STATUS OF SPACECRAFT CHARGING IN THE USA

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ABSTRACT

Spacecraft charging continues to be an area of interest to the space environments and effects community in the United States. This presentation will provide an overview of the current state of the art in spacecraft charging in the United States. Topics will include the status of surface and internal charging codes use to evaluate charging in the space environment, laboratory efforts to characterize charging properties of dielectric materials, development of new materials for use in charging environments, models used to specify the space charging environment, instrument development for in-situ monitoring of charging environments, updates to US spacecraft charging standards and design guideline documents, and additional areas of interest to United States government programs, private industry, and academia.

1. US SPACECRAFT CHARGING

Spacecraft charging continues to be an active and strong area of research, development, and operational support in the United States (US). Major US contributors to spacecraft charging and related disciplines are from government labs (including Department of Defense, Department of Energy, National Oceanic and Atmospheric Administration, and National Aeronautics and Space Administration), private industry, and academia. Major areas of work include:

- Flight experiments and on-orbit measurements
- Ground experiments
- Environment models
- Charging analysis tools
- Operational support and anomaly resolution
- Electric propulsion
- Standards.

2. FLIGHT EXPERIMENTS AND ON-ORBIT MEASUREMENTS

Some example US Flight Experiments of interest to the spacecraft charging community include:

- National Aeronautics and Astronautics Administration's (NASA) Radiation Belt Storm Probes continues to provide geostationary transfer orbit radiation and charging measurements with operations starting in 2012 and current plans to for the mission to extend to November 2018 (to be determined).

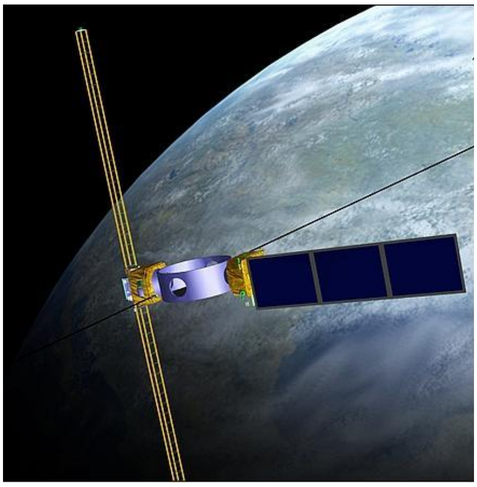

Figure 1. DSX Spacecraft [Image: AF]

- The Floating Potential Measurement Unit instrument suite will complete 10 years of operations monitoring plasma environments and charging on the International Space Station in August 2016.
- DSX – Demonstration and Science Experiments under development by Air Force (AF) Research Laboratory (AFRL) and Lincoln Labs) will be used to investigate wave-particle interactions at medium Earth orbit altitudes. The launch is scheduled for 2017.
- The AFRL CEASE-RR program is developing a 3U size Compact Environmental Anomaly Sensor (CEASE). This instrument is currently under considerations for the AF Energetic Charged Particle sensor to be flown on all AF satellites.
- Jet Propulsion Laboratory's (JPL) JUNO spacecraft will arrive at Jupiter in July 2016 and begin operations that will include measurements of the jovian radiation and charging environments.
- National Oceanic and Atmospheric Administration (NOAA) Geostationary Operational Environmental Satellite (GOES) and Polar Orbiting Environmental Satellites (POES) spacecraft continue to provide

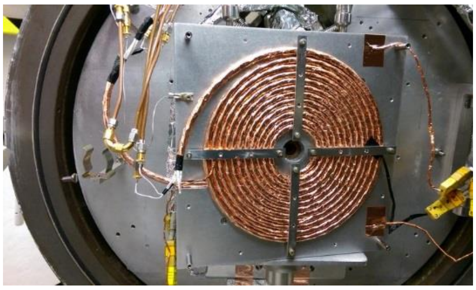

Figure 2. JPL Cable Studies
[Image: N. Green/JPL]

information on radiation and charging environments geostationary orbit (GEO) and low Earth orbit (LEO) polar orbits, respectively. GOES-R is planned for launch in October 2016 and will include an enhanced set of space radiation and plasma sensors.

3. GROUND EXPERIMENTS

US ground experiments continue to make fundamental measurements of importance to the physics of charging and to characterize charging threats to spacecraft. Examples include:

- AFRL led plasma expansion speed round robin testing identifies multiple expansion velocities due to components of expanding plasma including carbon, aluminum, and a Kapton fragment.
- JPL material electrical property and cable arcing studies.
- AFRL study of material aging and changes in charging properties (resistivity, secondary electron yield, and photoemission).
- AFRL attempts to detect Global Positioning System (GPS) satellite arcing from Arecibo, LWA, MRO, SOR. Evidence has been detected for large arcs may possibly be responsible for GPS power loss by contaminating arrays.

Figure 3. Arecibo Observatory

- The Roll-Uut Solar Array (ROSA) is an advanced flexible solar array developed by Deployable Space

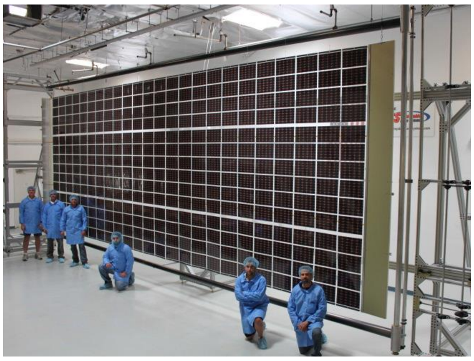

Figure 4. Roll-Out Solar Array
[Image: DSS [1].]

Systems (DSS). Recent collaborations with DSS Space Systems Loral, AFRL, JPL, and Marshall Space Flight Center (MSFC) for further development and testing have helped advance the arrays to a high technology readiness level [1]. Combined charging and impact testing using the Micro Light Gas Gun at the NASA MSFC Impact Test Facility has been used to evaluate the ability of the arrays to withstand impacts while charged.

4. ENVIRONMENT MODELS

US developments in environments models includes terrestrial and jovian environments:

- The AE9/AP9/SPM trapped terrestrial radiation models developed by Aerospace Corporal, AFRL, and the National Reconnaissance Office continue to be updated and improved and are finding wide acceptance in the radiation community. The models are the defacto world standard radiation belt climatology model. One application of the model contributed to the TACSAT4 discovery of high energy protons filling the slot region of the Earth's radiation belts.

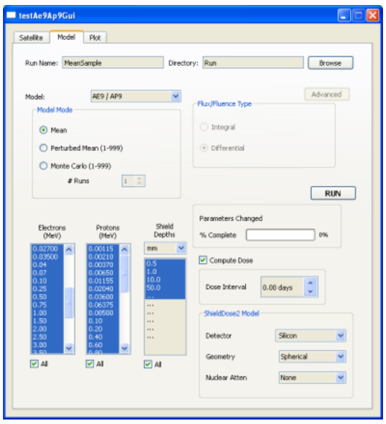

Figure 5. AE9/AP9/SPM User Interface

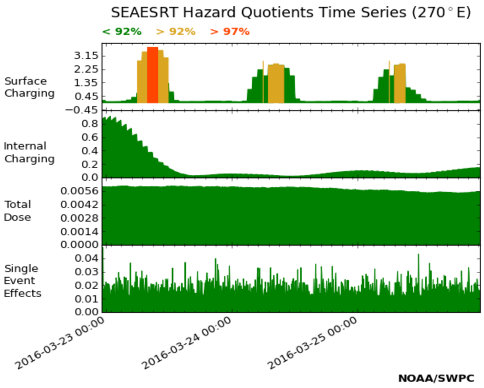

Figure 6. SEAESRT
[Image: NOAA SWPC]

- The AF Geospace suite of model developed by AFRL contains multiple space environment models with graphical user interface.
- JPL continues to update and improve radiation belt models for the outer planets including Jupiter, Saturn, and Uranus.

5. CHARGING ANALYSIS TOOLS

Among the new US Charging Analysis tools are the following:

- JPL NUMIT two and three dimensional internal charging models continue to be improved and updated.
- The NASA and Air Force Charging Analysis Program (NASCAP) Engineering Tool (Leidos) remains the standard surface charging model used in the US with continued AF support for development of the model.
- NOAA Space Environment Anomalies Expert System Real Time (SEAESRT) provides real time charging hazard quotients for geostationary satellites. NOAA Space Weather Prediction Center provides output from the model in real time.
- NASA Community Coordinated Modeling Center Integrated Space Weather Analysis (iSWA) Tools include a number of applications of interest to the radiation and spacecraft charging community. Applications include run on request models as well as real time applications.

6. OPERATIONAL SUPPORT AND ANOMALY RESOLUTION

The US supports spacecraft operations and anomaly resolution with the following programs (among many others):

- JPL investigations of the July 2015 anomaly on NASA's Soil Microwave Active Passive (SMAP) satellite included evaluation of radiation and spacecraft charging although they have been eliminated as a root cause.

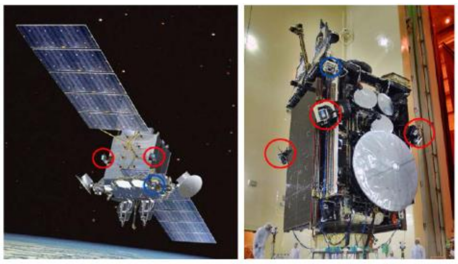

Figure 7. AEHF [Image: AF]

- Nascap-2k modeling was applied in support of a thruster degradation anomaly investigation for the AF Advanced Extremely High Frequency (AEHF) spacecraft (Leidos, AFRL).
- AF provided anomaly resolution support for a proprietary industry asset that included analysis of geostationary orbit relativistic electron fluences. The best fit to event times were obtained from integrating >2 MeV GOES-13 electron flux over a period of three days.

7. ELECTRIC AND ELECTRODYNAMIC PROPULSION

Electric and electrodynamic propulsion activities in the US includes the following efforts:

- The ElectroDynamic Debris Eliminator under development by Star, Inc is a electrodynamic tether mission that features a roving, propellantless space vehicle for virtually unlimited delta-V throughout LEO. The spacecraft uses vxB.l to generate propulsion, orbit-changing, grappling of debris.
- Iodine Satellite (iSAT) is a joint NASA MSFC and GRC electric propulsion technology mission currently in development.
- The Dawn spacecraft continues successful operations at Ceres using the JPL developed ion propulsion engine.
- The European Space Agency (ESA) LISA Pathfinder spacecraft is operating with Busek/JPL developed colloid thrusters for propulsion.

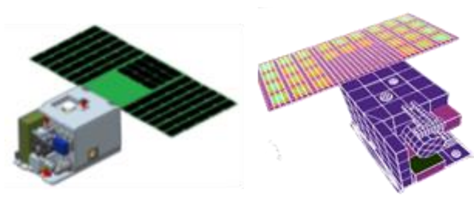

Figure 8. iSAT and Nascap-2k model.
[Image: L. Parker/Jacobs]

8. STANDARDS

Among the US standards efforts are:

- NASA-STD-4005A, Low Earth Orbit Spacecraft Charging Design Standard
  - High voltage solar array interactions with plasma environment in low Earth orbit.
  - Updated standard supersedes NASA-STD-4005.
- NASA-HDBK-4002A, Mitigating In-Space Charging Effects – A Guideline
  - Surface and internal charging threat mitigation guideline.
  - Review and update in progress
- ISO CD 19923 -Space environment (natural and artificial)
  - Plasma environments for generation of worst case electrical potential differences for spacecraft (Proposed by Japan with expertise from AFRL).
- ISO N 1100, NWIP Space environment (natural and artificial)
  - Spacecraft charging - Earth orbit (AFRL proposed with expertise from Japan, China, and Russia).

9. CONCLUSION

Spacecraft charging in the US is vibrant, alive, and looking towards a bright future.

10. REFERENCES

1. Hoang, B., B. Spence, S. White, and S. Kiefer, Commercialization of Deployable Space Systems' Roll-Out Solar Array (ROSA) Technology for Space Systems Loral (SSL) Solar Arrays, IEEE Aerospace Conference, Big Sky, Montana, March 2016.