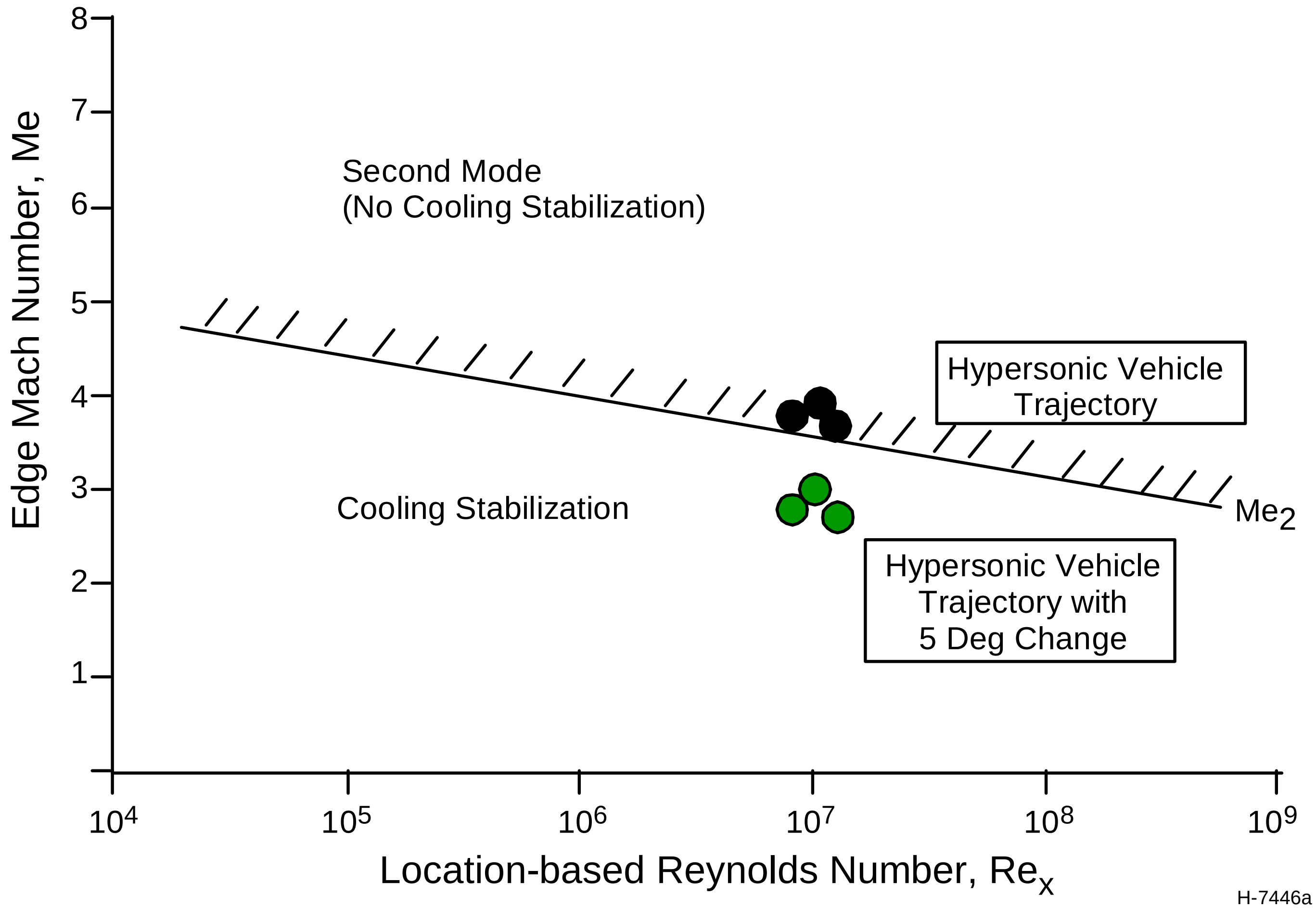

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Liquid Injection

- **NASA RAM C-III Flight Experiment 1973**
  - $n_e(cm^{-3})$ at boundary layer standoff distance 4 cm, 71-72 km altitude
    - No injection: 3.9×10^{10}
    - Water: 4.8×10^{9}
    - Freon-3: 3.8×10^{8}
  - Blunt vehicle, Teflon frustum, 5000 ppm alkali impurities, pulsed injection

- **Employed Non-equilibrium Boundary Layer (NEBL) code to compute effects of injectant on downstream electron density**
  - Same trans-atmospheric flight conditions as hydride
  - Instantaneous vaporization
  - 50 ppm alkali in carbon phenolic heatshield
  - Wall cooling effects

Water injection showed insignificant effects, but Freon-3 resulted in orders of magnitude n_e reduction depending on boundary layer cooling

Freon Injection Cases

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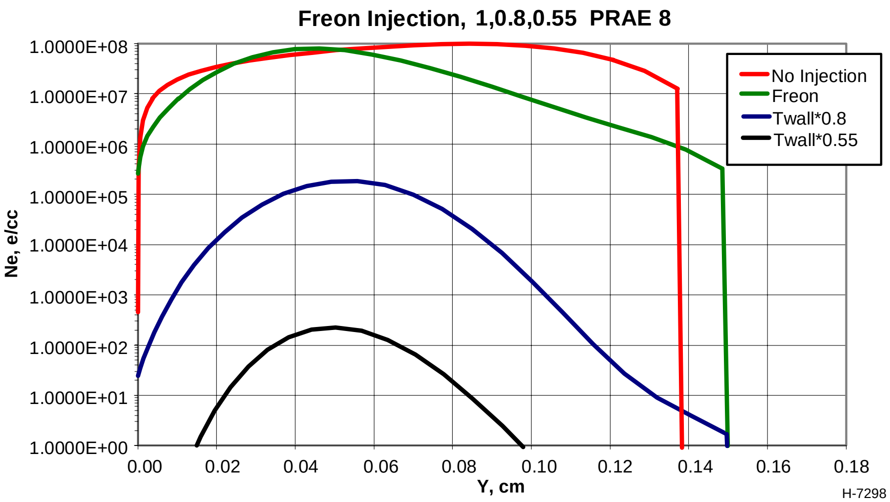
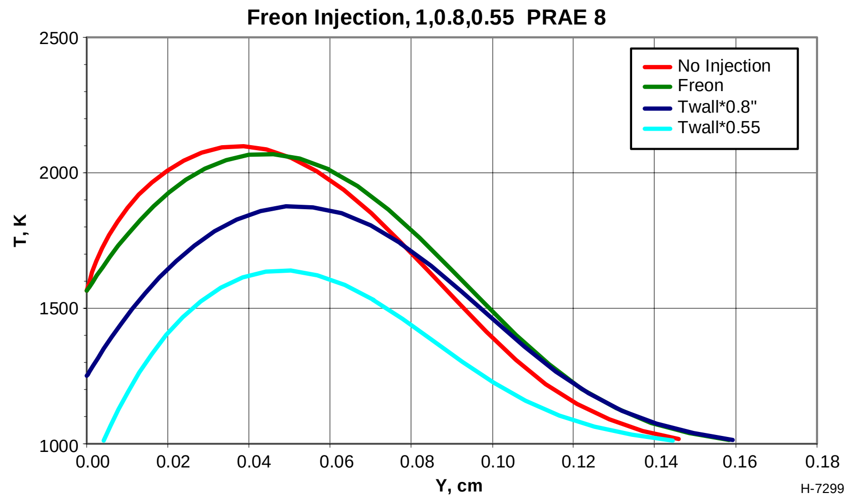
$n_e(cm^{-3})$



T(°k)



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Heatshield Electrophilic Scavenging Computations

- **Electrophilic particles take up electrons efficiently by the reaction**

$$P + e^- \underset{k_d}{\overset{k_a}{\bullet}} P^-$$

- **Applied heterogeneous chemistry model, Caledonia (1986)**
  - Electrophilic specie concentration (ppm)
  - Particle size (Å)
  - Work function (eV)
  - Temperature (K)

Electron Density Reduction

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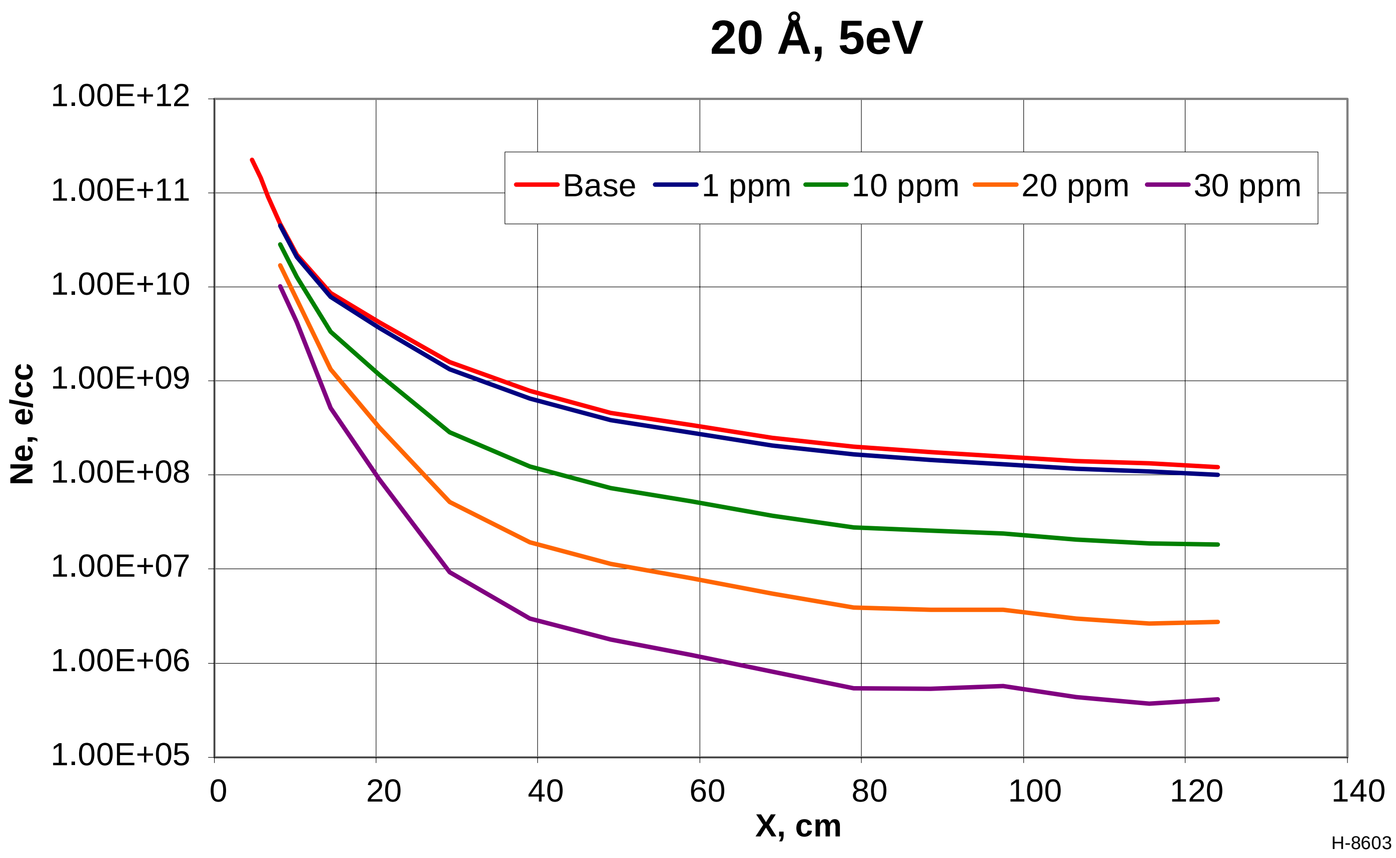

Large potential sheathing reduction using low concentration of electrophilic material

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Vehicle Application

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Requirements	Plasma Sheathing Control Techniques: Boundary Layer Transition Control	Additive Injection	Incorporation of Electrophilic Species
Missions			
Weapon	One-time control	Multiple control applications	Continuous
Surveillance	Multiple applications	Multiple control applications	Continuous
Altitude History			
Velocity Time	Velocity dependent 5-20 s	Some velocity dependence 5-20 s, pulse	Some velocity dependence Continuous or pulsed
Configuration			
Waverider	Compatible	Compatible	Compatible, distributed in heatshield or injected
Bi-conic	Compatible	Compatible	Compatible, distributed in heatshield or injected
Design			
• Volume Impact	Small	Modest	Very small
• Weight Impact	Small	Modest	Very small
• Power Impact	Very small	Small	None, small if injected

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Summary

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- **Three general techniques to control plasma sheathing have been identified.**

- **All three schemes are potentially viable for application to hypersonic cruise vehicles.**

- **Experimental validation and multi-phase modeling simulations are needed to pursue this promising technology further.**

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Backup Charts

Metallic Hydrides

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- **Transition metal hydrides**
  - $A_xB_{l-x}H_y$ type compounds
  - decompose rapidly and endothermically to produce H_2

$$A_xB_{l-x}\,H_y \rightarrow A_xB_{l-x} + y/2\ H_2$$

Heats of Desorption (and Adsorption)

$LaNi_5H_6 = LaNi_5 + 3\ H_2$ $\Delta H = 15.1$ kJ/gm H_2

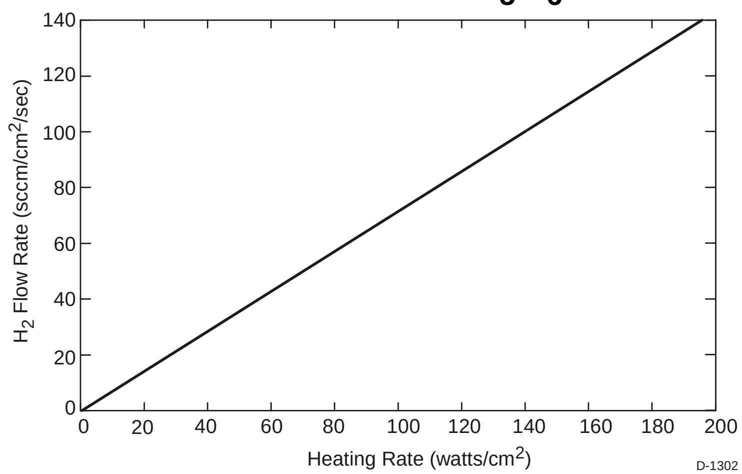
and

$(V_{0.89}Ti_{0.11})_{0.95}Fe_{0.05}H_x, =$

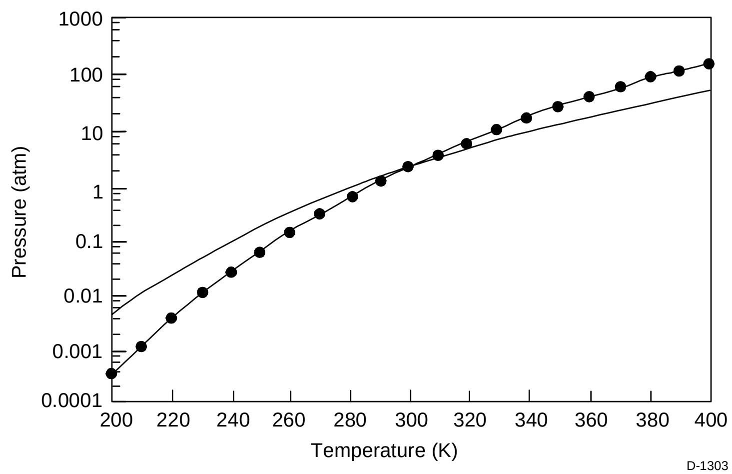
$(V_{0.89}Ti_{0.11})_{0.95}Fe_{0.05}H_{x-1} + 1/2H_2$ $\Delta H = 21.5$ kJ/gm H_2

- High energy, low temperature ablators

H_2 Flow as a Function of Heating Rate for $LaNi_5H_6$



H_2 Pressure Above $LaNi_5H_6$ (—) and $(V_{0.89}Ti_{0.11})_{0.95}Fe_{0.05}H_x$(•–•)



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Boundary Layer Models

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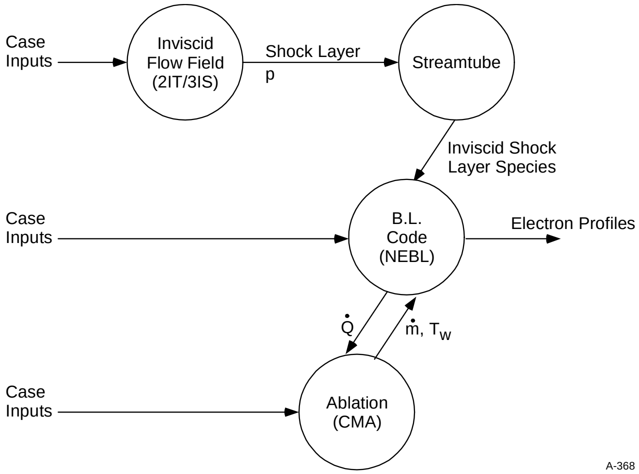
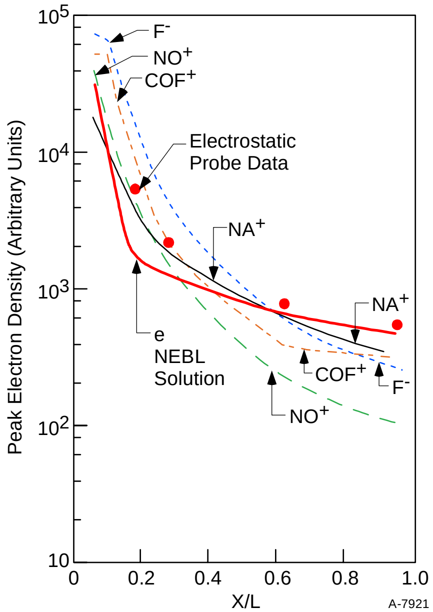
- **Non-Equilibrium BL (NEBL) Code**
  - implicit, fully-coupled model
  - unique chemistry models
- **TURBL**
  - 8 equation turbulence model
  - temperature fluctuations mirror plasma behavior
- **REACH (developed by SAIC)**
  - 3D BL Code

NEBL Methodology

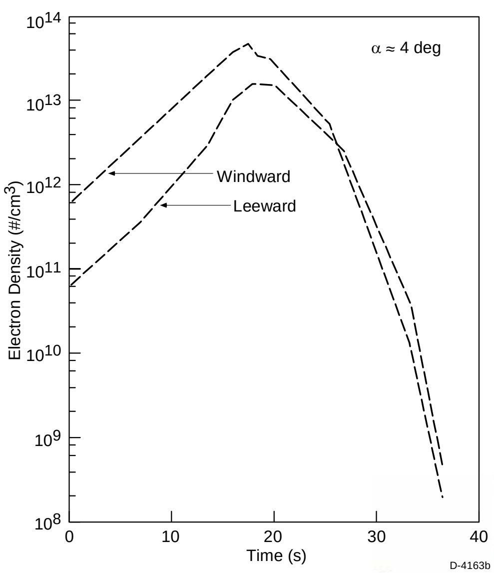


NEBL Calculation



Teflon
RMV-340
131 kft

REACH Simulation



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Water Injection Cases

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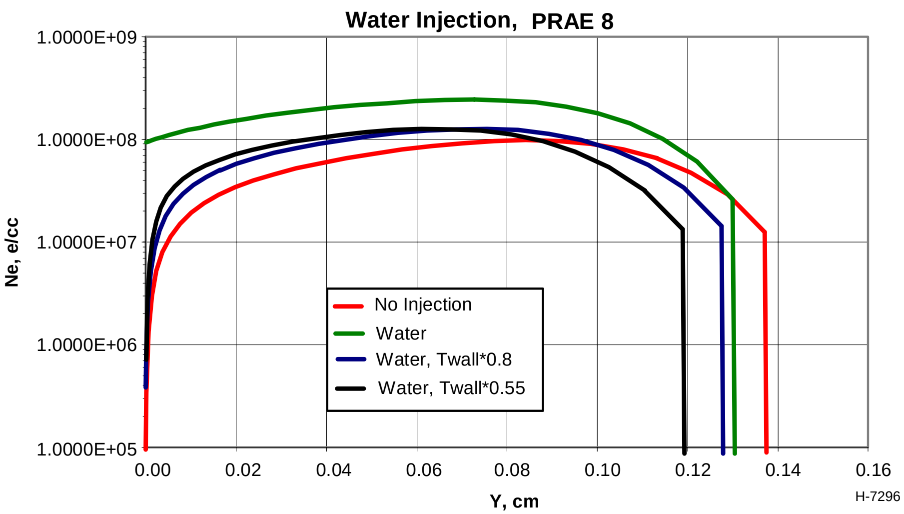
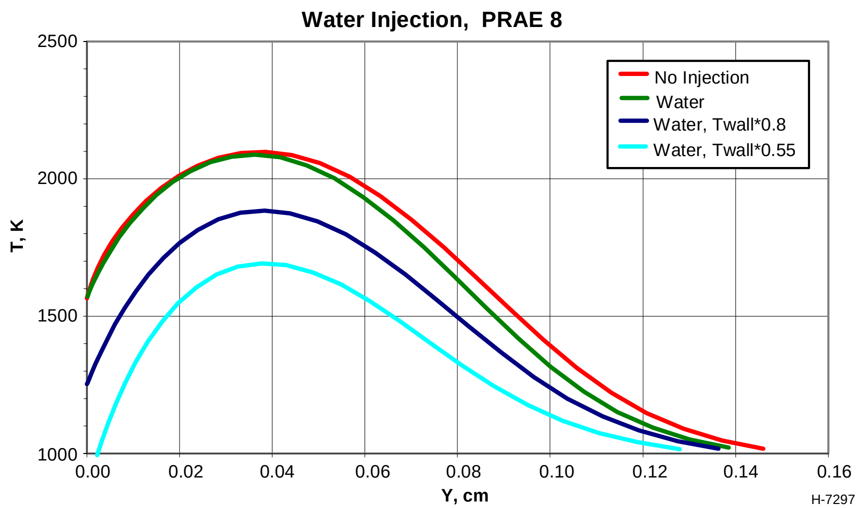
$n_e(cm^{-3})$

$T(^ok)$





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Freon Injection
Synergistic Effects: Hydride Cooling and Injection

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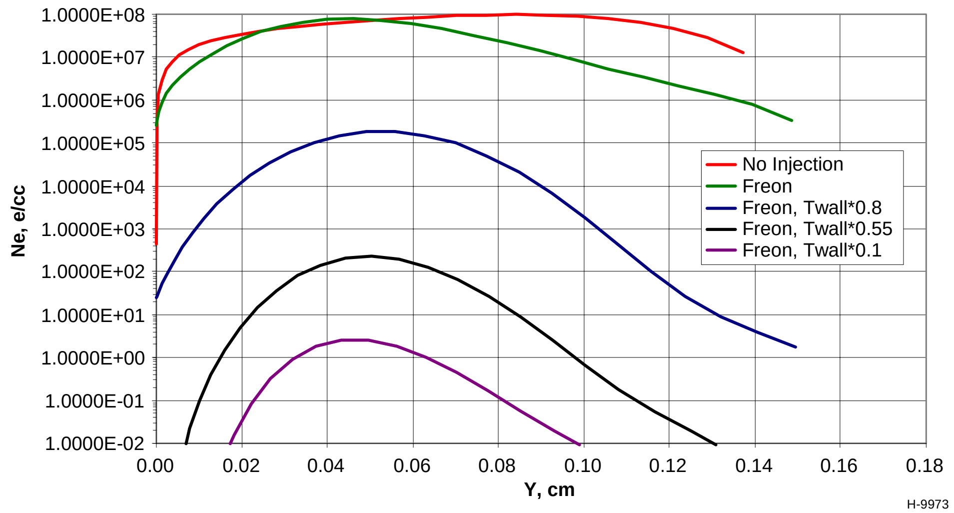
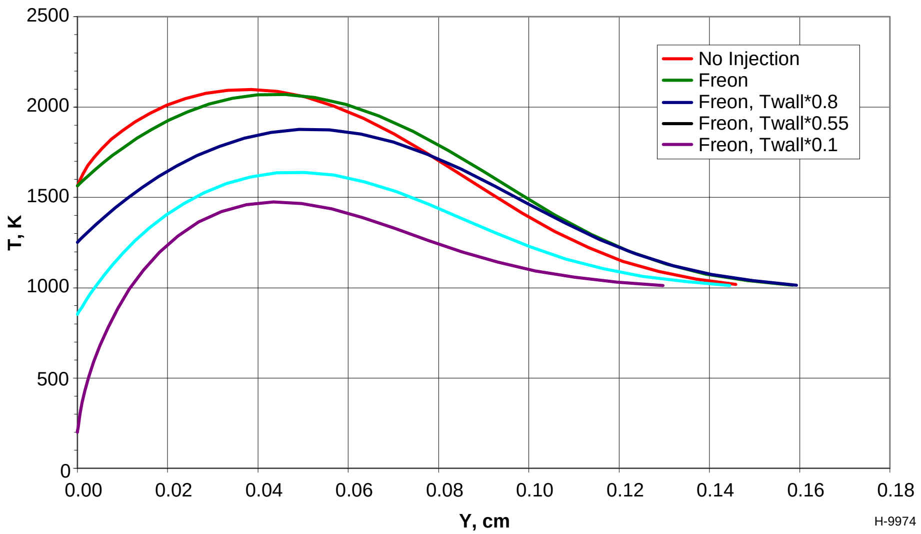
$n_e(cm^{-3})$



$T(^ok)$



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