Plasma Effects on Spacecraft Then and Now! A Welcome to Participants

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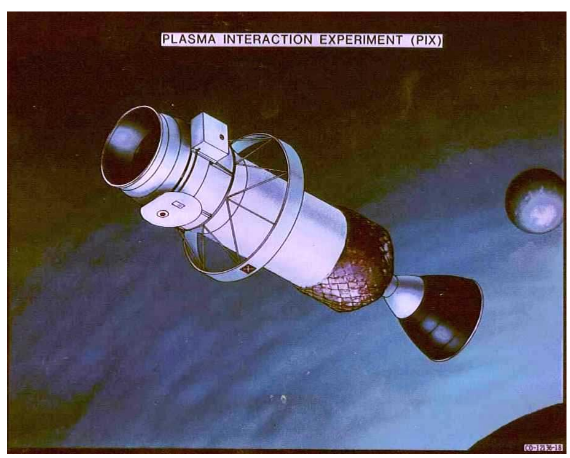
Welcome to the Spacecraft Charging Technology Conference. As co-sponsor of this event, let me welcome you and alert you to a change. Congress has voted to change the name of my institution, formerly the NASA Lewis Research Center, to the NASA John H. Glenn Research Center at Lewis Field. This is now legal, although it is still unofficial, the official change presumably coming when a ceremony has taken place. In any event, NASA Lewis has been involved in investigating spacecraft charging for a very long time, and I would like to give you a little pictorial background on spacecraft charging and our involvement.

In the 1970's, Lewis Research Center co-sponsored the first Spacecraft Charging Technology Conferences with the U.S. Air Force Geophysics Laboratory. We reported in those proceedings results from ground tests on items such as SCATSAT, shown here in NASA Lewis Tank 5. SCATSAT was an early mockup satellite, forerunner of the flight experiments SCATHA, etc., which was designed to allow ground testing of arc-current paths inside satellites. Lewis was also interested in, and was performing, ground tests on items placed in a simulated LEO plasma, under the leadership of N. John Stevens.



In 1978, NASA Lewis flew the Plasma Interaction Experiment (PIX), piggyback on a Delta. This early flight experiment obtained about one orbit's worth of LEO data showing that the effects seen in ground tests (arcing into the plasma and snapover of potentials onto insulating surfaces) are not just related to testing in plasma tanks, but also occur in space. A 1983 follow-on experiment named PIX-II, flown under the Lewis leadership of Carolyn Purvis, yielded good empirical thresholds and rates for arcing and ion and electron currents collected by pinholes and solar cells.

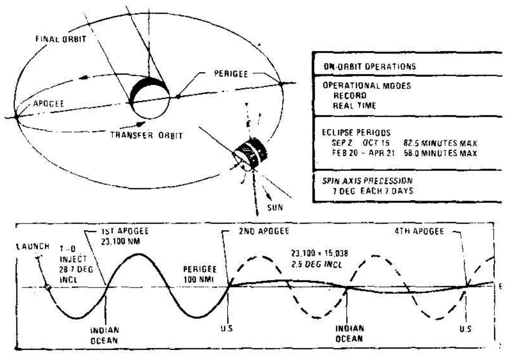


Figure 7. Orbital Parameters

In 1979, SCATHA (Spacecraft Charging At The High Altitudes) was flown by the U.S. Air Force. SCATHA was the first satellite devoted solely to GEO charging problems, and SCATHA data are still used to define typical and worst-case charging environments and effects.

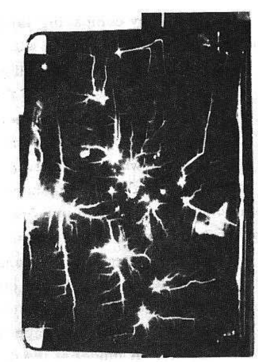
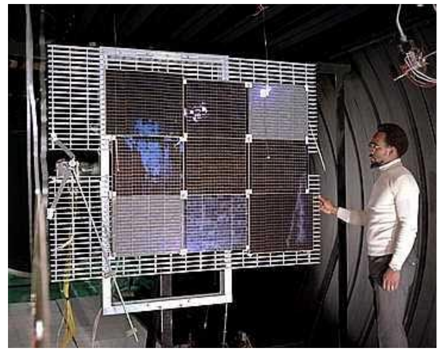


Figure 7. Discharges in Single Sheet Silver Teflon Sample

Ground tests were also being done under simulated GEO environmental conditions. Show here are discharges in a silvered Teflon sheet sample under 20 keV e-beam bombardment. (Lab work and photo taken by Stevens, Berkopec, Staskus, Blech, and Narciso.)

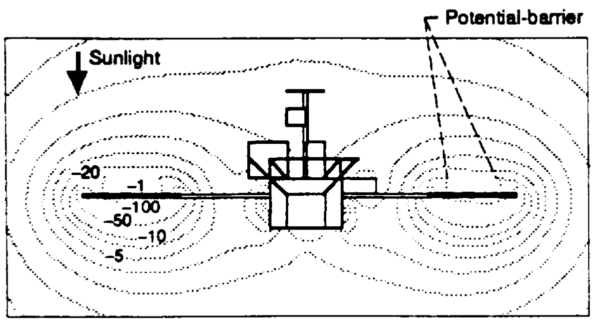
One ambitious spacecraft charging satellite developed at NASA Lewis was SPHINX (Space Plasma Hi-voltage INteractions eXperiment), but the photo (of a different launch with the same end) illustrates the final fate of this satellite, launched on the first Titan-Centaur. It is well-known that SPHINX kept transmitting until it hit the water.



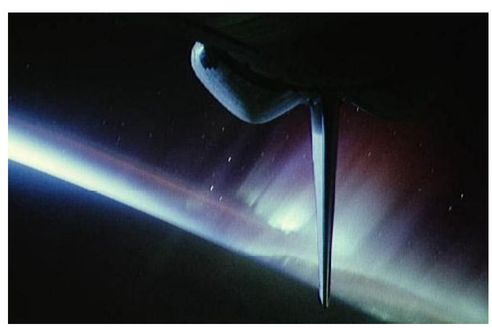
Ground testing in evacuated plasma chambers at NASA Lewis continued. Here is a photo of Norman Grier with his large area solar array panel test in NASA Lewis Tank 5 in 1979. These ground tests, along with those performed at Lewis by the late John Staskus, resulted in the first data on how to scale snapover and arcing effects with large area arrays.

In 1984, NASA Lewis and JPL issued the Design Guidelines for Assessing and Controlling Spacecraft Charging Effects by Purvis, Garrett, Whittlesey and Stevens (NASA TP 2361). Now affectionately known as the Spacecraft Charging Guidelines, this is the most widely accessed document for GEO spacecraft charging. Along with the NASCAP computer code, it still forms the basis for GEO spacecraft charging design around the world. By the time you read this, it may even be downloaded from the worldwide web at:

http://powerweb.lerc.nasa.gov/pvsee/publications/.

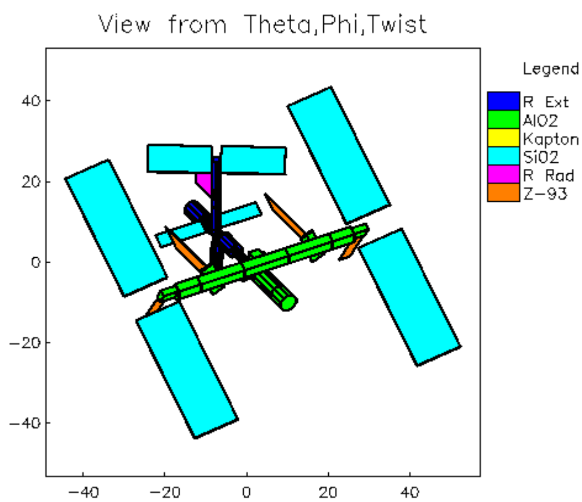


Also in 1984, the NASCAP-GEO computer code was released. This code was funded by NASA Lewis and produced by S-Cubed, now the Systems Division of Maxwell Technologies. It allows the calculation of differential potentials between spacecraft surfaces due to spacecraft charging. The illustration shows a NASCAP calculation of equipotentials around solar arrays on ACTS (the Advanced Communications Technology Satellite), showing potential barrier effects. This calculation was performed by Joel Herr, of Sverdrup Technologies, while working at NASA Lewis.

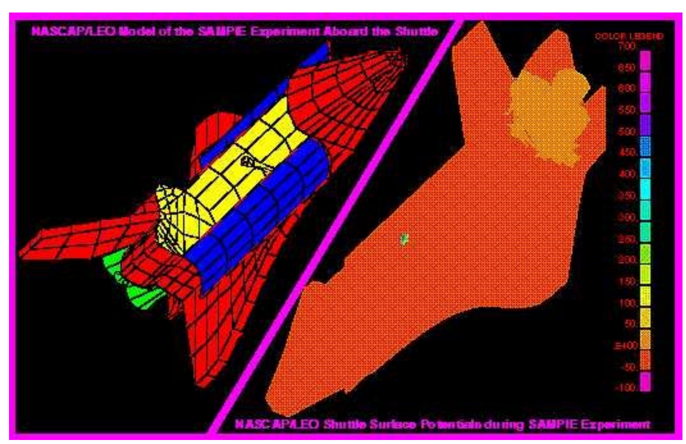


Perhaps the worst of both plasma worlds (LEO and GEO), the Aurora Borealis is shown here, as seen from the Space Shuttle.

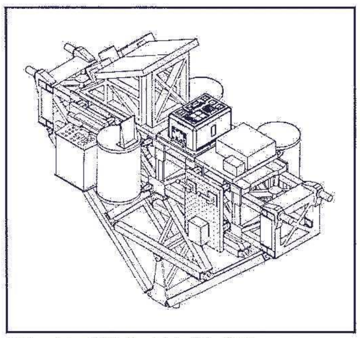
In the late 1980's, Lewis funded, along with SDIO, a tool to integrate together in one computer code all of the relevant spacecraft environments and effects on LEO spacecraft. This code was called EPSAT (for Environmental Power System Analysis Tool). In the early 1990's , this tool was transformed into Environments WorkBench (EWB), the official International Space Station (ISS) plasma analysis software. EWB integrates models of the spacecraft orbit, systems, environments, and their interaction with those environments for numerous interactions, such as plasma, micrometeoroids and debris, atomic oxygen, etc.



EWB was used to analyze the International Space Station for plasma effects. It was found that because of the negatively grounded high voltage solar arrays on ISS, its structure would float some 14 0 V negative of the plasma it was to fly through, and this would lead to arcing destruction of its thermal coatings. This would have made ISS the biggest high voltage plasma experiment of all. Shown here is a Maxwell Technologies EWB model of ISS build 15a. It was also shown that addition of a plasma contactor (PC) to ISS would solve these problems. The ISS PC has now been constructed, with hollow cathode elements produced by Michael Patterson and others at Lewis, and will be launched and turned on before the large area ISS arrays are actuated.

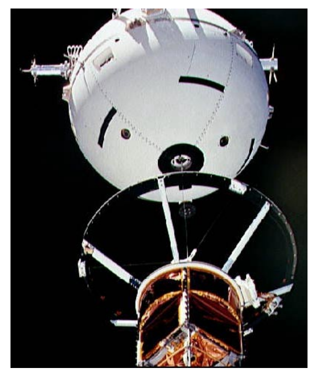


Another NASA Lewis product is the computer code NASCAP/LEO (also produced by S-Cubed), a LEO version of NASCAP. Shown here is a model of potentials on Space Shuttle Columbia while operating SAMPIE (Solar Array Module Plasma Interactions Experiment). This model was developed by Ricaurte Chock, of NASA Lewis. Notice that the entire current collection of the SAMPIE experiment is balanced by current collection only on the Space Shuttle bell nozzles.

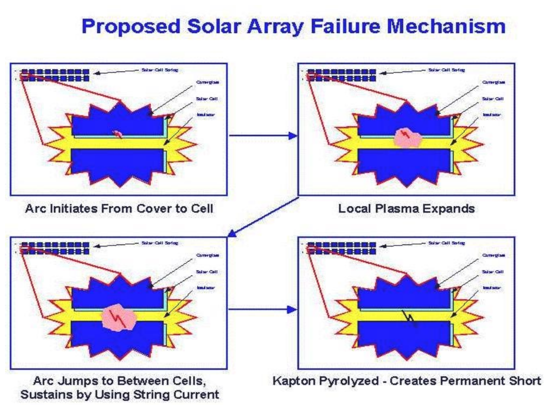


SAMPIE mounted on a Hitchhiker-M carrier for launch aboard STS-62.

SAMPIE (1994), a Lewis experiment flown in the Space shuttle payload bay, found arcing and current collection of anodized aluminum, solar arrays, metals, etc. Barry Hillard was the project scientist on SAMPIE, and the author was the Principal Investigator. Results from SAMPIE and another part-Lewis experiment called PASP Plus were used to size the ISS PC. SAMPIE data also led Tom Morton of NYMA, Inc. at Lewis and Victoria Davis of S-Cubed to development of an advanced Langmuir probe algorithm.



In 1996, a NASA MSFC experiment called TSS-1R arced its 20 km long electrodynamic tether in two. This showed how a sustained current and voltage source can sustain arcs for seconds or minutes until catastrophic damage occurs (oops!)



In 1997, the Space Systems/Loral TEMPO-2 satellite was afflicted with several bouts of solar array string failure. These were the first documented sustained-arcing solar array string failures in GEO. The Lewis, Maxwell Technologies, and Loral team which investigated the failure, and showed how to prevent such failures through ground testing, was the beginning of a NASA/industry collaboration to mitigate sustained arcing that continues to this day. David Snyder, Joel Galofaro and Boris Vayner were the key Lewis personnel involved in the testing. The second figure above shows the mechanism proposed to explain the failures that was subsequently tested in plasma chambers at NASA Lewis. (Figure courtesy of D. Allen, Schaefer Assocs.) The initial arc may occur either in LEO or GEO.

In 1998, this failure mechanism was also shown through laboratory testing to pertain to the solar arrays on the NASA GSFC scientific satellite EOS-AM1. This figure shows a sustained arc occurring in Lewis laboratory testing on the EOS-AM1 Q-Board at the operational LEO on-orbit intercell voltage. The next figure shows the damage produced by this sustained arc. Fixes have been implemented on the flight array using diodes to limit current to the arc sites to values below the threshold for sustained arcing. It is expected that EOS-AM1, when launched in mid 1999, will have no difficulties, largely because of the careful ground testing done at Lewis.

Arcing and spacecraft charging continue to be problems for satellites because of several trends in spacecraft and solar array design. These new trends include:

- I. High voltage solar arrays
  - a. Higher efficiency PMAD (lower I^2R losses)
  - b. Direct-drive electric propulsion
- II. Flexible substrates (Kapton® and variants) & thin-film arrays
  - a. Lower weight
  - b. Deployable
- III. High efficiency solar arrays
  - a. High output cells, high string currents
  - b. Tight intercell and interstring spacings

I am pleased to report that to mitigate the arcing and plasma related failures the new trends bring with them, there are several new initiatives (some of which remain to be funded), that include:

- I. Interactive Charging Guidelines (hyperlinked, expert system-like)
- II. NASCAP 2K - a new, more interactive charging code for all environments
- III. Charging Properties of New (& Old) Spacecraft Materials
- IV. High Voltage Solar Array Plasma Interactions
- V. Deep Dielectric Discharge Modeling and Testing
- VI. High Voltage Array Experiments (SPEDE and HIVAX)

No matter what the future holds, the NASA Lewis Research Center (now to be known as the John Glenn Research Center) will continue to be on the forefront of research into and mitigation of effects due to spacecraft charging and plasma related arcing and current collection.