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NASCAP/LEO SIMULATIONS OF SHUTTLE ORBITER CHARGING DURING THE SAMPIE EXPERIMENT

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ABSTRACT

The electrostatic charging of the Shuttle Orbiter during the operation of the Solar Array Module Plasma Interaction Experiment (SAMPIE) has been modeled using the NASCAP/LEO computer code. The SAMPIE experiment, scheduled to be flown in the shuttle payload bay in 1993, consists of an array of various solar cells representing the present technologies. The objectives of the experiment are to investigate the arcing and current collection characteristics of these cells when biased to high potentials in a low Earth orbit (LEO) plasma. NASCAP/LEO (NASA Charging Analyzer Program/Low Earth Orbit) is a 3-D code designed to simulate the electrostatic charging of a spacecraft exposed to a plasma at low earth orbit or ground test conditions. At its most extreme configuration, with the largest array segment of the SAMPIE experiment biased +600 V with respect to the Orbiter and facing the ram direction, the computer simulations predict that the Orbiter's potential will be approximately -20 V with respect to the plasma.

I. INTRODUCTION

NASCAP/LEO simulations comparing ground test results with low earth orbit conditions have highlighted the difficulties encountered when trying to extrapolate solar array behavior under LEO conditions from vacuum chamber experiments. NASCAP/LEO (NASA Charging Analyzer Program/Low Earth Orbit) is a 3-D code designed to simulate the electrostatic charging of a spacecraft exposed to a plasma at low earth orbit or ground test conditions (ref. 1). Using this code it has been found that small changes in cell geometry, such as allowing a cell cover glass overhang of 6 mils, will greatly impact the cell's current collection behavior (ref. 2). In order to better understand such behavior, actual flight experiments are needed. One of these is the Solar Array Module Plasma Interaction Experiment (SAMPIE), scheduled to be flown in the Orbiter bay in 1993 (ref. 3).

The SAMPIE experiment consists of an array of various solar cells, representing the present technologies. The objectives of the experiment are to investigate the arcing and current collection characteristics of these cells when biased to high potentials in a LEO plasma. These collection and arcing measurements will be made with the cells biased up to ± 600 V facing the ram and wake directions.

In LEO the Orbiter's potential will change so that the net current to the Orbiter from the plasma is zero. The potential at which this occurs is defined as the Orbiter's floating potential. With the SAMPIE cells biased to +600 V and facing the ram direction there is a possibility that the Orbiter's floating potential will be driven highly negative to balance and cancel out the incoming electron current.

In order to better design the experiment so as to avoid possible arcing damage to the Orbiter, NASCAP/LEO was used to model the Orbiter's electrostatic charging and obtain possible Orbiter floating potentials under different experimental configurations. From the available data (ref. 4), we can infer a floating potential of about -70 V for Skylab. This floating potential did not cause any problems during Skylab operations so -70 V was used as an acceptable floating potential.

II. NASCAP/LEO SIMULATION

First a finite element model of the Orbiter was created (see Fig. 1) using PATRAN® (a registered trademark of PDA Engineering), a commercially available 3-D mechanical computer-aided engineering software system. The Orbiter is modeled as being a dielectric object whose only conductors are its main engine and thruster nozzles. The SAMPIE experiment is placed in the approximate center of the bay.

The SAMPIE experiment itself is modeled as a box with the dimensions (.45x.45x.25 m) of the actual experiment and all of the top plate defined as a conductor. The top plate has no individual features such as solar cell assemblies or other experiments. This is because NASCAP/LEO's resolution can't distinguish individual features on the plate and still include the Orbiter in its computational grid.

NASCAP/LEO is a modular code. Each module is a program, or collection of programs, which solve a particular aspect of the spacecraft charging problem. A call to the CURRENT module, for example, will calculate currents from the plasma to the spacecraft. Other available modules are RDOPT and IPS. In the RDOPT (Read Options) module the user can input parameters such as plasma temperature and density, spacecraft speed and conductor potentials among others. The IPS (Initial Potential Specification) module calculates the electrostatic potentials of the spacecraft's surfaces and it's surrounding space environment. To run any given simulation one calls each of the modules individually.

The floating potential of the Orbiter with the SAMPIE experiment in operation was calculated using the RDOPT, IPS, and CURRENT modules. The procedure is straightforward. One performs several NASCAP/LEO code runs varying the Orbiter's potential until the net current to the spacecraft is negligible. The potential at which this occurs is then taken as the Orbiter's floating potential.

This procedure would only take into account sheath generated particles but by including three QUICK, CHARGE, POTENT cycles in the simulation we can take into account ambient particles as well. QUICK, CHARGE, and POTENT are other modules available from the NASCAP/LEO code. All the computer runs for this paper were done on a Celerity 1200 mini computer running Accel 4.2 UNIX. Further details on this procedure or about the NASCAP/LEO modules can be found in the NASCAP/LEO User's Guide (ref. 5). A sample of NASCAP/LEO input is shown in Fig. 2.

At the end of each simulation a CURRENTS utility, not to be confused with the CURRENT module, is run. The output from CURRENTS consists of the electric current values to the Orbiter/SAMPIE surfaces. This output is divided into material and conductor surfaces. In the present simulations one can read individual current values to the Orbiter, thruster nozzles, bay area, body (wings, empennage, cabin), the top of the bay doors, and the SAMPIE plate as well as the total current to the Orbiter/SAMPIE object.

In this paper, the simulations consist of the four experimental configurations listed below:

Case 1: SAMPIE in the Orbiter's ram, biased to +600 V.
Case 2: SAMPIE in the Orbiter's ram, biased to -600 V.
Case 3: SAMPIE in the Orbiter's wake, biased to +600 V.
Case 4: SAMPIE in the Orbiter's wake, biased to -600 V.

All SAMPIE biases are with respect to the Orbiter potential. Orbiter potentials are with respect to plasma ground.

III. FLOATING POTENTIAL DETERMINATION AND SIMULATION RESULTS

Case 1 is the most critical. With the SAMPIE experiment biased highly positive and facing the incoming ram particle flux, one can expect SAMPIE to draw large negative currents from the plasma. To cancel out this current the Orbiter will charge negatively in order to repel electrons and attract ions from the plasma. Depending on the magnitude of these currents the Orbiter may charge highly negative, thus exceeding safety limitations and interfering with the successful completion of the experiment.

When SAMPIE is biased negative and facing the ram direction it will collect ions proportional to the ram ion flux on its surface. Ram ion flux for LEO is in the order of 10^{-5}-10^{-3} A/m^2 (ref. 5) so one would expect small currents for case 2, thus a low floating potential.

One would also expect low floating potentials for cases 3 and 4 because of the reduced plasma density due to wake effects. A spacecraft flying through the plasma at a typical LEO velocity of 7500 m/s creates a region behind it in which both electron and ion densities are reduced in comparison with an undisturbed plasma. This spacecraft velocity is about six times larger than the ion thermal velocity (using a .1 eV oxygen ion) so a spacecraft would travel a distance equivalent to several of its own radii before the ions could fill in the region behind it. Electrons are more mobile and can fill in the

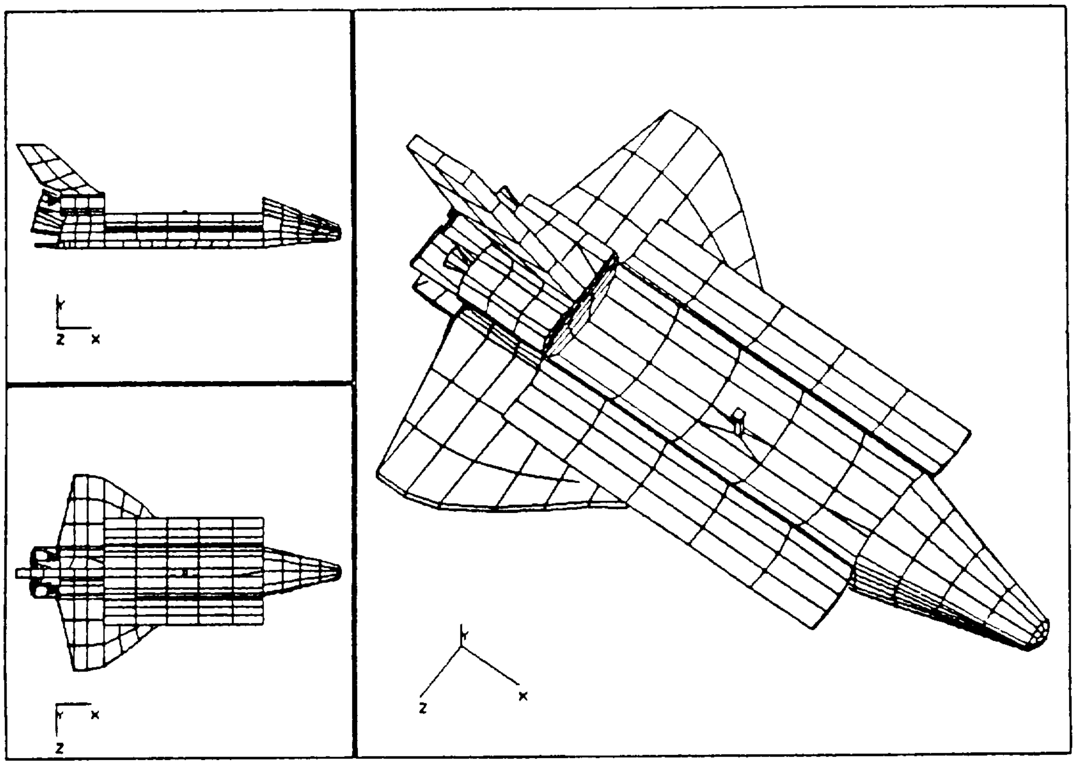

Fig. 1: NASCAP/LEO model of the Shuttle orbiter with the SAMPIE experiment on the center of the bay.

```
rdopt 5                                   # Read computational options
     temperature .1                       # Plasma temperature (eV)
     rho 1.1e11                           # Plasma density (#/m³)
     errlim 0.1                           # convergence error parameter
                                           for IPS module
     pcond 1 -200                         # Sets conductor 1 to -200 V
     bias 2 600                           # Biases conductor 2 600 V positive with respect
                                           to conductor 1
     satvel 7500 0 0                      # Object speed (x y z) m/s
     ionmass 16 amu                       # Oxygen ion mass
     sheath boundary 1                    # Sheath defined at the 1 V contour
     end                                  # End of computational options
wake                                      # Calculates reduced ion densities due to wake
                                           effects
ips 5                                     # Initial Potential Specification
   all matl -.3                           # Assigns a surface potential of -.3 V to material
                                           matl as an initial guess
   end                                    # End of IPS options
quick
charge
potent
quick
charge                                    # 3 QUICK, CHARGE, POTENT cycles
potent
quick
charge
potent
current                                   # Calculates currents to spacecraft
end                                       # End of NASCAP/LEO run
```

Fig. 2: NASCAP/LEO sample input.

wake region more rapidly. However this is limited by the space charge of electrons already present in the wake, so for most of the wake region the electron and ion densities are comparable (ref. 5). Results of measurements done by Murphy et al. (ref. 6) from within the Orbiter bay indicate a decrease of 3 orders of magnitude in electron density as a conservative estimate for the near wake region.

Case 1: SAMPIE in the ram, biased +600 V with respect to the Orbiter

As the Orbiter potential increases from 0 V to -400 V we see that currents to the Orbiter body and the top of the bay doors are negligible compared to the other currents, see Fig. 3. The door tops are shielded by SAMPIE's sheaths most of the time. The Orbiter/SAMPIE object collects current mainly through the Orbiter nozzles, the SAMPIE plate, and the bay area. The majority of the ions are collected by the nozzles while the electrons are collected by the experimental plate and the bay. The bay area is a dielectric surface but the fact that it is moving into the ram and that SAMPIE's sheaths focus charge into the bay will allow it to collect charge up to approximately -2.4 mA, from then on it will not collect larger currents.

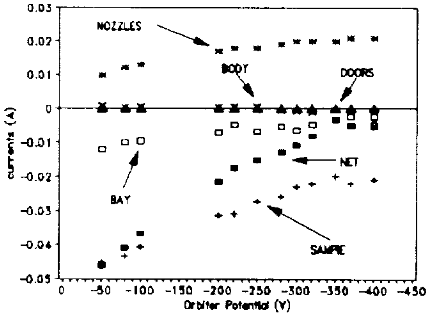

Fig. 3: Case 1, currents to spacecraft vs. orbiter potential. NET is the net current to Orbiter.

At an Orbiter ground potential of -350 V the currents collected by the nozzles cancel out the current collected by SAMPIE, see Fig. 4. However at this potential the bay is charged up to about -3.4 mA. There is no positive charge large enough to cancel the bay charge. The positive current collected on the body is on the 10^{-4}A range and these currents will not flow through the dielectric body to the bay. From these results one might infer a floating potential of about -350 V for case 1.

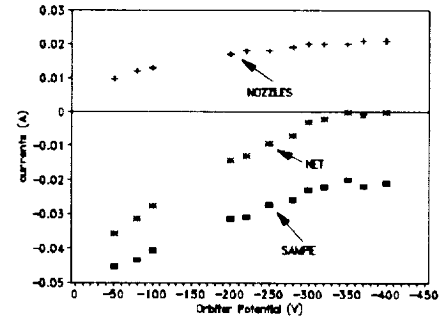

Fig. 4: Case 1, currents to spacecraft vs. Orbiter potential.

The floating potential may not be as large in reality because only a small area of the plate (some cell interconnects) will be biased to +600 V relative to the Orbiter instead of the whole plate surface as the simulation assumes. These cell interconnects would then be the effective collecting area. Assuming that the sheath through which SAMPIE current is collected scales proportionally to the conducting area of the plate we can scale the currents to SAMPIE by reducing the plate area. One can use these new currents to obtain a better estimate of the Orbiter/SAMPIE floating potential by reducing the currents to SAMPIE by a factor of actual collecting area vs. total experimental plate area. This should provide an estimate of the actual current collected by the experiment. These currents are then plotted to obtain a new I/V curve from which one can deduce a floating potential.

First it is important to verify if reducing the area of the SAMPIE plate on the simulation by a given factor reduces its current collection by a similar factor. Upon inspection of the Orbiter/SAMPIE object it can be seen that one can reduce the area of the experimental plate to half of its original value and still be within the margins of NASCAP/LEO's grid resolution. One can use this second Orbiter/SAMPIE model in a simulation and compare its currents to the original model. If the currents to this new SAMPIE object are approximately half their original value the approach is correct.

The new Orbiter/SAMPIE object will be referred to as SAMPIE2, where SAMPIE2's experimental plate is one half the area of SAMPIE1's plate model. In the SAMPIE2 simulation at high voltages the ratio of currents SAMPIE2/SAMPIE1 is very near to .5 as was previously assumed while the currents to the nozzles remains the same (see Fig. 5). At low voltages the ratio is between .4 and .5 which is not in bad agreement with our assumption. It can also be seen that for an Orbiter ground potential smaller than -300 V the ratio of current to the bay is .1. So if one reduces the collecting area, the bay currents will become negligible. One can thus be reasonably confident in scaling the currents to the SAMPIE plate by an appropriate area factor.

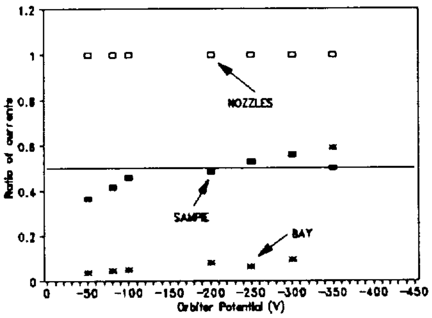

Fig. 5: Case 1, ratio of currents to spacecraft. SAMPIE2 vs. SAMPIE1 simulations.

Assuming a worst case in which the whole surface area of the cell will act as a conductor, i.e. the cells will be "snapped over", a likely possibility with this high positive bias. With four Space Station Freedom type solar cells as the base line there is a total surface area of about $2.48 \times 10^{-2} m^2$. The ratio of this area to the original SAMPIE plate area is approximately .124. Reducing the SAMPIE currents by .124 and graphing them (see Fig. 6) one finds a floating potential of about -20 V.

The NASCAP/LEO simulations therefore predict that when the SAMPIE experiment is biased +600 V with respect to the Orbiter and facing the ram, the shuttle's floating potential will be in the range of -20 V. One also sees that for this type of experiments there is a limiting size to the experimental array beyond which using the shuttle becomes impractical and possibly hazardous. The simulation shows that a plate .2 m^2 in area can not be biased to high positive voltages without driving the shuttle's floating potential highly negative.

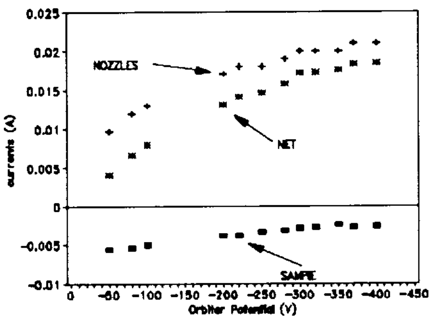

Fig. 6: Case 1 floating potential determination.

Case 2: SAMPIE in the ram, biased
-600 V with respect to Orbiter

One proceeds in the same manner as described above. Since this case is not expected to be critical the original Orbiter/SAMPIE model (SAMPIE1) may be used.

One expects low currents for this configuration and the simulations bear this out. The Orbiter ground voltage was changed from -50 V to +300 V. At all voltages SAMPIE current collection was small, around 6.5×10^{-4} A to 8.2×10^{-4} A. The sheath is localized around the SAMPIE box and does not affect current collection as in case 1. In this case the Orbiter connects to the plasma through the nozzles as if no experiment were present therefore the net current to the Orbiter consists of the nozzle's current.

The floating potential for case 2 can be calculated to be in the range of -10 V, see Fig. 7.

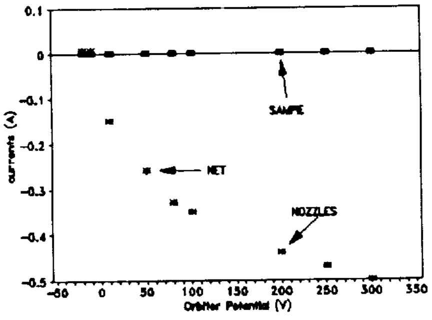

Fig. 7: Case 2 floating potential determination.

CASE 3: SAMPIE in the wake, biased +600 V with respect to Orbiter

SAMPIE collects electron current but only on the order of 10^{-5}A which is small when compared to the 10^{-3}A to 10^{-2}A nozzle current. So once again the net current to the Orbiter is the current to the nozzles. This current is zero for an Orbiter potential between -5 V and -2 V (see Fig. 8).

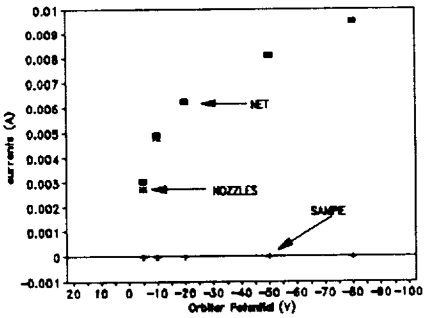

Fig. 8: Case 3 floating potential determination.

CASE 4: SAMPIE in the wake, biased -600 V with respect to Orbiter

As before the only connection to the plasma is through the Orbiter nozzles. The SAMPIE plate in the wake is a poor ion collector. In Fig. 9 it may be seen that the Orbiter will float at about 0 V. The CURRENTS output seems to indicate it will float slightly positive between 0 V and +1 V.

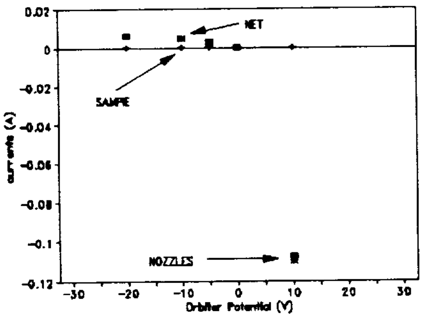

Fig. 9: Case 4 floating potential determination.

III. CONCLUSIONS

The NASCAP/LEO simulations predict that while the operation of the SAMPIE experiment will have an impact on the Orbiter's floating potential, it will not be a serious one. A worst case of -20 V has been predicted which is within the -70 V mentioned before as an acceptable floating potential. They also indicate possible limitations in similar experiments, for example, the same experiment with an active array collecting area of .2 m^2, biased highly positive, would drive the shuttle's potential to unacceptably large negative voltages. The SAMPIE experiment will not have this problem because the biased area is small and the platform upon which it is mounted, i.e. the Orbiter, has good contact with the plasma via the thruster nozzles. However, it is imperative that the Orbiter nozzles not be in the Orbiter's wake during the SAMPIE experiment for this will decrease the nozzles electrical contact with the plasma. Other high voltage experiments mounted on platforms which do not have a large exposed conductive area may charge up to large potentials which may then interfere with the experiment's operation.

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