Using COMSOL© Multiphysics Software to Validate a Neutral Gas Velocity Sensor Design

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Motivation

REDD, the Ram Energy Distribution Detector, is a new satellite-borne instrument capable of measuring many characteristics of neutral particles in the Earth's upper atmosphere. Ion-neutral coupling is responsible for scintillations in electromagnetic waves, and is also important for studies of gravity waves. Gathering more neutral energy distribution data will greatly enhance the scientific knowledge of these processes. Extending to applications beyond our planet, data that REDD gathers would increase understanding of atmospheric drag and aero-braking in planetary atmospheres.

The REDD Sensor

A derivative of the Ram Wind Sensor (RWS) [1], flown on the Communications/Navigation Outage Forecasting System (C/NOFS) satellite, REDD is designed for reduced size, weight and power applications [2]. Shown below in Figure 1, the sensor consists of four major areas: the extraction plates, the ionization chamber, the retarding potential array grids, and the microchannel plate collector. The figure displays a computer generated cut-a-way view of REDD, a COMSOL© generated diagram of ion flow from the grids to the MCP, and the assembled REDD sensor.

Due to the limited availability of micro-tip emitters, a filament was used as the electron source to facilitate our most recent testing. This requires a large potential on the filament to accelerate the electrons to an energy sufficient to ionize atomic oxygen. [3] Thus, instead of the standard grid voltages used in RWS and earlier versions of REDD [2] a different setup was used. The following conditions are enforced in the simulations:

1. High speed plasma and neutrals enter the aperture of the instrument (refer to Figure 1).
2. The extraction plates are biased to collect any charged particles before they enter the ionization chamber. In the ionization chamber, a filament emits electrons to collisionally ionize the neutrals in the chamber. These newly created ions are incident on the grids.
3. Three grids are biased to perform energy analysis. The first grid is biased negatively to attract ions away from the negatively biased filament. The second grid is the retarding grid - its potential is swept to prevent ions of differing energies from passing through. The third grid is negatively biased so that ions that pass the second grid continue to move toward the collector. The MCP collects the ions and amplifies the signal.

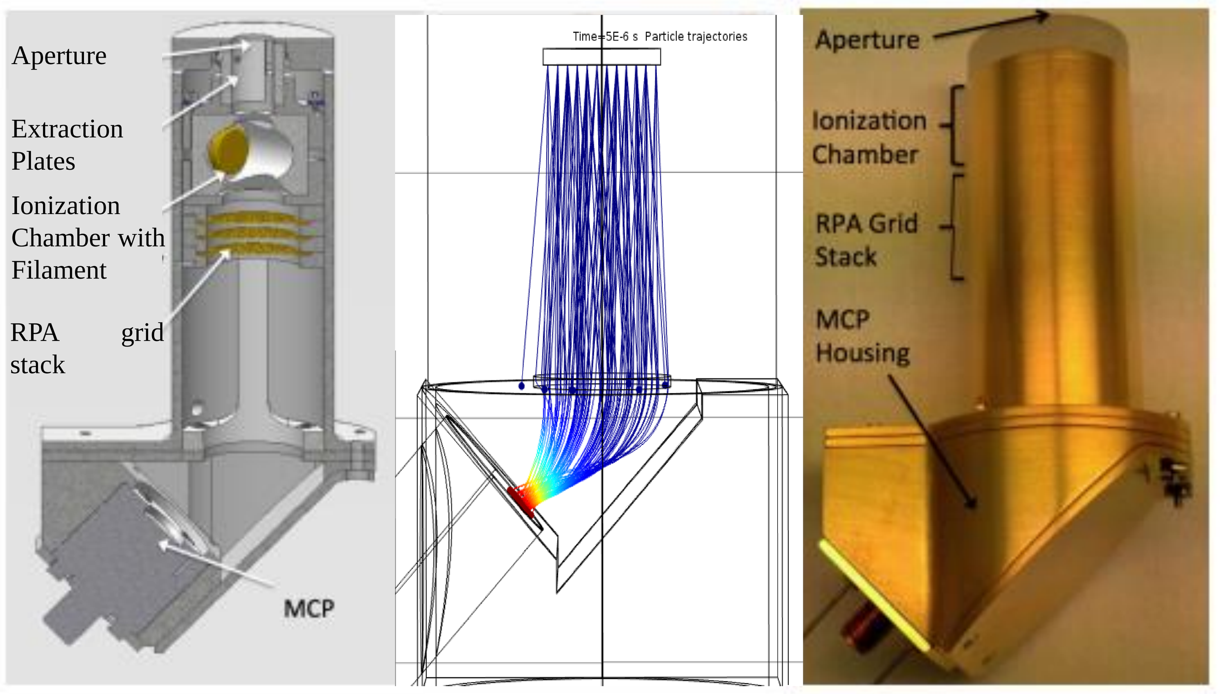

Figure 1 – The left panel shows a cross-section of the REDD device and labels the key subsystems. The middle panel shows the results of a simulation study to trace ion trajectories from the grid stack to the front surface of the MCP. The right panel shows the assembled sensor with corresponding labels of the hidden components

COMSOL© Multiphysics

COMSOL© Multiphysics simulation software allows numerical study of different physical processes. After drawing or importing a device geometry, the software uses numerical methods to simulate heat transfer, stress and strain, acoustics, optics, electromagnetics, or fluid flow, among others. Allowing parameters solved for in one simulation to affect another makes COMSOL© Multiphysics a powerfully realistic tool.

In the case of the REDD instrument, after defining the potential on known surfaces, COMSOL© solves for potentials elsewhere in the instrument. The paths of the charged particles are traced based on these potential fields, and can include inter-particle effects. The simulations help to direct the lab testing of the proof-of-concept design.

Electric Potential

A process of trial and error, with a goal of ionizing enough neutrals in a region where they would not be attracted by the very negative filament, resulted in the potentials shown in Figure 2. The outer walls of the device are at ground, and the voltage on the filament is -130 V so the electrons emitted gain enough energy to ionize the neutral particles. The first grid is set to -100 V to attract the ionized neutrals toward the grid stack. The second grid is the retarding grid – it is swept from -60 V to +10 V. The third grid is set to -60 V to ensure that any ions passing through the second grid continue traveling toward the MCP. Figure 2 shows the potential as a color map overlaid on the geometry. Figure 3 displays this potential along the z-axis down the center of the ionization chamber.

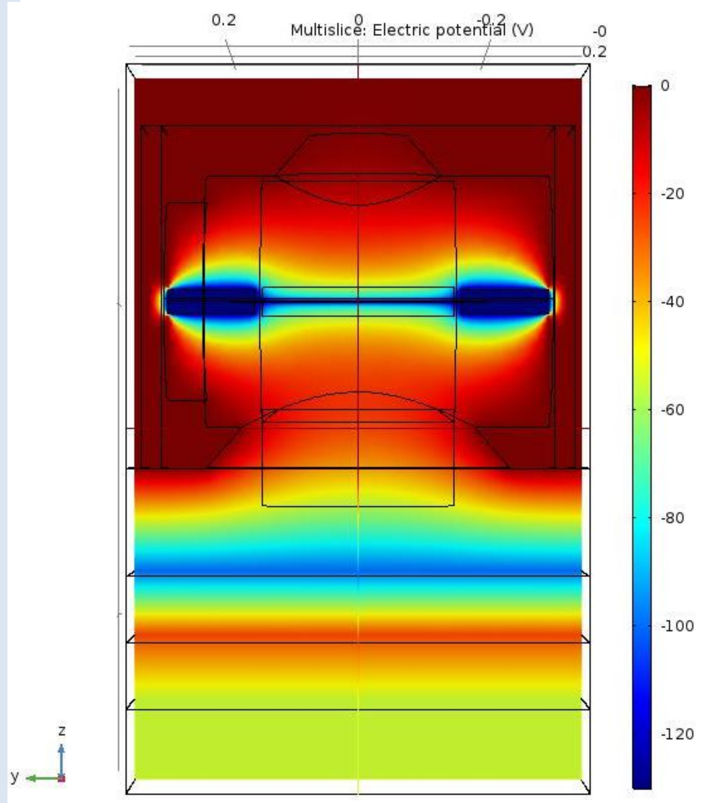

*Figure 2 – REDD ionization chamber and grid stack with electric potential generated by COMSOL©
Filament = -130V, Grid 1 = -100V,
Grid 2 = -25V, Grid 3 = -60V*

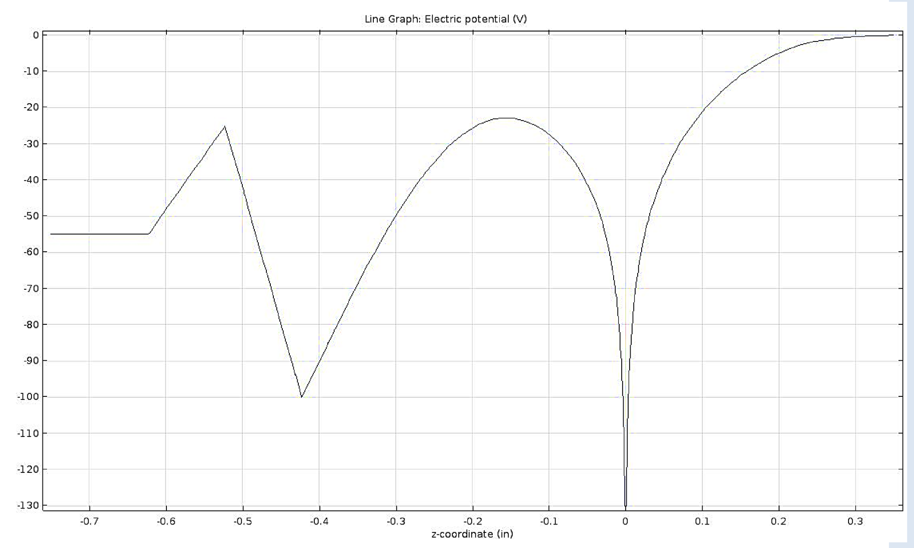

*Figure 3 – Potential along the z-axis of the REDD ionization chamber and grid stack generated by COMSOL©
Filament = -130V, Grid 1 = -100V
Grid 2 = -25V, Grid 3 = -60V*

Charged Particle Flow

Shown in Figure 4 are the traces of thermal electrons emitted from the filament as they are accelerated by the potential field. Figure 5 shows the traces of ions with a constant initial energy released from the region surrounding the filament (where the electrons have 60 eV to 130 eV of energy, which is sufficient to maximize the ionization probability). On the left the retarding grid is set to -50 V so any ion flowing toward the grids passes through the grid stack. On the right, the retarding grid is set to -25 V and many ions are repelled by the retarding grid.

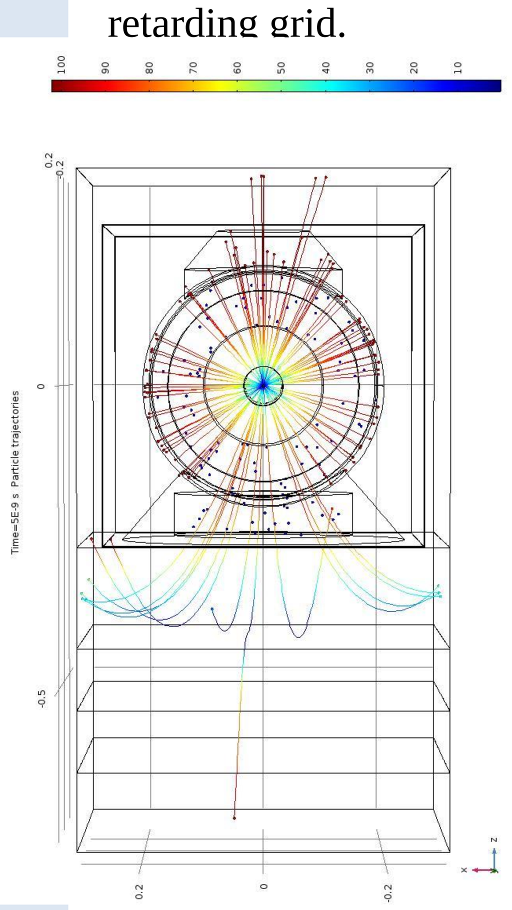

*Figure 4 – REDD ionization chamber and grid stack with the paths of electrons emitted by the filament shown.
Color scale is representative of energy in eV*

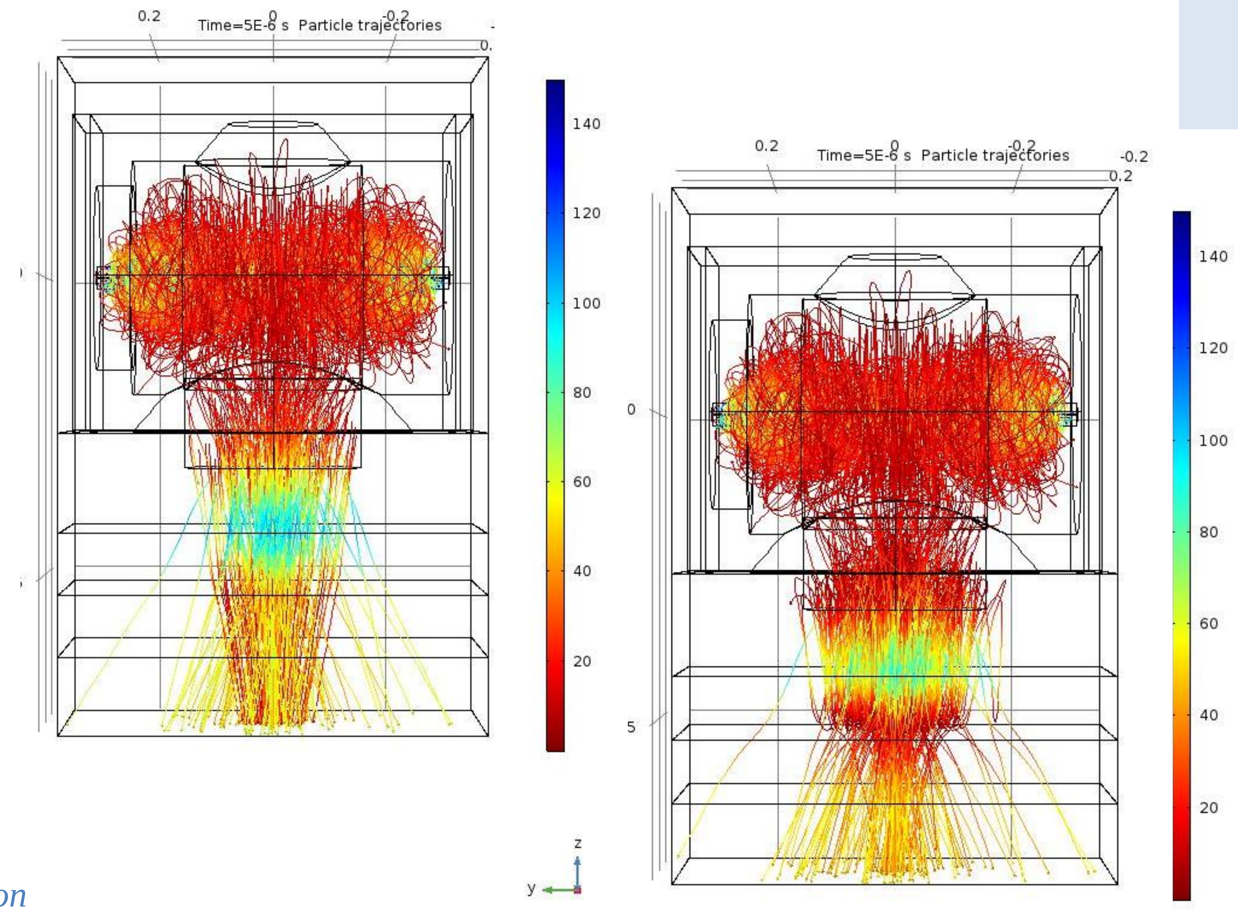

*Figure 5 – REDD ionization chamber and grid stack with the paths of ions shown
Color scale is representative of energy in eV.*

Varying Initial Energy

Even though the initial energy distribution of the neutrals is disturbed by the strong potential field once the particles are ionized, a difference in initial energy is discernable in the collected current vs. retarding grid voltage plots. Thus the neutral velocity can be inferred from the current-voltage (IV) characteristics obtained from the REDD instrument. Figure 6 shows these simulated IV curves for various constant neutral beam velocities, using a population of 500 ions and counting the number reaching the bottom of the simulation space for differing retarding grid voltages and differing initial energies. The inflection point of each curve is plotted in Figure 7; these were calculated numerically by finding the zero of the second derivative.

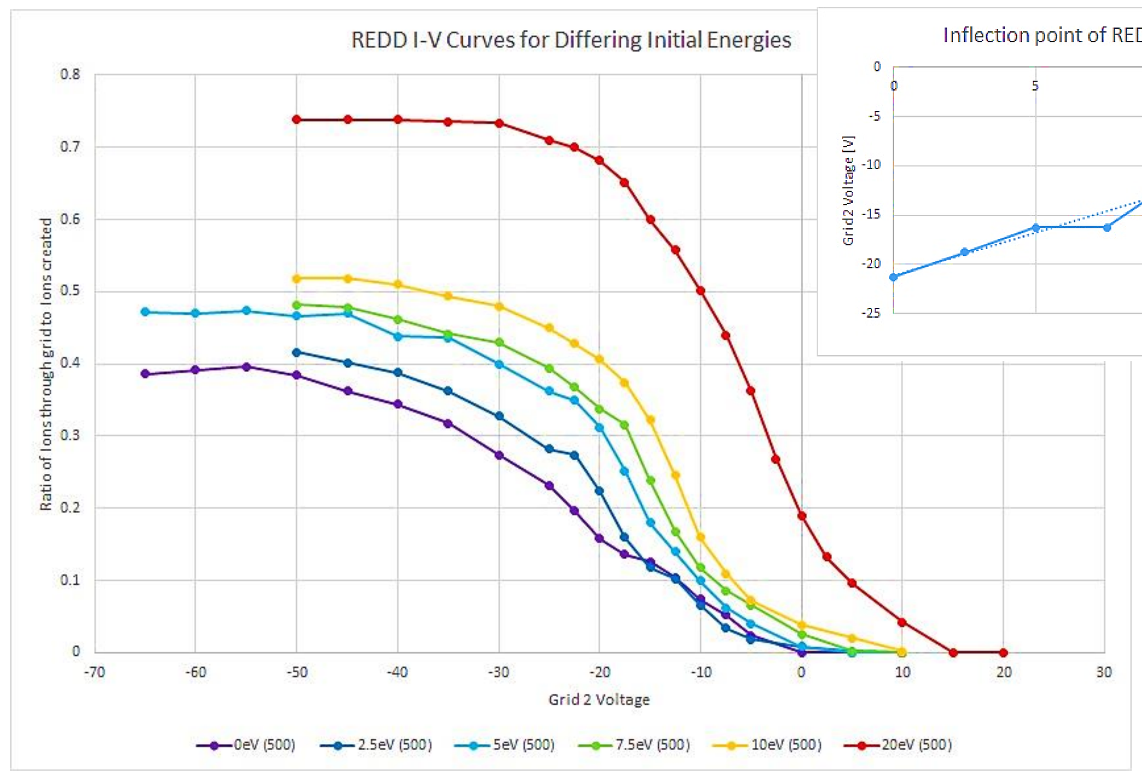

Figure 6 – Collected current vs. Retarding Grid Voltage for ions of different initial energies

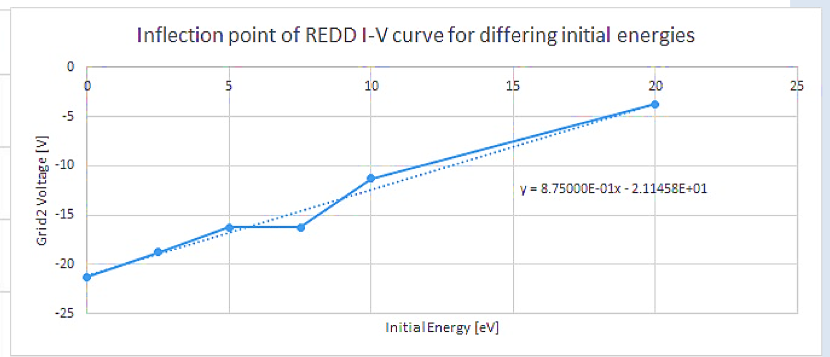

Figure 7 – Inflection points of the curves in Figure 6 calculated using numerical differentiation

Conclusions

Despite many of the ions "orbiting" the filament and the perturbation of the initial velocities of the neutrals, the final current vs. potential curve is dependent on initial energy. COMSOL© simulations have shown that this design, while not ideal, is viable.

Future Work

- Simulate cases with different grid and filament biases
- Additional COMSOL© studies using more particles and adding particle-particle interactions
- Compare to other simulations, including a 1-dimensional MATLAB script
- Research other multiphysics simulation tools such as CST Studio Suite from Dassault Systemes
- Test the full system in a realistic environment such as NASA's Atomic Oxygen Beam Facility at Marshall Space Flight Center
- Mechanical redesign of the instrument for ease of assembly and testing

Acknowledgements

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References

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