An Update on the Charged Aerosol Release Experiment *CARE*

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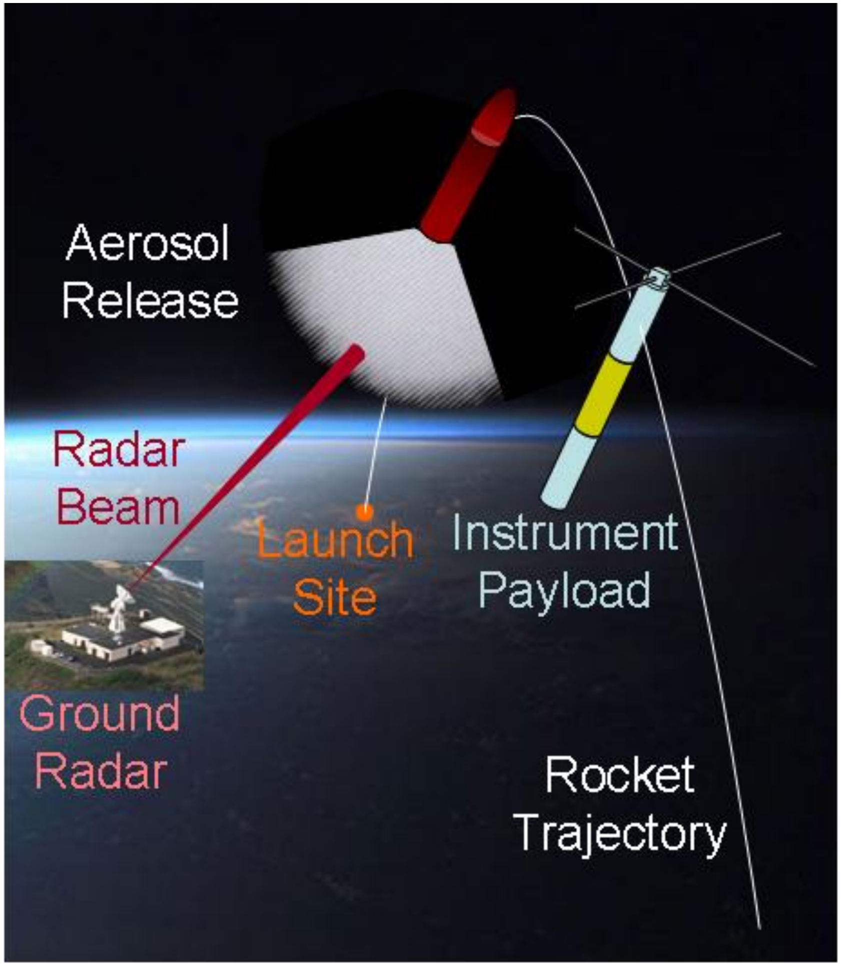
12th Workshop on the Physics of Dusty Plasma
19 May 2009

Charged Aerosol Release Experiment Modified/Enhanced *CARE Concept*



Radar and In Situ Diagnostics of Artificial Dusty Plasma Cloud

Objectives: Examine the effect of artificially-created, charged-particulate layers on the penetration of UHF, L-Band and S-Band radars.

Design and build a rocket payload with a chemical release and instruments to solve the mystery of radar echoes from dusty plasmas

Description: A series of rocket experiments will be conducted to test the theories for radar scatter from charged dust.

- Rocket Experiment
  - Chemical Release (280 km Altitude, 111 kg)
  - Instrumented Payload
    - Radio Beacon (CARE I)
  - Ground Radars for Backscatter Observations
  - Launch Sites
    - Wallops Island, Virginia (CARE I 2009)
    - Andoya, Norway or Poker Flat, Alaska (CARE II)
    - Kwajalein, Marshall Islands (CARE II Alternate)
- Supporting Theory
  - Chemical Release: Plume Model
  - Particle Dispersal: Monte Carlo Simulations
  - Plasma Turbulence: Electrostatic PIC Code
  - Radar Scatter: Electromagnetic Theory

CARE Personnel

Name	Affiliation
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Dr. Miguel Larson	Clemson
Dr. Erhan Kudeki	Illinois/Urbana
Dr. Julio Urbina	PSU
Dr. Phil Erickson	Millstone Hill
Dr. George Jumper	AFRL/RVBYA

Name	Affiliation
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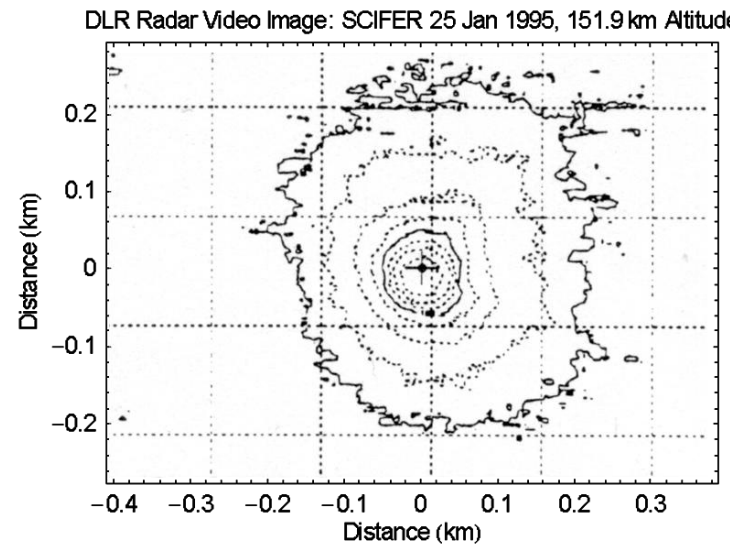
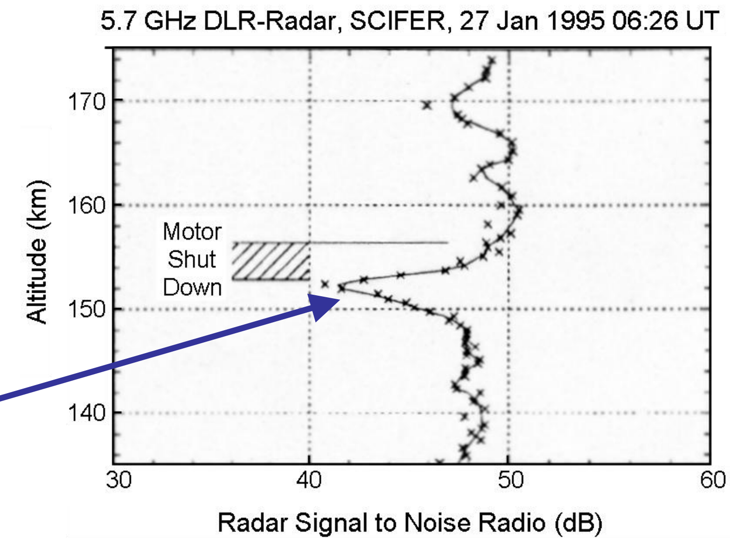
Eric Johnson	NSROC/EE-Power
Valerie Gsell	NSROC/GNC
Cathy Hesh	NSROC/VSE
Adam Sturgis	NSROC/SQA
Greg Ellis	NASA/Ground Safety
Roland Wescott	NASA/Flight Safety
Ron Walsh	NASA/PM
Libby West	NASA/SRPO

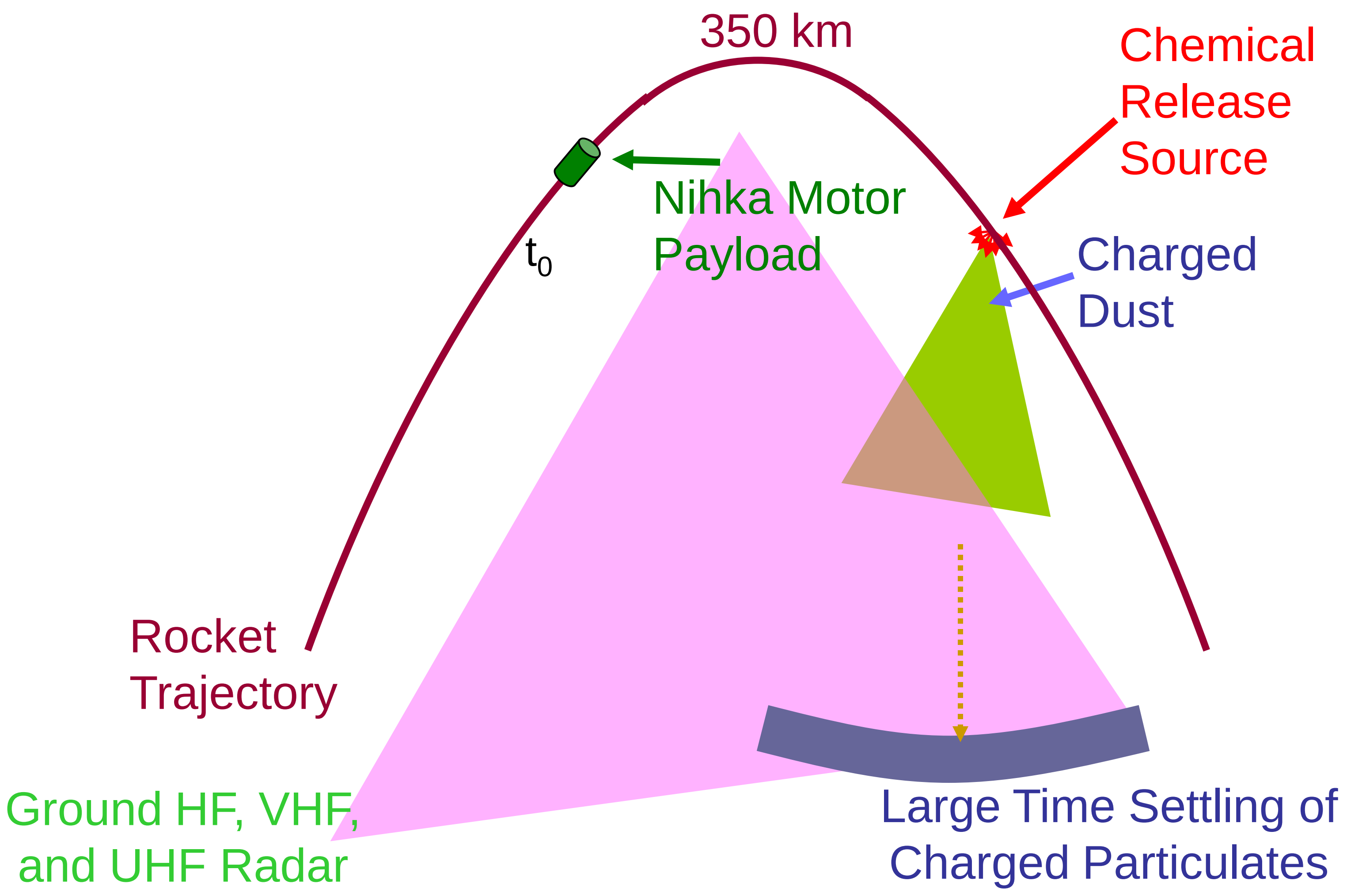
Particulate Release Observations During the SCIFER Mission on 25 January 1995





- 25 January 1995 Four Stage Black Brandt XII Launch from Andoya Norway
- Nihka Motor Fired from 98.7 to 156.3 km Altitude
- Dust Cloud Observed for 66 Minutes
- 5.6 GHz Radar Echoes Attenuated by 7 dB

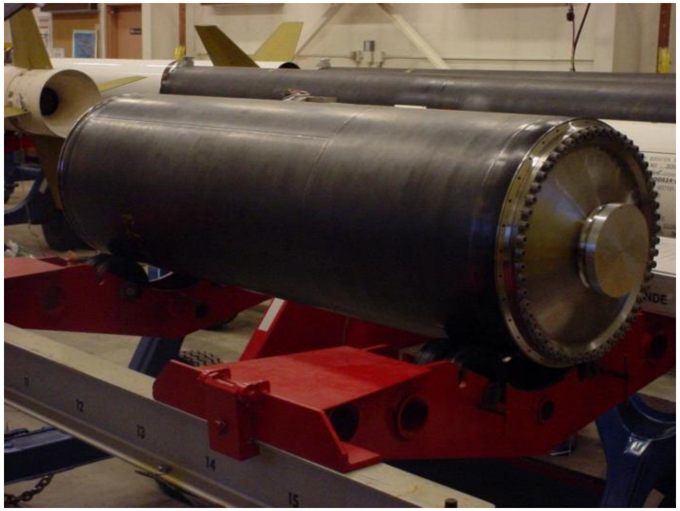
New Artificial Dust Layer Concept



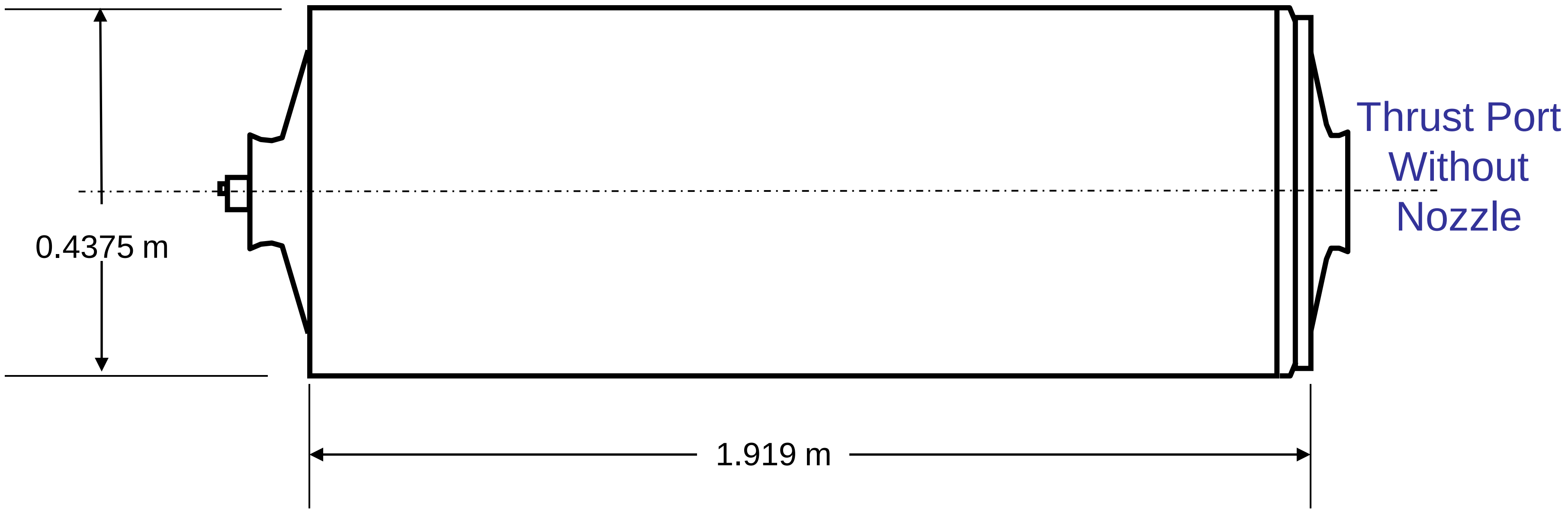
Objectives of CARE Program

- Artificial Noctilucent Cloud Formation
  - Physics of Enhanced Radar Scatter
  - Radar, Lidar and Optical Diagnostics
  - Satellite Measurements (AIM)
- Release from Nihka Solid Rocket Motor
  - Large Concentration of Dust
  - Supersonic Injection Velocity
- Experiment Enhancements
  - Ground and Ship Ionosonde Diagnostics
  - Direct Injection by Chemical Release Module

Nihka Motor Dust Generator for CARE
(111 kg Al_2O_3 in 17 Seconds)



Constituent	Mole Fraction	Total Mass
Carbon Monoxide	0.2039	69.1 kg
Carbon Dioxide	0.0186	9.9 kg
Monatomic Chlorine	0.0124	5.3 kg
Hydrogen Chloride	0.1478	65.2 kg
Hydrogen	0.2712	6.6 kg
Monatomic Hydrogen	0.0317	0.4 kg
Water	0.1393	30.4 kg
Nitrogen	0.0817	27.7 kg
Aluminum Oxide	0.0897	110.6 kg



Truncated Nozzle for Nihka Motor

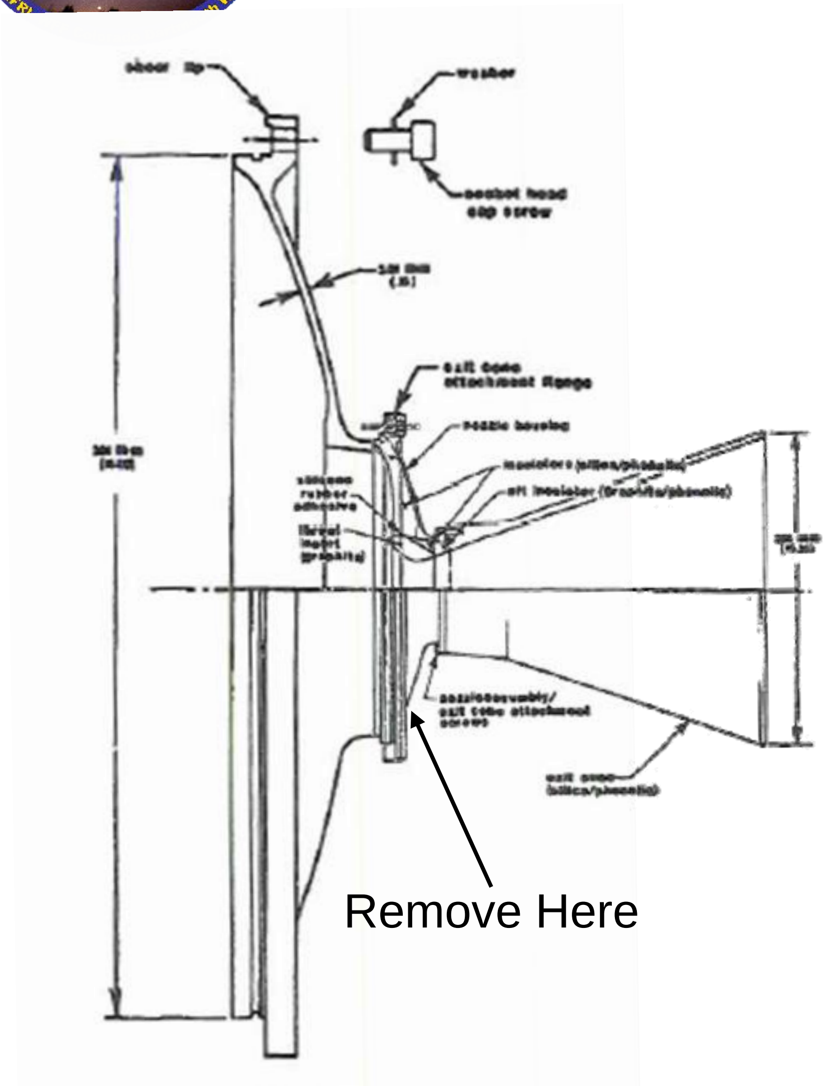
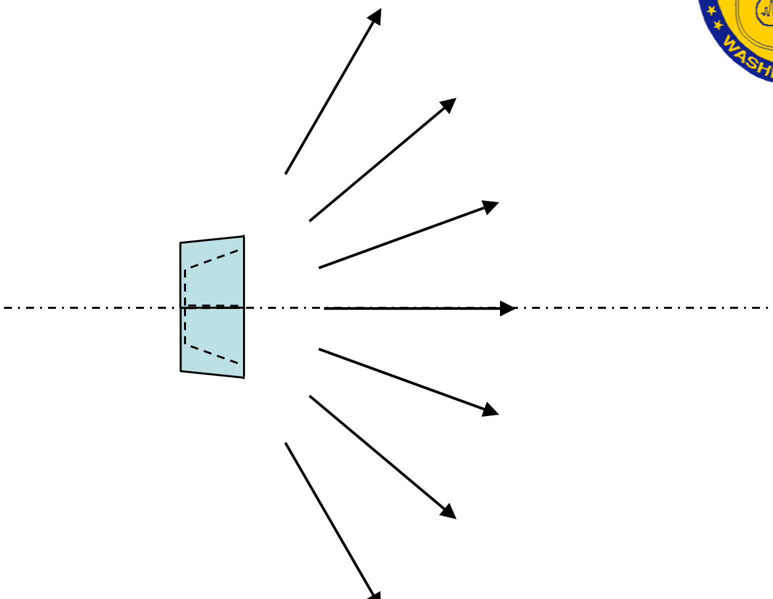
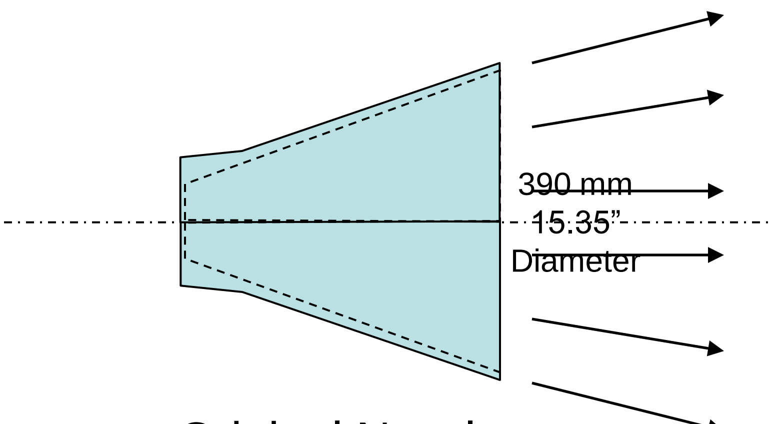


FIG. 3 NOZZLE HOUSING



Deleted Nozzle at Throat



Original Nozzle

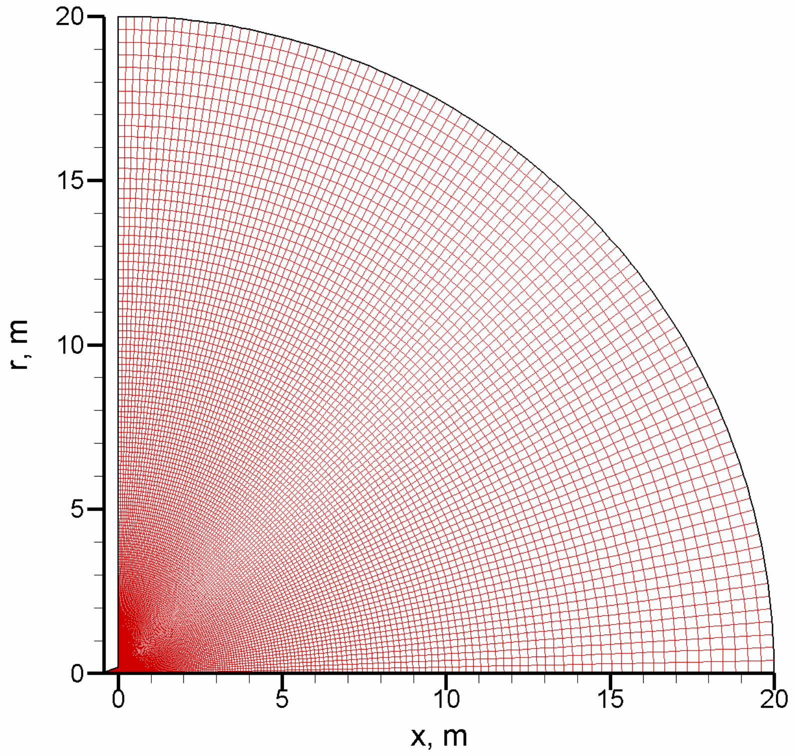
DSMC Computations of Nozzle Effect on Plume Properties for Nihka Motor

Jonathan Burt and Iain Boyd

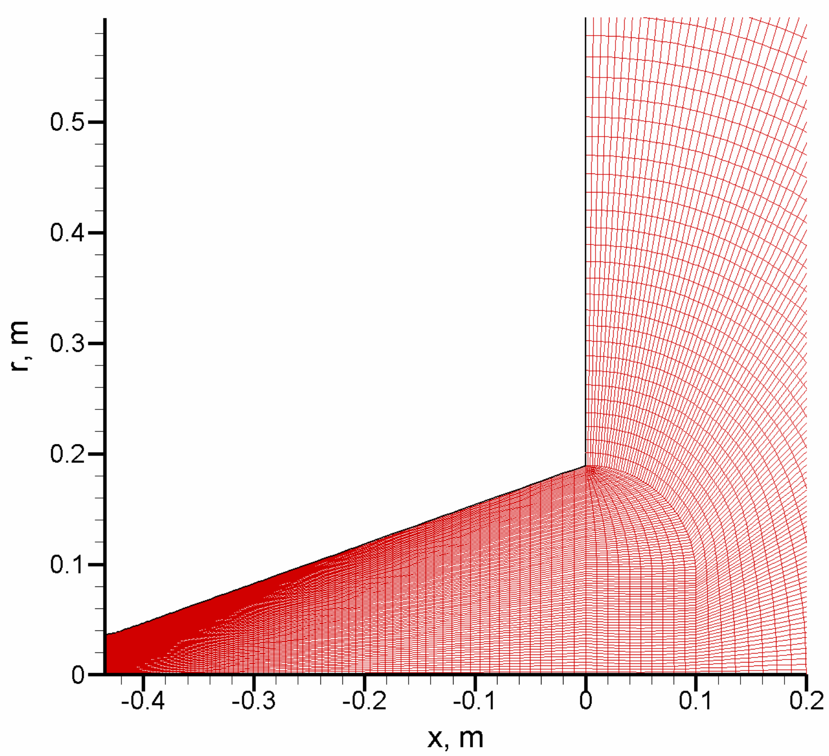
May 2009

With Nozzle

- Computational mesh



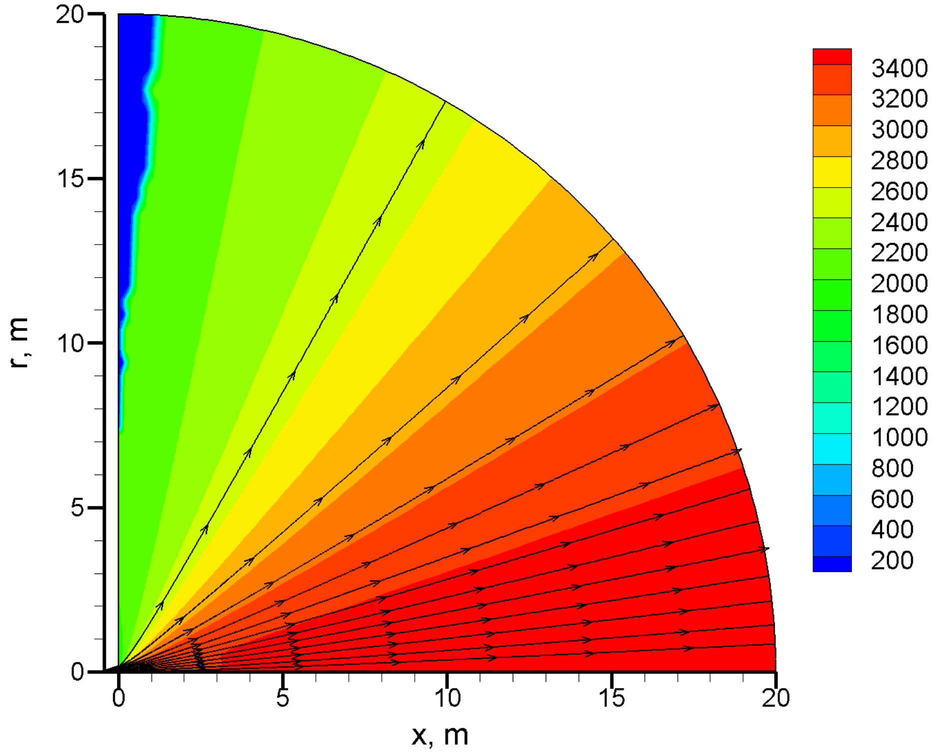
Flow Field



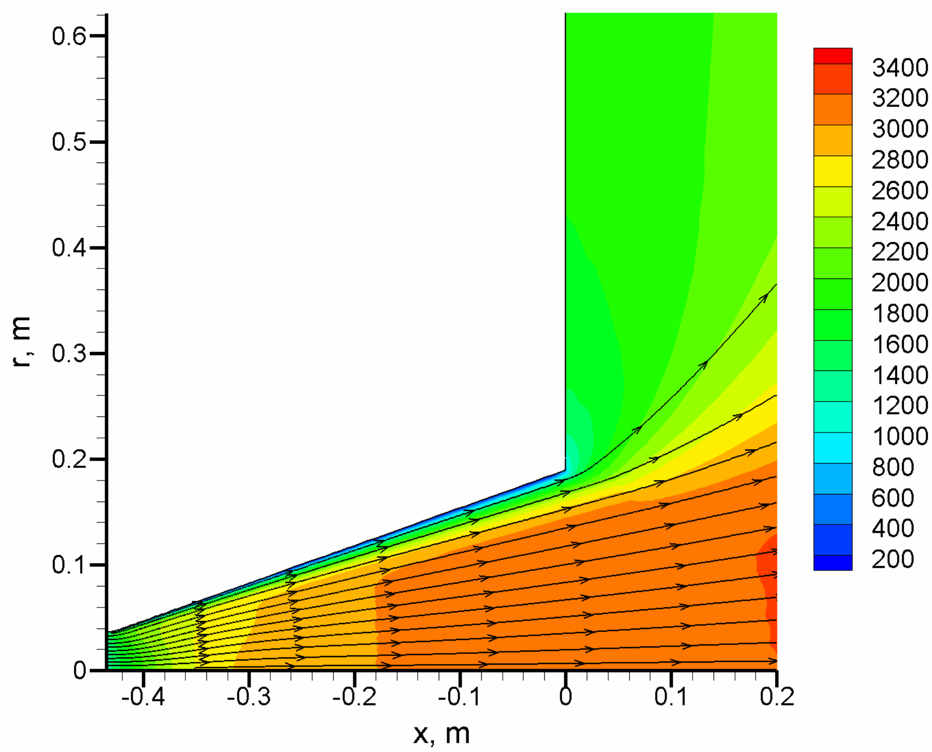
Detail at Nozzle

With Nozzle

- Streamlines, contours of bulk gas velocity (m/s)



Flow Field

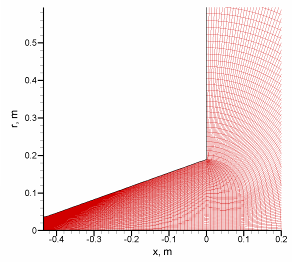


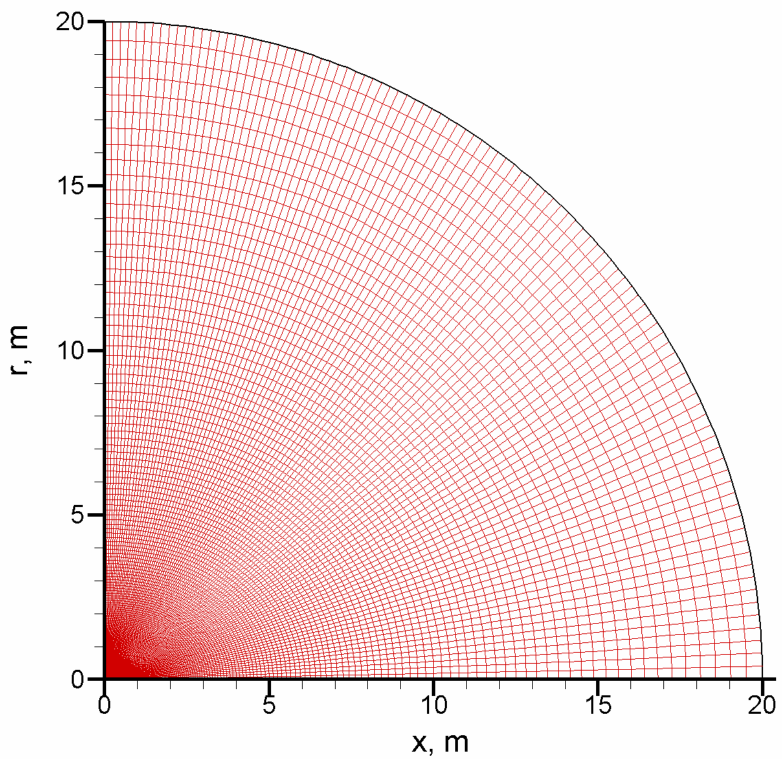
Detail at Nozzle

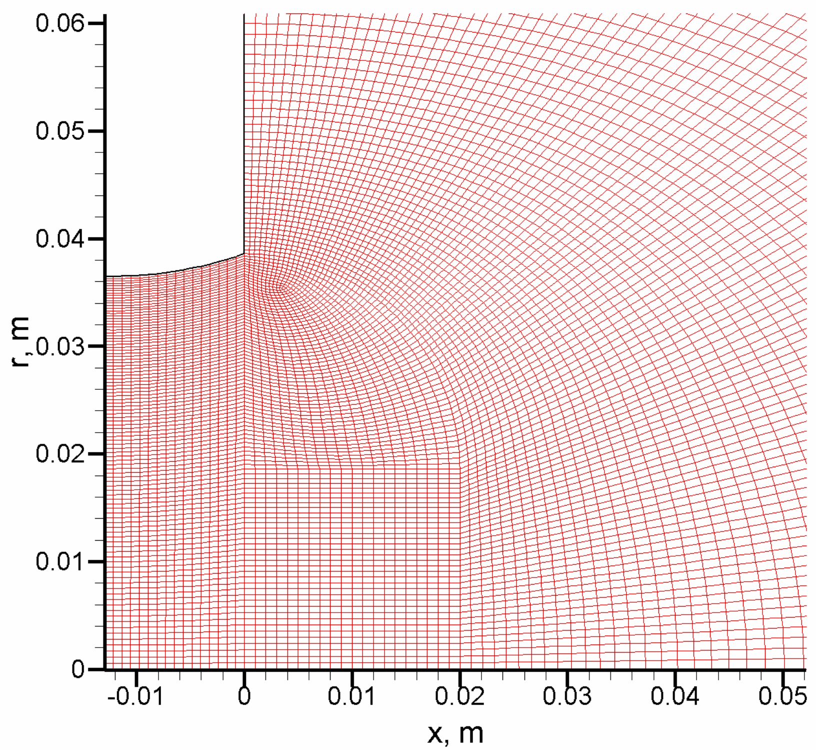
Nozzle Removed

- Computational mesh

Nozzle mesh for comparison



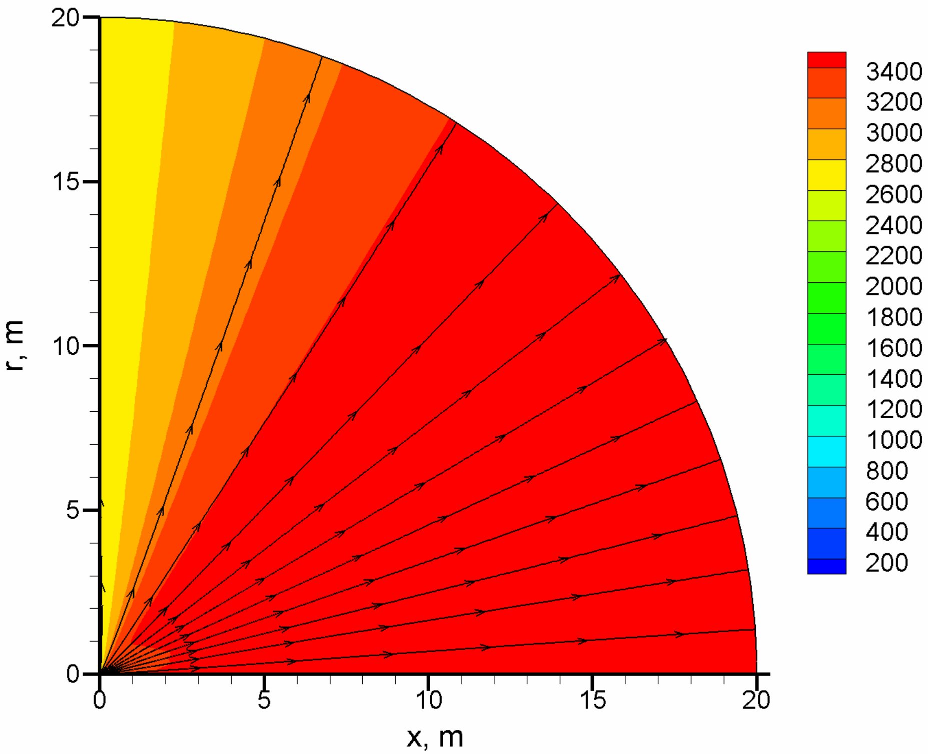


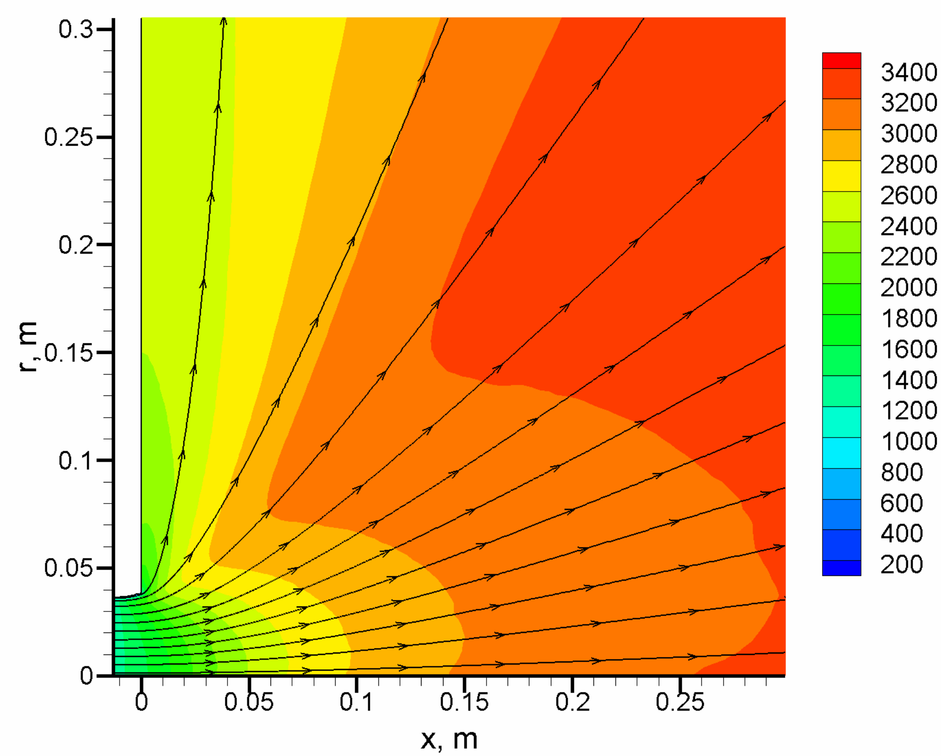


- Nozzle is truncated 1.3 cm downstream of the throat

Nozzle Removed

- Streamlines, contours of bulk velocity (m/s)



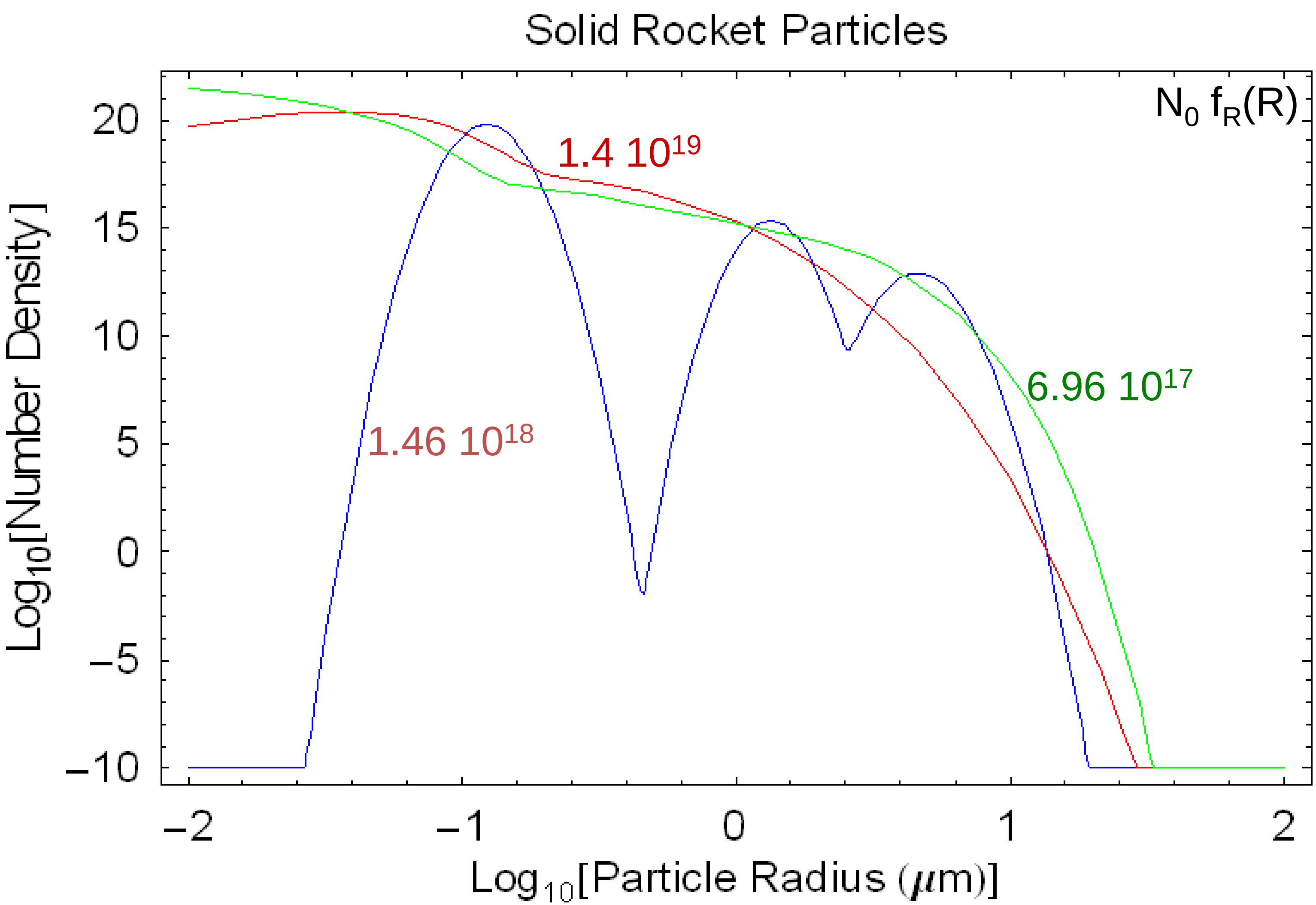


Distributions of Solid Rocket Particulates

(1) Mueller, A. C. and D. J. Kessler, The Effects of Particulates from Solid Rocket Motors Fired in Space,. Adv. in Space Res., 5, 77-86, 1985.

(2) Jackman, CH, DB Considine, and EL Fleming, A Global Modeling Study of Solid Rocket Aluminum Oxide Emission Effects on Stratospheric Ozone, Geophys. Res. Lett., 25, 907-910, 1998.

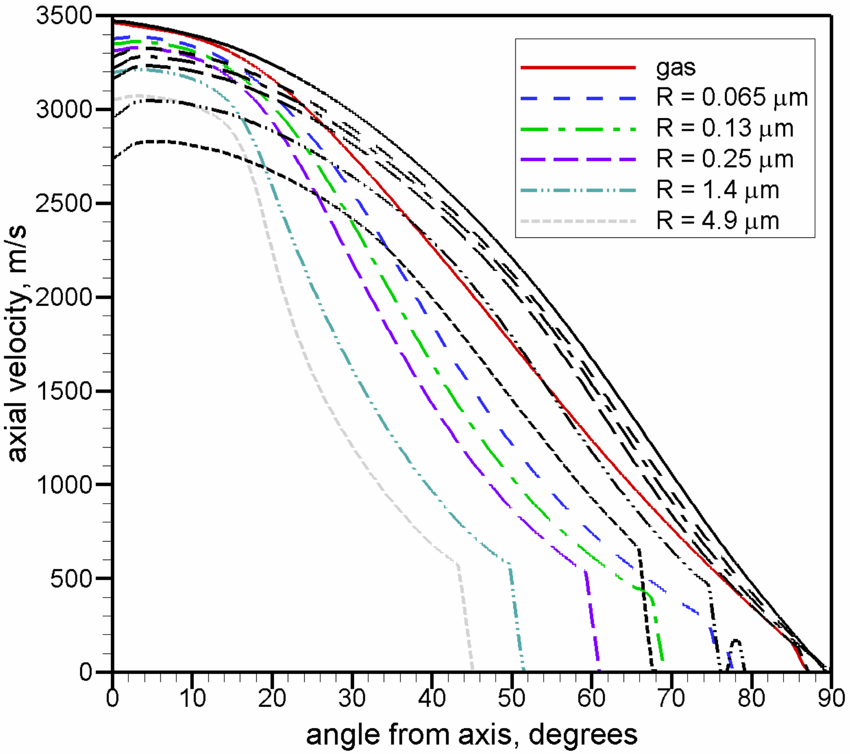
(3) S Gossé, L Hespel, P Gosart and A Delfour, Morphological Characterization and Particle Sizing of Alumina Particles in a Solid Rocket Motor, J. Prop. Pwr., 22, 127-135, 2006.



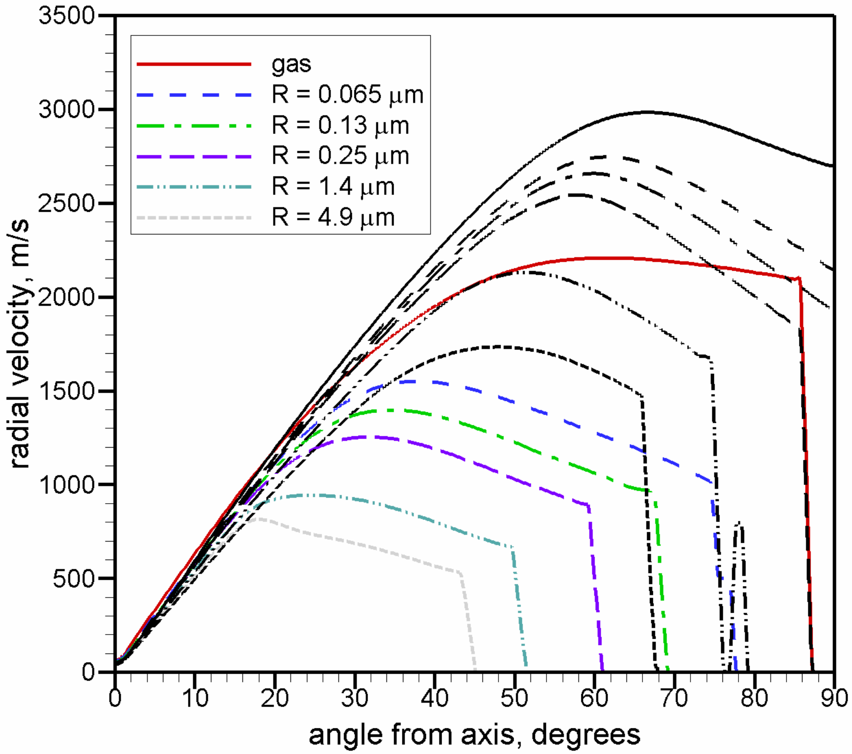
Farfield Comparison

- Comparison between nozzle (**multicolored lines**) and without nozzle (**black lines**) cases for axial and radial velocity along outflow boundary

Axial Velocity (m/s)



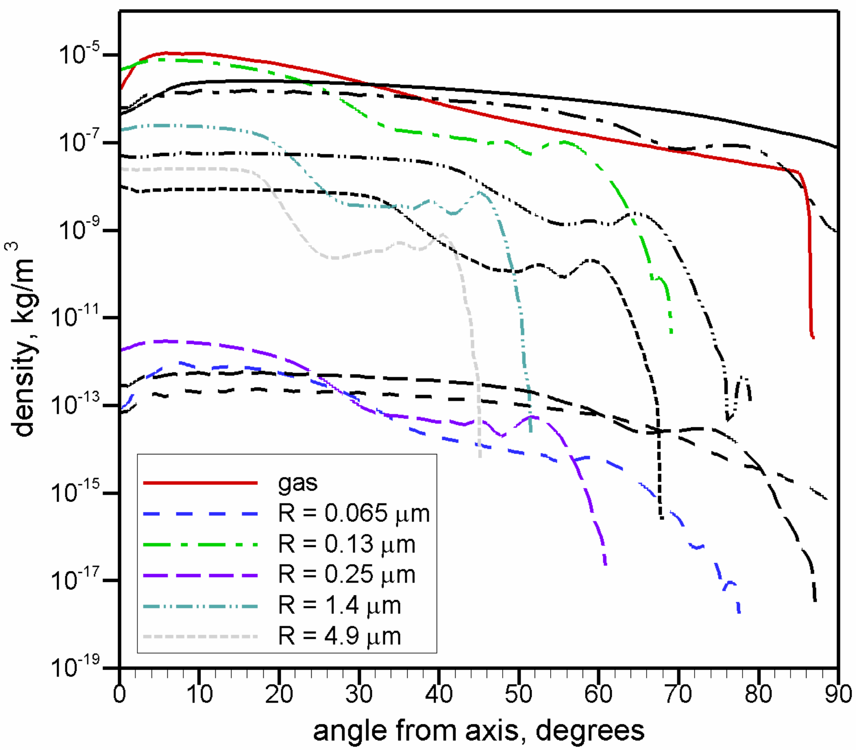
Radial Velocity (m/s)



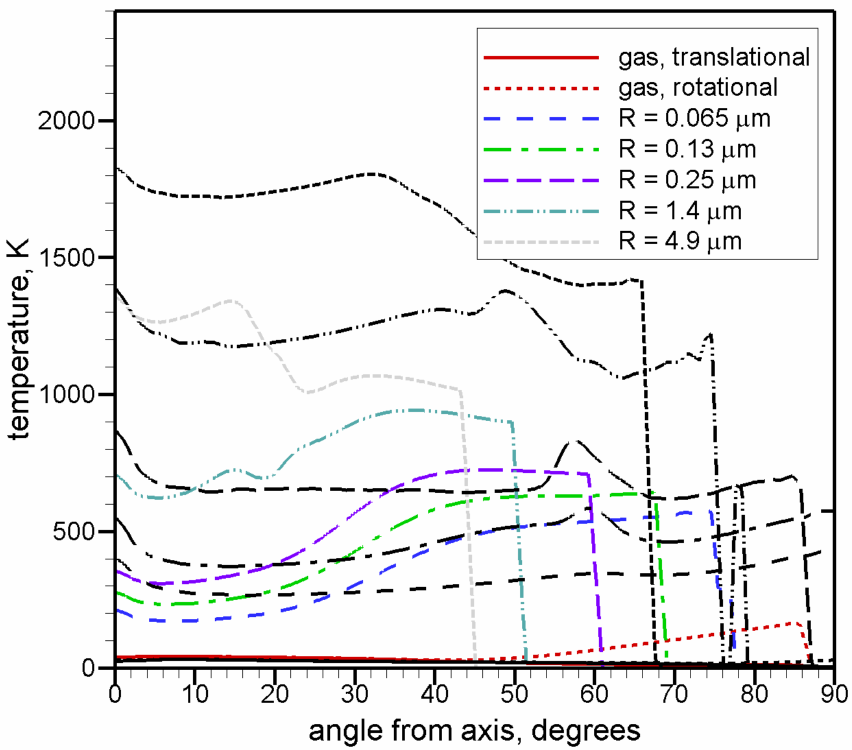
Farfield Comparison

- Comparison between nozzle (multicolored lines) and without nozzle (black lines) cases for density and temperature along outflow boundary

Density (kg/m³)



Temperature (K)

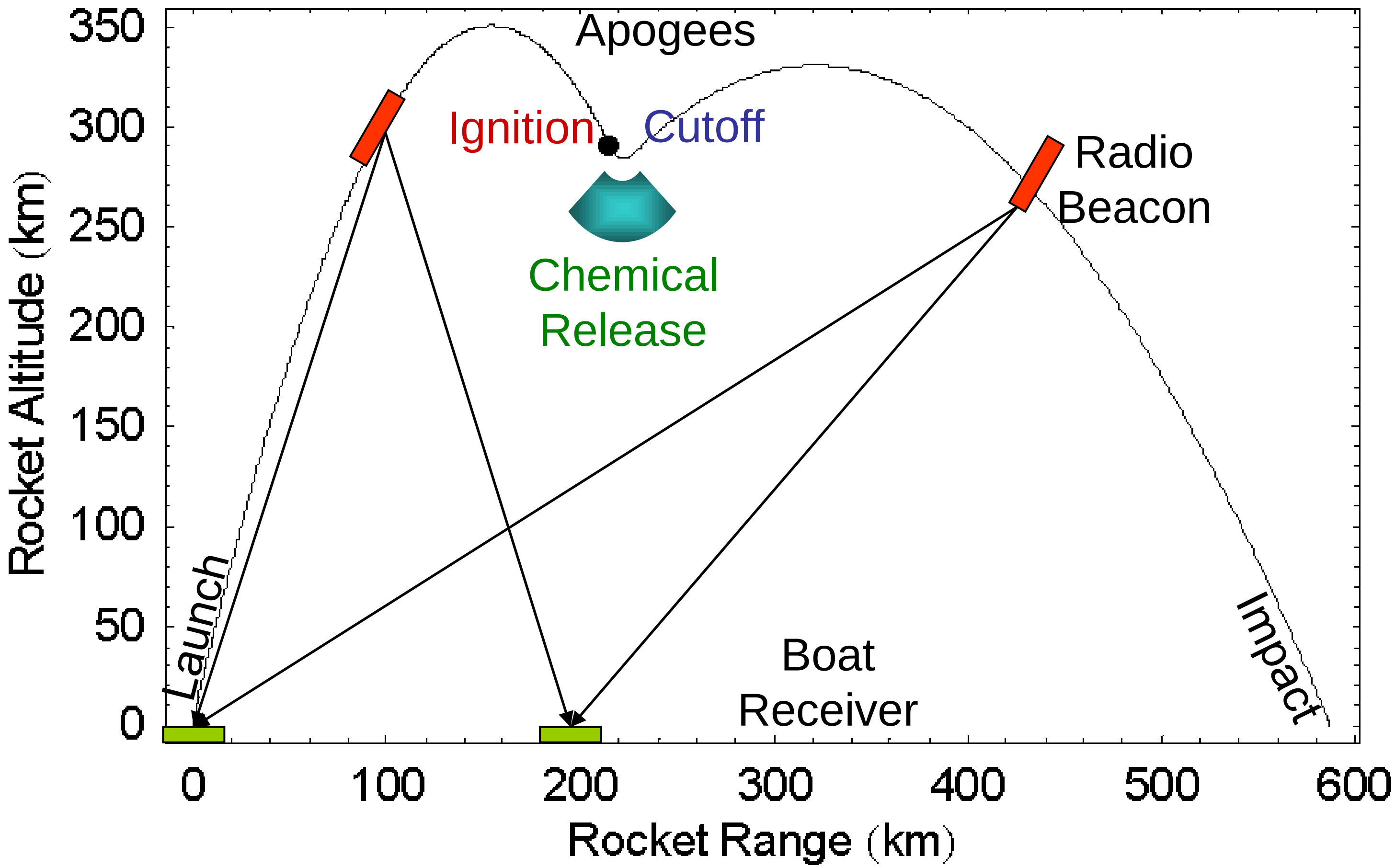


Thrust Calculation

- Thrust is evaluated by integrating contributions due to pressure and axial momentum flux from the gas and from each particle size over the farfield outflow boundary.

Case:	Nozzle	Without nozzle
Gas contribution (kN)	22.58	13.76
Particle contribution (kN)	11.75	7.40
Total (kN)	34.33	21.17

Nozzle Nihka Motor Chemical Payload Trajectory and Radio Propagation Experiment for CARE



Dynamic Dust Model for CARE

- Dust Charging (Charge Impact, Photo-Detachment)

$$Q_d = 4\pi\varepsilon_0 r_d \phi_d, \quad \frac{dQ_d}{dt} = I_e + I_i + I_p, \quad I_e = \sqrt{8\pi}\, r_d^2 q_e n_e v_{Te} \exp[-\frac{q_e \phi_d}{KT_e}]$$

$$I_i = \sqrt{8\pi}\, r_d^2 q_i n_i \sqrt{v_{Ti}^2 + v_T^2 + v_r^2}\,[1 - \frac{q_i \phi_d}{KT_i}], \quad I_p = -\pi r_d^2 q_e J_p Q_{ab} Y_p \exp[\frac{q_e \phi_d}{KT_p}]$$

- Dust Particle Equation of Motion (Drag, Lorentz Force, Electric Fields, Gravity, Mean-Free-Path)

$$\frac{d^2\mathbf{r}(t)}{dt^2} = \text{-}\nu_a(\mathbf{r},\ \mathbf{u})\ \frac{d\mathbf{r}(t)}{dt} + \frac{Q_d(t)}{m_d}(\mathbf{E} + \frac{d\mathbf{r}}{dt}\times\mathbf{B}) + \mathbf{g}$$

$$\nu_a(r,\ u) = \frac{\sqrt{V_r^2 + V_T^2}}{L_p(r)}, \quad L_p(r) = \frac{2\, m_p}{C_D\ \rho_n(r)\ A_P} = \frac{8\rho_P}{3\rho_n} r_d$$

$$\text{with } A_P = \pi r_p^{\ 2}, \ m_P = \rho_P \frac{4}{3}\pi r_p^{\ 3}, \ C_D = 2 \text{ for } r_d \ \square\ L_p$$

Dust Electric Fields

- Quasi-Neutrality

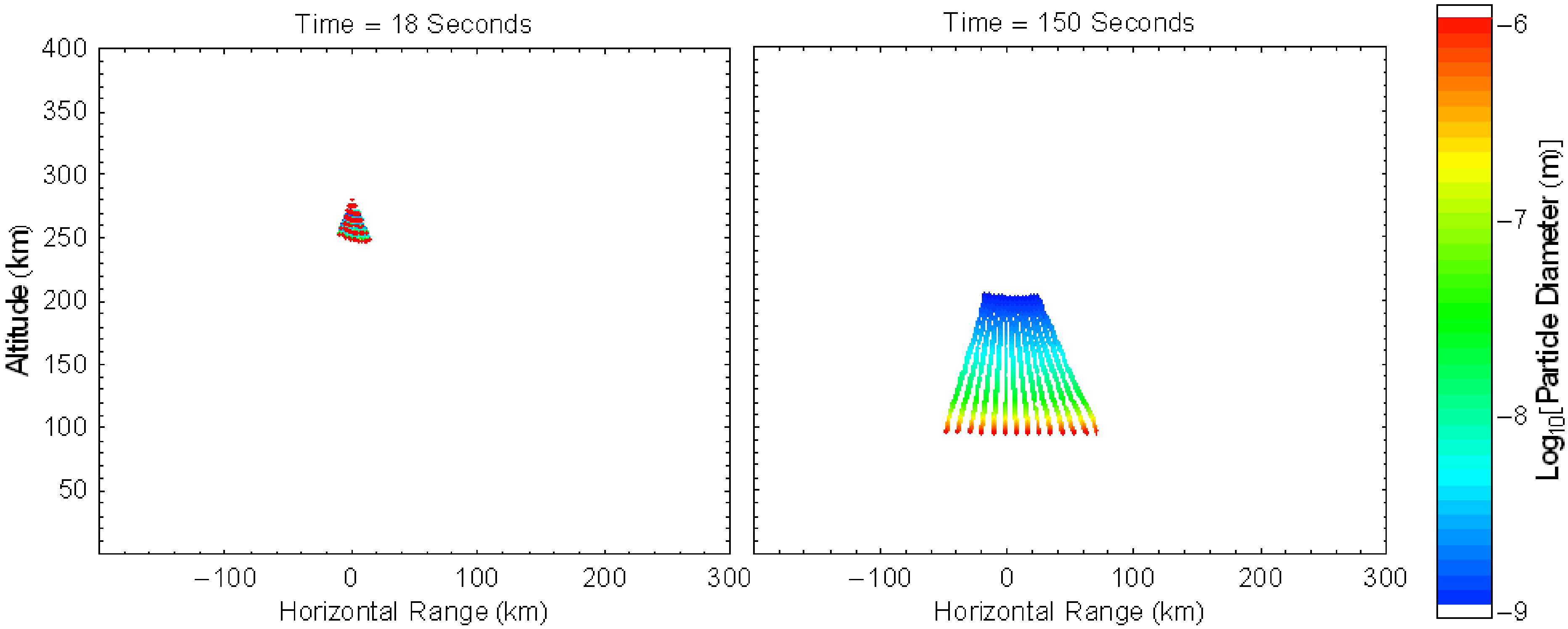
$$q_i n_i + q_e n_e + n_d \langle Q_d \rangle = 0; n_e = n_i - n_d \frac{\langle Q_d \rangle}{q_e}$$

- Ambipolar Electric Field

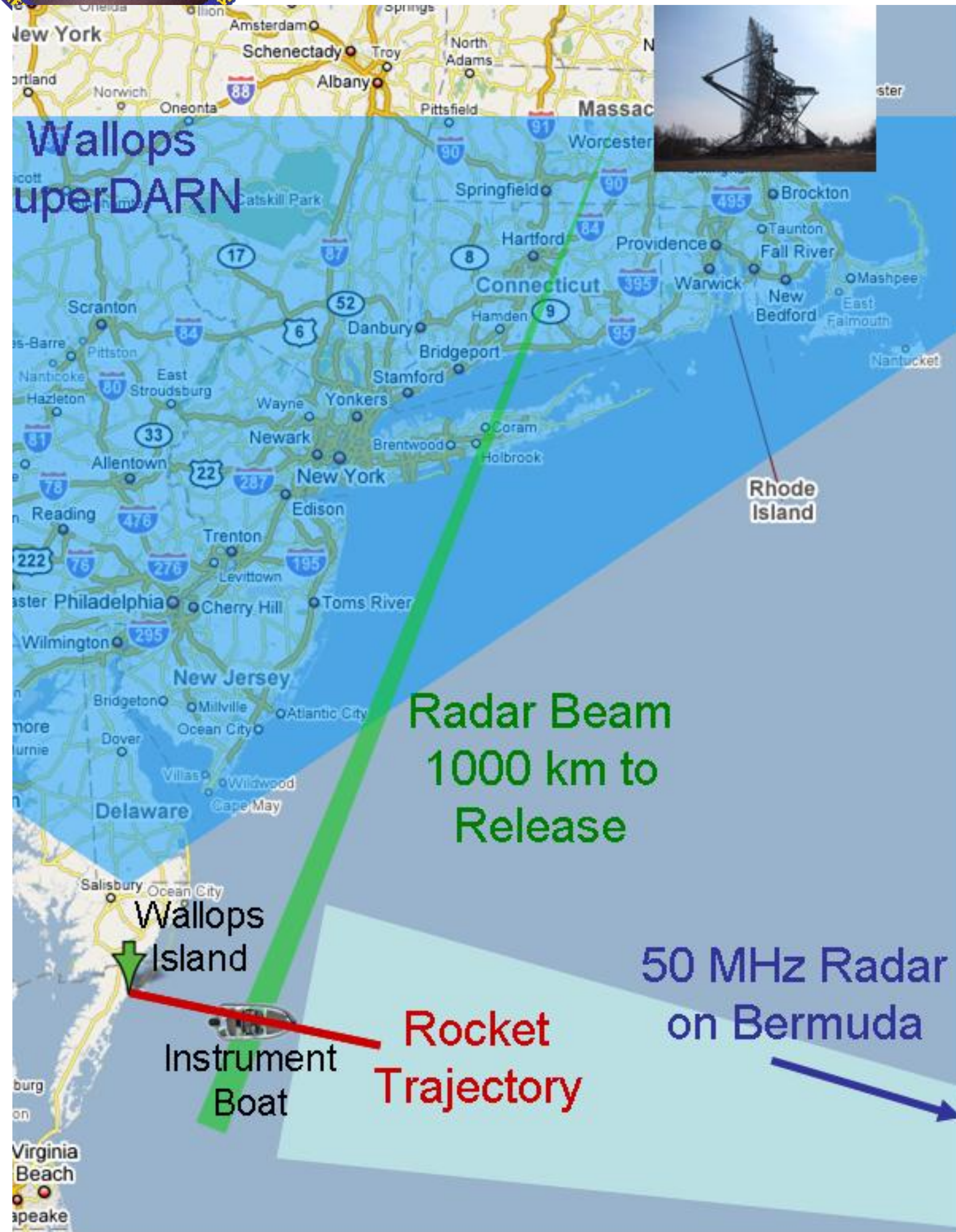
$$\mathrm{E}_{\parallel} = \frac{kT_e \nabla_{\parallel} \partial \mathrm{n_e(z, t)}}{\mathrm{q_e \; n_e(z, t)}} = \frac{kT_e \nabla_{\parallel} \left(\mathrm{q_e n_i - n_d \langle Q_d \rangle} \right)}{\mathrm{q_e} \left(\mathrm{q_e n_i - n_d \langle Q_d \rangle} \right)} \cong - \frac{kT_e \nabla_{\parallel} \left(\mathrm{n_d \langle Q_d \rangle} \right)}{\mathrm{q_e} \left(\mathrm{q_e n_i - n_d \langle Q_d \rangle} \right)}$$

  - Transient Parallel Electric Fields
  - Electron Acceleration?
  - Effect on Ions?

20 Degree Nozzle Dust Layer



Radar Observation Geometry of Rocket Launches from Wallops Island by the Millstone Hill Radar

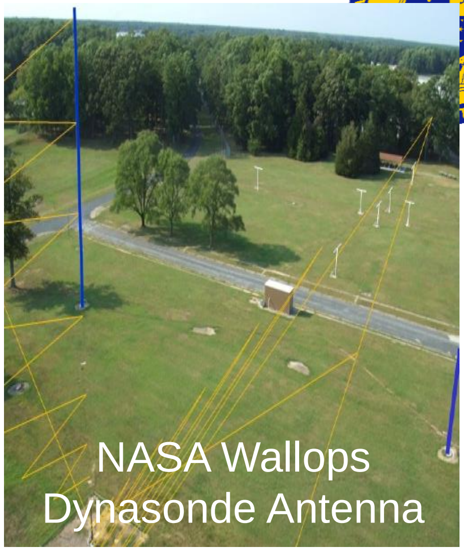


Millstone Hill Incoherent Scatter Radar at MIT Haystack, MA

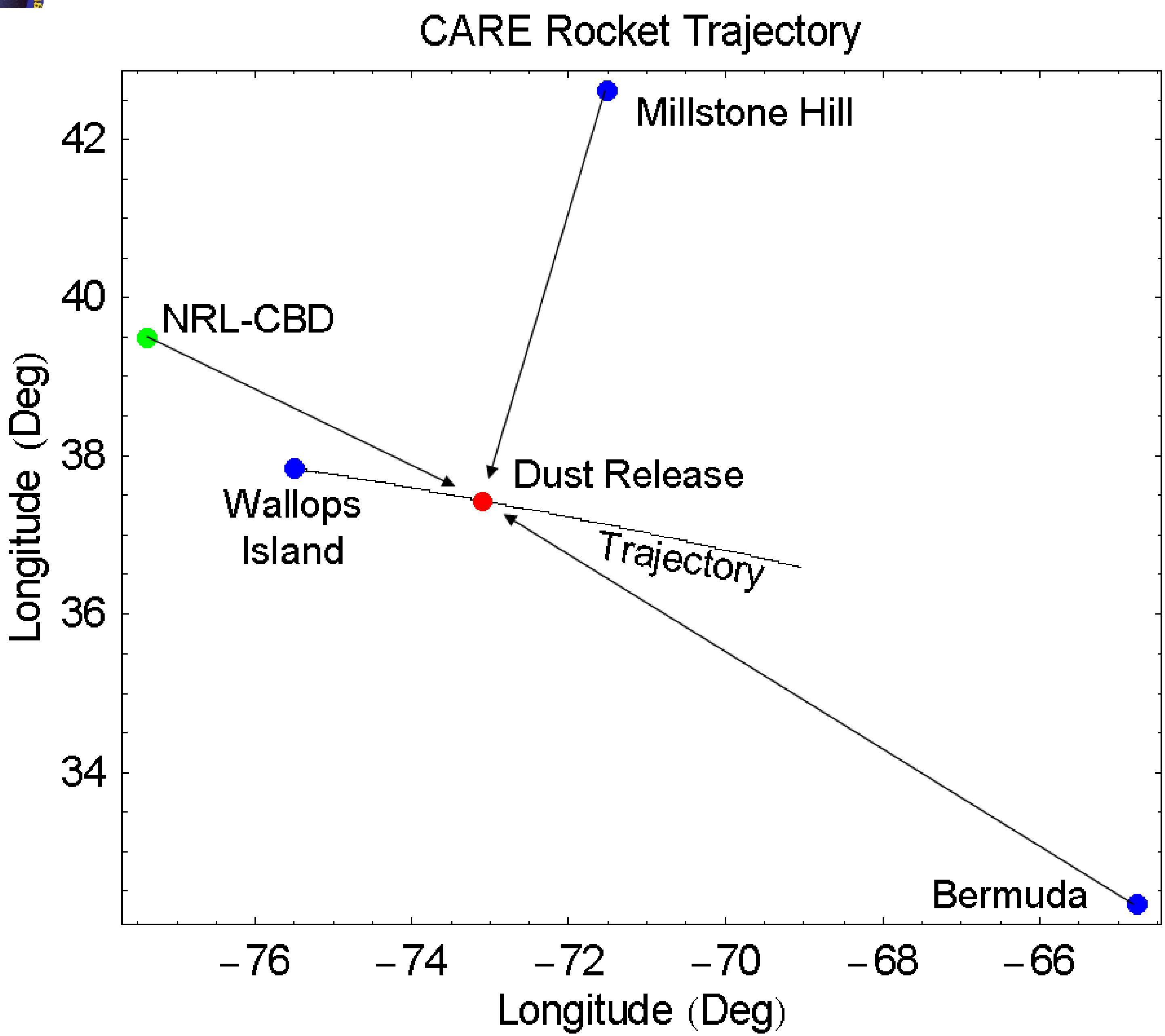
- 440 MHz UHF Radar
- Fully Steerable 150 foot Dish
- Line of Sight Densities, Drifts, and Temperatures

CARE Ground Radars and Lidars

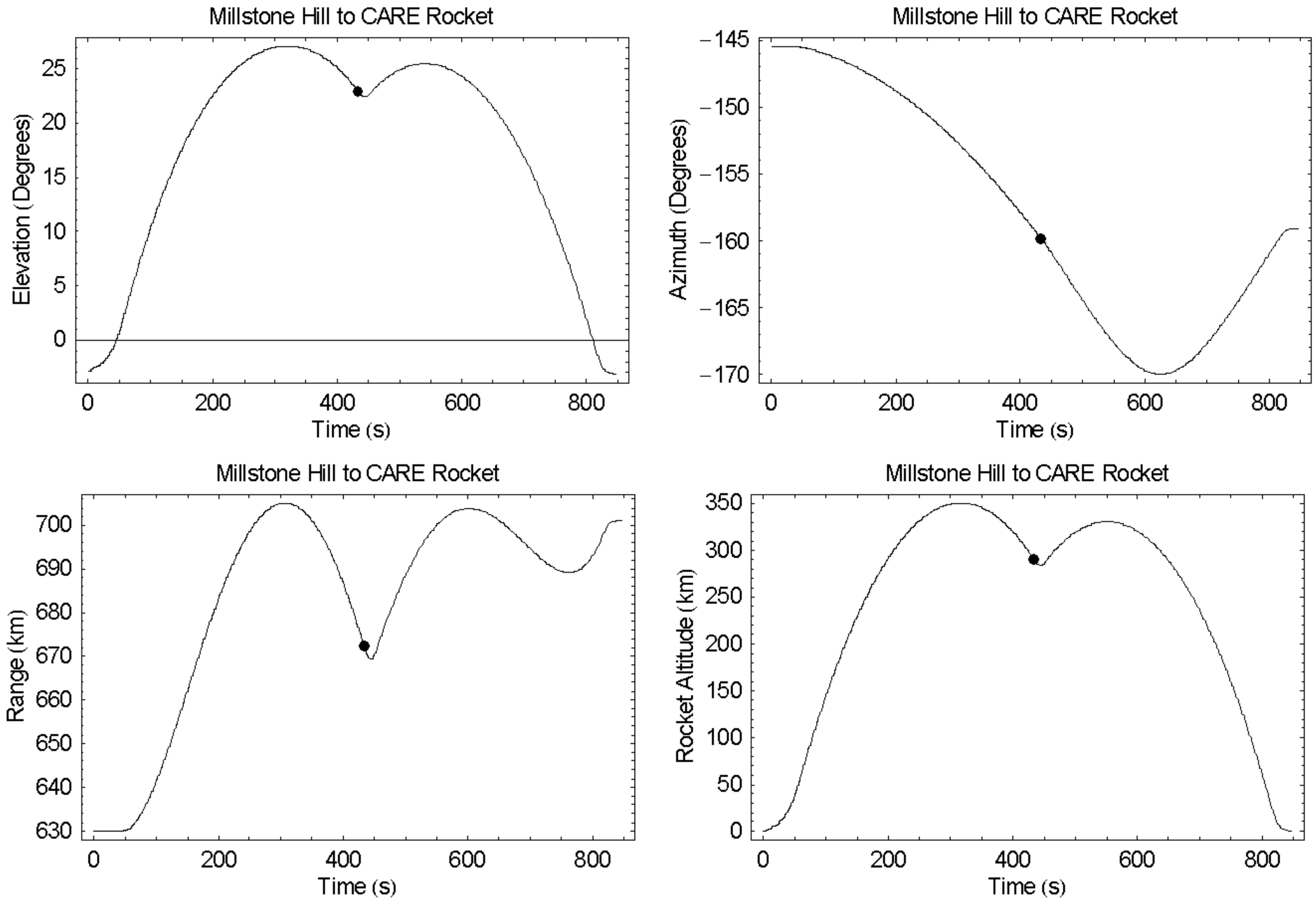
- HF Radar
  - Wallops Ionosonde (Digisonde and Dynasonde)
  - SuperDARN (Virginia Tech)
    - Dr. Raymond A. Greenwald, Ruohoniemi Mike,
    - Joseph Baker
  - Data Products
    - HF Backscatter
    - Background Ionosphere
- VHF Radar
  - 50 MHz Penn State/U. Illinois
    - Professor Julio Urbina
  - Data Product
    - Background Irregularities
    - VHF Backscatter
- UHF Radar
  - 440 MHz Millstone Hill Radar, Haystack, MA
    - Phil Erickson, Frank Lind, John Foster
  - Data Products
    - UHF Backscatter
    - Background Ionosphere
- LIDAR (Laser and Telescope)
  - NRL Optical Test Facility, MRC, VA
    - 0.5, 1.0, 1.5 micron Lasers with 5 ps Pulse
    - Linda Thomas and Ray Burris
  - Data Products
    - Particle Size Distribution
    - Transport of Dust



Ground Diagnostic Sites for CARE



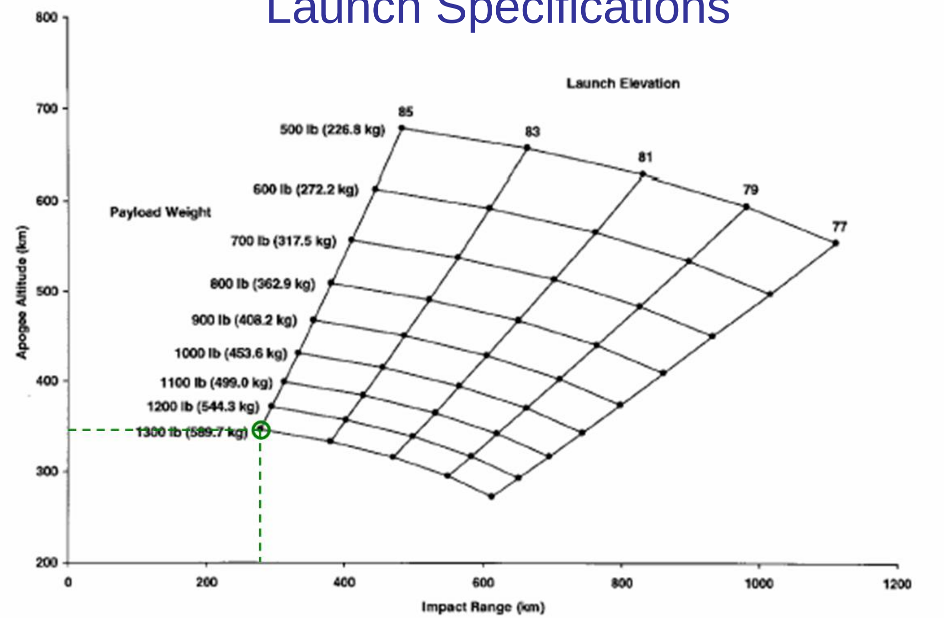
CARE Chemical Release Position Relative to the Millstone Hill UHF Radar for Nihka with Nozzle

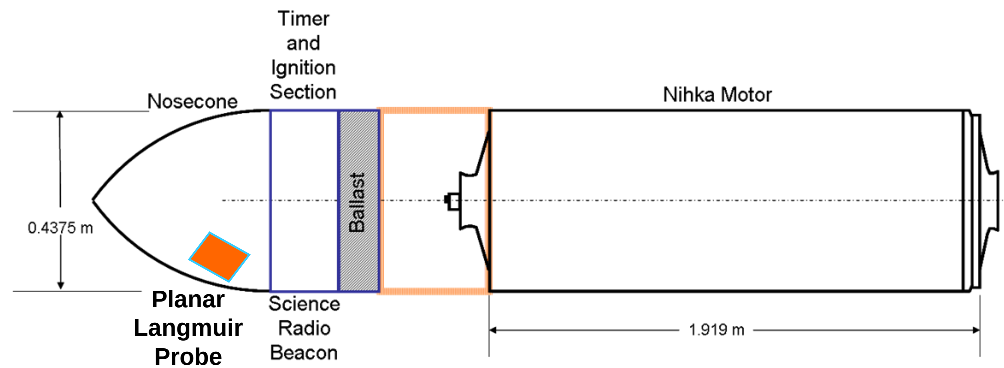


Single Nihka Motor Payload

- Nihka
  - Gross Mass: 399 kg (879 lb), Empty Mass: 70 kg (154 lb).
  - Propellants: Solid.
  - Thrust (vac): 50.500 kN (11,353 lbf).
  - Isp: 285 sec., Burn time: 17 sec.
- Total Chemical Payload Mass
  - Gross Nihka Mass 400 kg
  - Supporting Hardware 190 kg
  - Total Mass 590 kg
- Payload Apogee 350 km
- CARE Release Point ~280 km on Downleg
  - Chemical Payload Descending at 1 km/s
  - Exhaust Injection at 2 km/s Downward
  - Full Dust Cloud Released in 17 Seconds

Launch Specifications

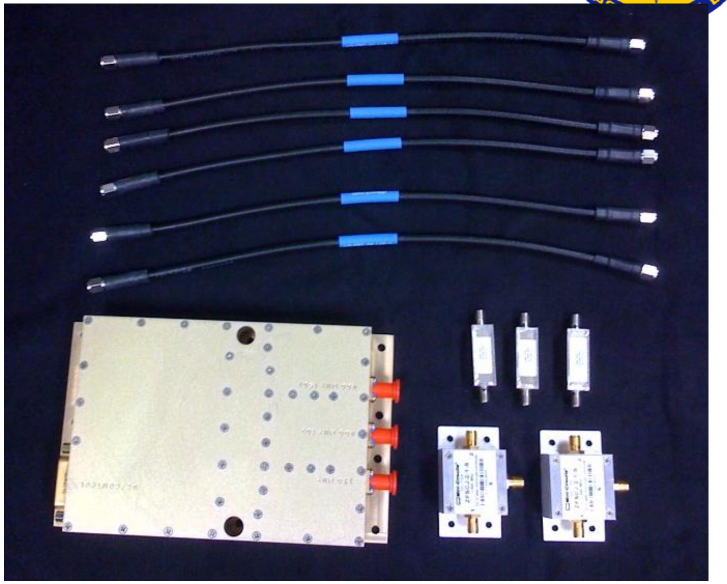


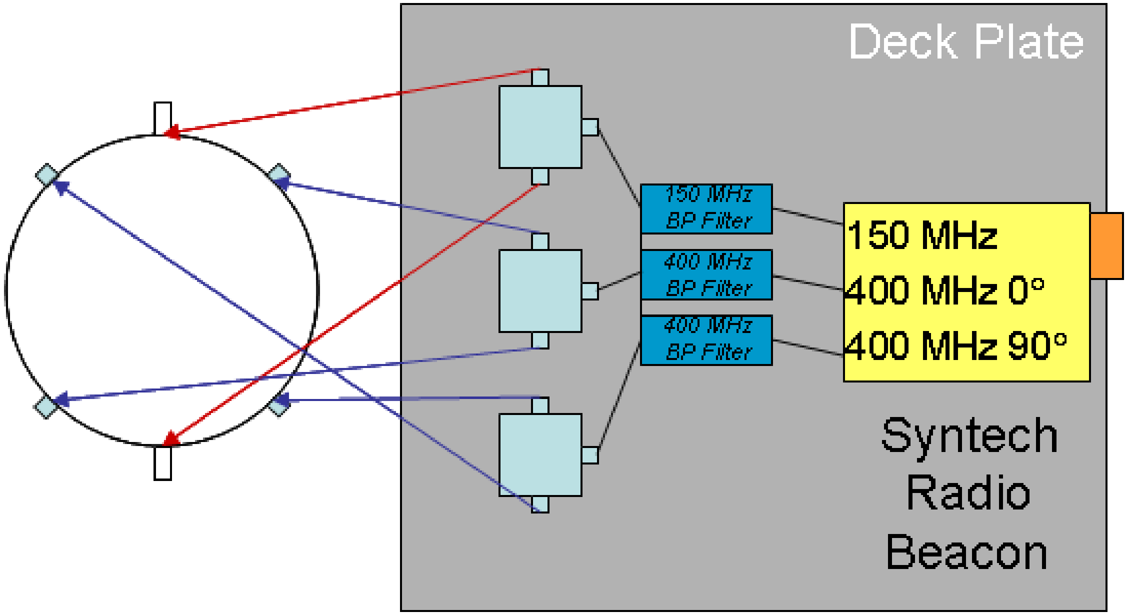


Payload Components

NRL CERTO Rocket Beacon
Paul Bernhardt, Matt Wilkens

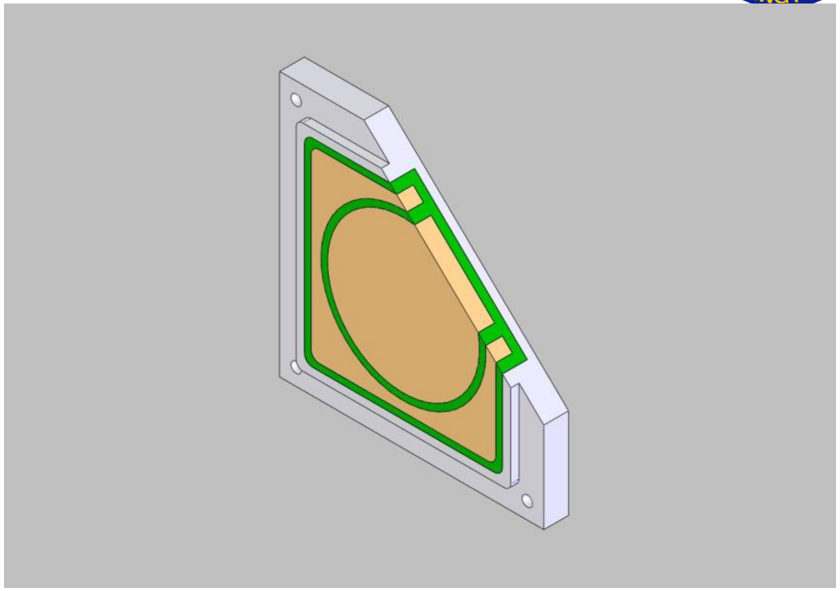
- Plasma Measurements
  - Radio Beacon (Bernhardt)
  - Radio Scintillations at VHF and UHF
  - Background Electron Density
  - Electron Removal by Chemical Release

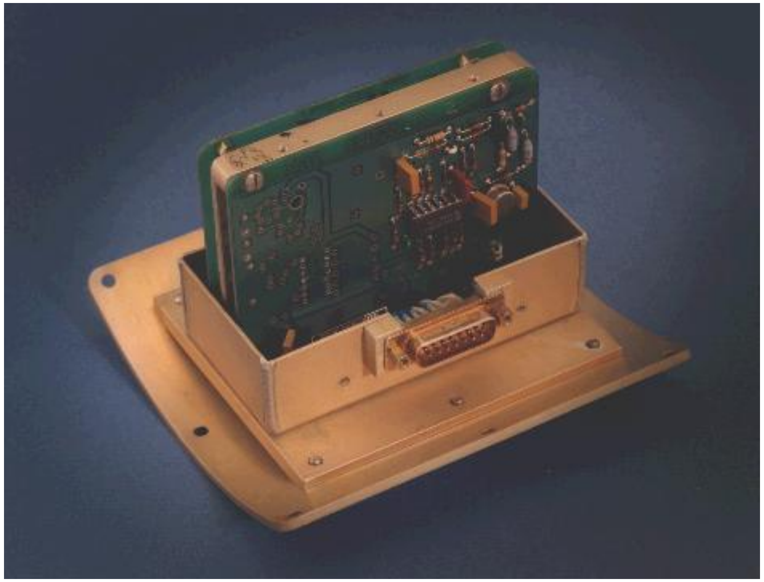




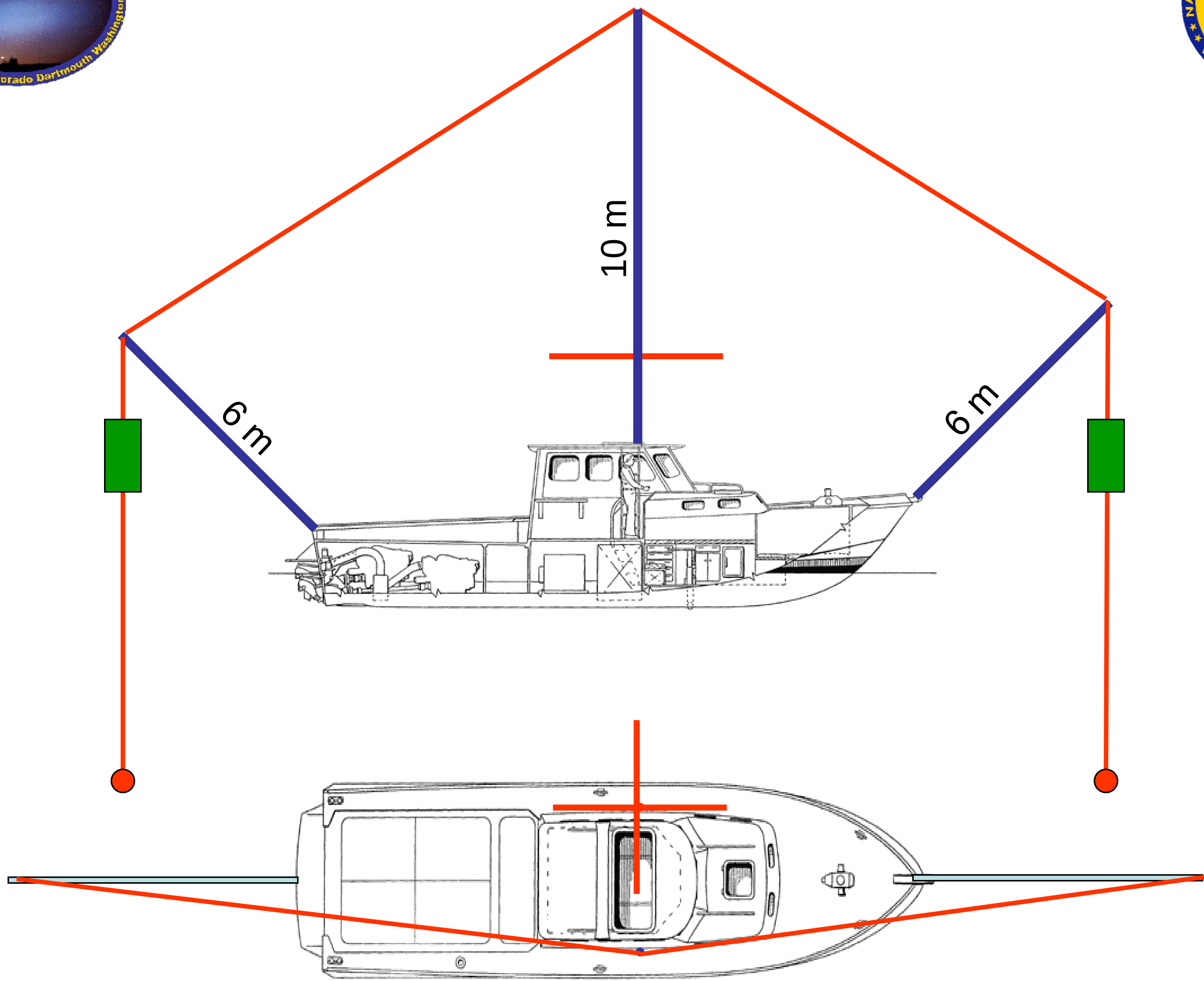
AFLR Planar Langmuir Probe
John Balenthin, PI

- Ion Density at Nihka Motor Section
- Backplate
  - 1/2", 5"x5" Square Aluminum
  - 4"x4" Raised Portion Flush to Skin.
- Behind Probe
  - 1/8" thick aluminum
  - Teflon (1/8" flat plate) for High Temperature
  - G10 epoxy board for Low Temperature
- Gold Conductor
  - Square 2.3" x 2.3”
  - Circle 1.5“ Diameter
  - 1/4" thick
- Gold Plated Stainless Steel
  - 304 grade
  - Attached by Screws Through Back Panel
- Connector Pins
  - Pin 1: Ch1+   6000s/s A/D channel
  - Pin 9: Twisted pair or shield ground for Pin1
  - Pin 2: Ch1-   1000s/s A/D channel
  - Pin 10: Twisted pair or shield ground for Pin2
  - Pin 7: +28VDC
  - Pin 14: 28V Return
  - Pin 8: +28VDC
  - Pin 15: 28V Return

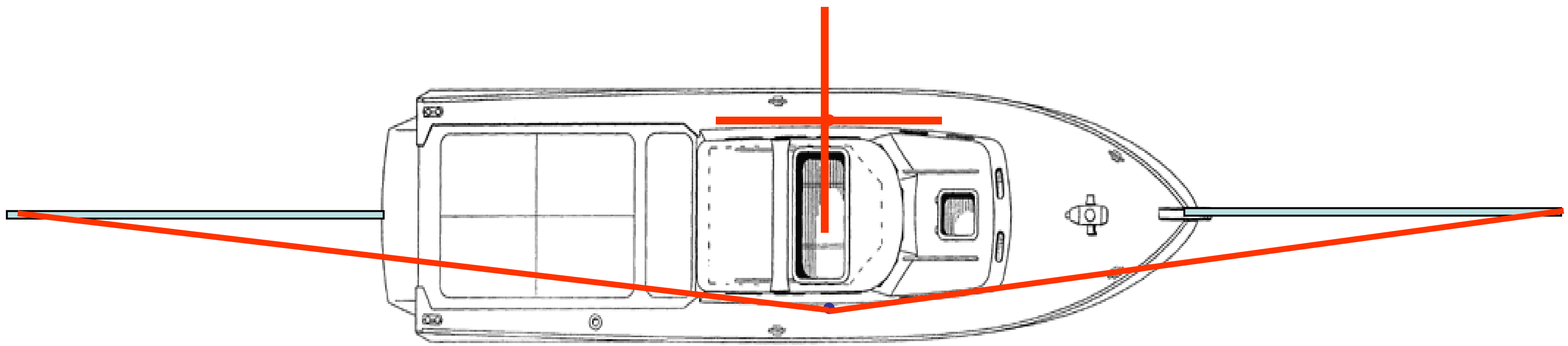




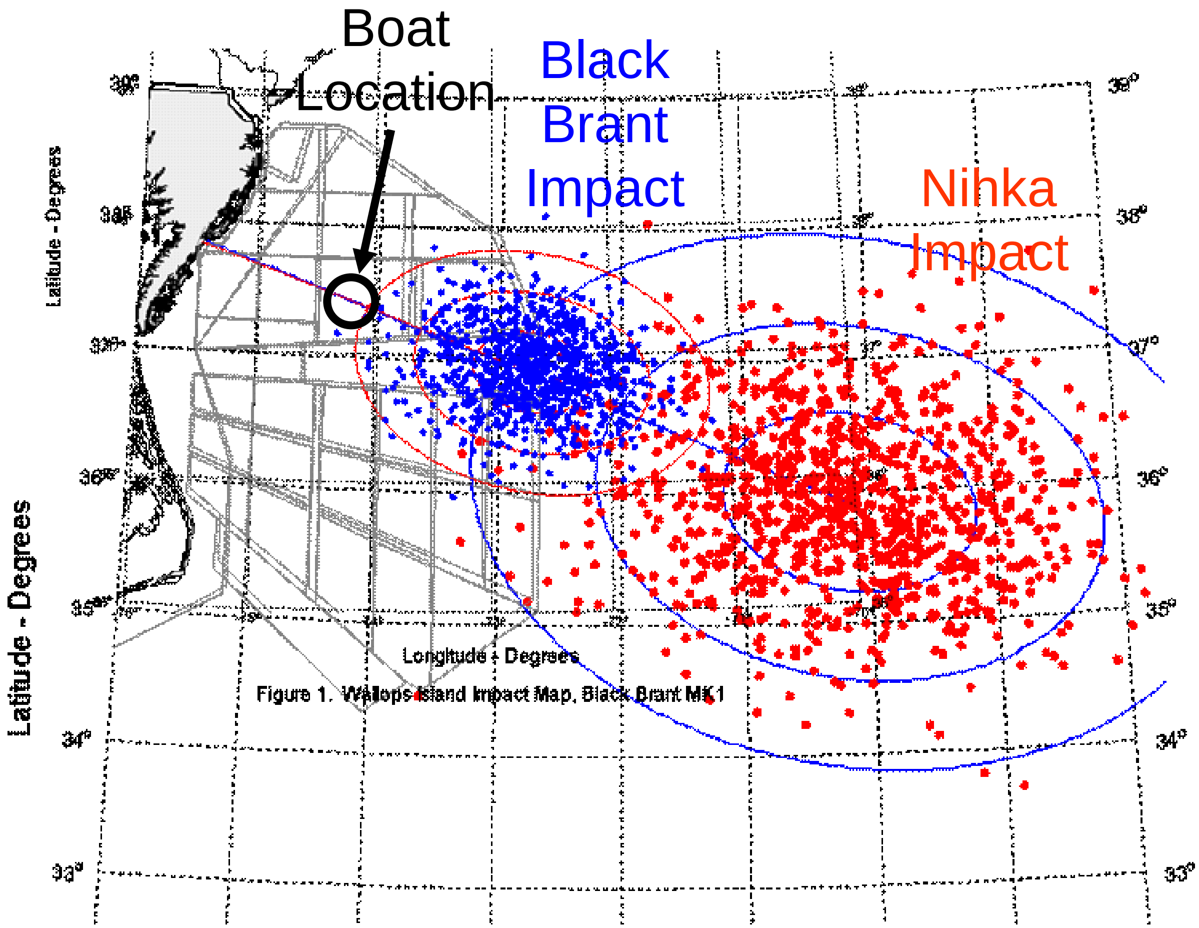
Instrumented Thomas Reed Boat for CARE



Instrumented Thomas Reed Boat for CARE



Instrumented Boat Station



Satellite Sensor for CARE

- Diagnostics of CARE Artificial Dust Cloud
  - AIM Panoramic UV Nadir Imaging System
- Global Transport of Dust Layer

CARE Launch Window

- Requirements
  - Clear Skies at 3 Observation Sites
  - Moon Below Horizon
  - Evening Sun at 12 to 18 Degrees Depression Angle
  - No Sporadic-E One Hour Before Launch
    - Sporadic-E Will Interfere with Dust Radar Scatter Observations
- Launch Window
  - Release Time
    - Date 8-19 September 2009
    - Release Time 19:18 to 19:00 EST (Date Dependent)
  - Optical Observation Period
    - Date 8-19 September 2009
    - Viewing Until 19:50 to 19:31 EST (Date Dependent)
    - Viewing Time ~ 30 Minutes
  - Sporadic-E is Bad in August so September Chosen