Meeting the Grand Challenge of Protecting an Astronaut’s Health: Electrostatic Active Space Radiation Shielding for Deep Space Missions

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Presentation Outline

• Space Radiation Shielding Overview
• NIAC Phase I Goals
• Electrostatic Radiation Shielding Concept
• Charged Gossamer Structures
  – Concept Description
  – Small-Scale Vacuum Chamber Experiments
  – Larger Structures
• Power Analysis
• Charge Deflection Experimental Validation
• Conclusions
• Deep space Radiation exposures are very different from LEO
• Material radiation shielding has matured; has limited or no potential of avoiding continuous radiation exposures; is low earth orbit (LEO) technology
• Biological uncertainties from long duration radiation exposures are unknown
• Best strategy is to avoid radiation hitting the spacecraft
• Magnetic fields have been found to have adverse health effects
• The best hope is electrostatic active shielding
• Comprehensive technology; synergistically includes electrostatic, material and hybrid magnetic shielding (only if safer)
NIAC Phase I Goals

• Simulate, test and validate an electrostatic Gossamer structure to provide radiation protection
• Experimentally verify electron deflection efficiency with charged Gossamer structures
• Study suitable Gossamer shapes to enhance deflection and stiffness
• Investigate larger charged Gossamer structure
• Consider power requirements
Electrostatic Radiation Shielding Concept

Charge Flux due to Solar Flare events or Cosmic radiation

Electrostatically Charged Gossamer Membrane Structures

Negative Electrostatic Force Field

Positive Electrostatic Force Field

Safezone

negative radiation

positive radiation
Charged Gossamer Structures

- Active radiation shielding requires a light-weight solution
- Electrostatic deflection requires a large capacitance (i.e. surface)

- Solution: charged Gossamer structures
Small-Scale Vacuum Chamber Experiments

Vacuum Chamber:
- No charge flux
- 10cm structure
- External power supply

Illustrates electrostatic inflation of Gossamer Structure

Ramp Up to 10 kV
Electrostatic Inflation of Ribbed Structure for Spheroidal Shapes
How fast can a large, spherical electrostatic Gossamer structure be accelerated?

![Diagram of Electrostatic Inflation and External Acceleration]

Allowable G’s of Acceleration

- Sphere Radius [m]
- Spacecraft Voltage $\log_{10}(V_{sc})$ [V]
\[
\Phi(x = \xi, y = \xi, z = \xi)
\]

Positive barrier deflects protons

Negative barrier deflects electrons

Damaging high-energy protons kept out of this region

Vast quantities of low-energy electrons kept out of this region

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Nominal solar wind and photo-electron current dominate power evaluation

$T = 40\text{eV}$
$n = 10\text{cm}^{-3}$

The outer negative objects deflect the electrons, and don’t reach the inner positive spheres

Electrons create a wake, but don’t reach inner positive objects (green)
Nominal solar wind and photo-electron current dominate power evaluation

\[ T = 40\text{eV} \]
\[ n = 10\text{cm}^{-3} \]

The outer negative objects deflect the electrons, and don’t reach the inner positive spheres.

Ions are first focused, then scattered, in complex patterns.
Low energy solar wind and photo-electron current dominate power requirement.

MeV ions of solar storms and GeV ions of galactic radiation have such low densities to result in minimal power requirements.
Solar Particle Event Power Analysis

Power analysis for 1956 solar particle event (Webber Spectrum) – minimal power requirements
GCR Spectrum Power Analysis

1977 solar minimum GCR spectrum power analysis - minimal power requirements
Coulomb membrane structures with up to 10kV are subjected to an electron flux with up to 5keV in a vacuum chamber to investigate charge deflection, as well as membrane structure stability. Current is measured through a faraday cup on a moving boom.
In the presence of charge flux, interesting coupling between the electrostatically supported membrane and the charge flow have been observed. The vibrations are on the order of 4Hz, and depend on the flux energy, membrane voltage, and structure shape.

Electron gun emitting at 5 keV, 5 mA
Membrane structure starting voltage of 4kV with vibrations present
Conclusions

• Active radiation shielding employing charged Gossamer structures is feasible and achievable with the existing technology
• Significant reduction in radiation exposure is achieved with large electrostatic repulsion
• Significantly helps alleviate biological uncertainties
• Carefully configured positive and negative components create a charge flux wake effect, i.e. radiation safe zone
• Future work will need to investigate further to coupling between high energy radiation deflection, Gossamer shapes and sizes, power considerations, and space weather impact.
• Synergistically include electrostatic, material and hybrid magnetic shielding (only if safer)
Questions?
Backup
Accomplishments

- Experimentally verified electron deflection efficiency with charged Gossamer structures
- Experimentally and analytically studied several Gossamer shapes and materials to enhance deflection and stiffness
- Identified ~ 5 Hz structural vibrations due to electrostatic inflation and charge flux coupling
- Studied power requirements for deep space shielding
- 1 journal paper; 5 conference papers; 4 reports
- 1 patent