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ABSTRACT

A computer code, the NASA Charging Analyzer Program (NASCAP), has been developed to study the surface charging of bodies subjected to geomagnetic substorm conditions. This program will treat the material properties of a surface in a self-consistent manner and calculate the electric fields in space due to the surface charge. Trajectories of charged particles in this electric field can be computed to determine if these particles enhance surface contamination. A preliminary model of the Spacecraft Charging At The High Altitudes (SCATHA) satellite has been developed in the NASCAP code and subjected to a geomagnetic substorm environment to investigate the possibility of electrostatic contamination. The results indicate that differential voltages will exist between the spacecraft ground surfaces and the insulator surfaces. The electric fields from this differential charging can enhance the contamination of spacecraft surfaces.

1.0 INTRODUCTION

In the past there has been concern over the possibility of spacecraft being contaminated by outgassing products.[1] Thermal control paints, thermal blankets, solar panels and adhesives are known to outgas for extended periods in space. It is believed that these molecular outgassing products can deposit on spacecraft and contaminate sensitive surfaces.

Normally, it was assumed that all spacecraft surfaces would not be charged more than a few volts above or below the space plasma potential. Accordingly, there was little concern for possible charged particle contamination since the fields around the spacecraft would not be sufficient to ionize neutral molecules.

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The data from ATS-5 and -6 Auroral Particles Experiments have shown, however, that the environment at geosynchronous orbit can charge spacecraft surfaces to appreciable negative values.[2,3,4] The data indicates that the satellite structure can be charged to potentials as large as -19 KV during eclipse periods and to -2 KV during sunlight environmental charging occurrences.[5] The phenomenon, known as "spacecraft charging", is believed to be caused by the satellite encounter with kilovolt energy particle clouds (geomagnetic substorms). Furthermore, other satellites are believed to have encountered such substorms and to have experienced anomalous electronic switching events.[6]

If a spacecraft structure can be charged to such levels (even when sunlit), then it is conceivable that the insulator surfaces of a satellite could be charged to similar levels. A shadowed insulator could be charged to a voltage level substantially different from the structure or from another insulator that was illuminated. Hence, it is possible that large differential voltages could develop on a satellite experiencing a geomagnetic substorm.

With large negative differential voltages on satellites, the electrical stresses within an insulator could exceed the breakdown conditions and arcing can occur. Laboratory experiments have shown that arcing is possible under conditions likely to be experienced by satellites in substorms[7] and that arcing can be accompanied by low energy charged particle emission and loss of material.[8] The electrostatic fields, generated by the surface potentials, can attract charged particles back to the satellite, enchancing contamination.

It is also possible for other processes to occur when spacecraft surfaces are charged. An electrostatic precipitation effect could occur. Neutral molecules could be polarized by the electric field and be returned to the spacecraft surfaces by gradients in the field. Another process that could occur due to fields generated by the charged surfaces is acceleration of the charged particles in space, increasing the probability of molecular ionization by collisions. The resulting ions could return to spacecraft surfaces.

This possible enhanced contamination of spacecraft surface by environmental charging of surfaces is of concern. The first attempt to evaluate this contamination in a space environment will be conducted on the Spacecraft Charging At The High Altitudes (SCATHA) satellite by the Spacecraft Charging/Contamination Experiment.[9,10]

An analytical tool that will predict surface charging on any spacecraft surface due to the environment is required to study this electrostatic contamination. This tool should have the capability of computing the voltage distribution on the surface and into the environment and of determining particle trajectories. Such a tool has been developed as part of the joint AF/NASA Spacecraft Charging Investigation.[11] This tool is called NASCAP, an acroynm standing for NASA Charging Analyzer Program.

As an example of the use of the program to study electrostatic contamination, a preliminary model of the SCATHA satellite was developed and its charging studied. Results of this study will be presented in this report along with a description of NASCAP and its capabilities.

2.0 DESCRIPTION OF NASCAP

2.1 Introduction

The NASA Charging Analyzer Program (NASCAP) has been developed as an engineering tool to determine the environmental impact on spacecraft surfaces and systems. It is capable of analyzing the charging of a 3-dimensional, complex body as a function of time for given space environmental conditions. The material properties of the surfaces are included in the computations. The surface potentials, low energy sheath, potential distribution in space and particle trajectories are calculated. Therefore, this program is adaptable to the study of electrostatic contamination of any satellite in the space environment.

NASCAP is a quasi-static computational program, i.e. it assumes that all processes are in equilibrium at each time step. This is a reasonable assumption since charging times are long compared to the time steps.

In the following paragraphs the program elements will be briefly discussed. A detailed description can be found in the literature.[12] The program is currently operational on UNIVAC 1100 computers and a User's Manual is available.[13]

2.2 Program Elements

The NASCAP flow diagram outlining the sequence of elements of the program is shown in figure 1.

a. Program Set-up. - The computer model is set-up in an embedded mesh, 3-dimensional network (see fig. 2). The spacecraft is described in the inner mesh region which is currently limited to 17 x 17 x n points where n can be any number up to 33.

The space surrounding the spacecraft model is defined in a series of cascading outer mesh regions. Each outer region is double the size of the adjacent inner region. This cascading is to reduce computational time. At the outermost boundary, undisturbed environmental parameters are specified. The environment can include solar inputs as well as particle fluxes.

b. Object Definition. - The spacecraft object must be defined in terms of rectangular parallelipiped or sections of parallelipiped. Curved surfaces are not allowed, but can be approximated by sections of parallelipipeds.

The surface can be bare or covered by a thin dielectric film. At present the material properties of aluminum and magnesium for structure and teflon, kapton and quartz for dielectric coverings are stored in the program. Other materials can be used but their material properties (secondary emission, backscatter, photoemission and resistivity) must be specified as a function of energy and angle of the incident particles.

Since a spacecraft can be a complex shape and errors in describing the model in terms of the program limitations can arise, a graphical output of the spacecraft model can be generated by the computer. Any set of axes or rotation angle can be specified for viewing the object. The computer will also remove all hidden lines. Therefore, it is possible to obtain 3-dimensional object definitions or projections in specified planes. As an example of the graphical output, the NASCAP model of the ATS-6 is shown in figure 3. This model has been generated within the 17 x 17 x 33 point size limitation and with sections of parallelipipeds. It is recognizable.

Finally, the graphical output will identify the specified surface materials of each cell. Hence, it is possible to determine that the computer model is the desired representation of the spacecraft prior to running the computational portions of the program.

c. Computational Elements. - The initial potentials on each spacecraft model node must be specified. These potentials can be set to zero if it is desired to obtain a time dependence on the charging. Specified values can also be used if the charging conditions from a given potential are to be determined. A program restart can use this capability.

The trajectory calculations are conducted to determine the incoming flux of particles. There are two basic operational modes for these calculations: particle pushing and Maxwellian approximations. In the particle pushing mode, the trajectories are traced backward from the surface, matching them to the specified environment distribution function at the outer boundary. There is available within the program six days of ATS-5 environmental data ranging from quiet to severe substorm conditions. In addition, other data can be used, if cast into the proper format. This mode of operation is computationally slow. If the environmental conditions can be approximated by a Maxwellian distribution, then this can be used for faster computations. The Maxwellian approximation to substorm conditions does not appear to be unreasonable.[15]

The surface interactions are computed in order to determine the charge distributions on the spacecraft surface. The processes considered are secondary emission, backscatter, photoemission and leakage through the material. Surface conduction between adjacent cells is not presently considered. The program will compute space charge due to secondary and photoemitted electrons in the region adjacent to the spacecraft only.

A conjugate gradient technique is used to determine the surface potential distribution as well as the potential distribution in space. The program assumes that there are no space charge effects other than those adjacent to the spacecraft model.

The program will iterate on these computational elements until a self-consistent solution is obtained. It has been found that from 5 to 20 iterations are sufficient to obtain a valid potential distribution for a time step. A valid potential distribution is one that does not change significantly as the iterations are continued.

d. Output. - For each time step (if desired), a printout can be obtained of the charge or potential throughout the embedded mesh network. If desired, graphical outputs of the potential contours and particle trajectories in the plane of any axes combination can be requested.

3.0 PRELIMINARY SCATHA MODEL

3.1 Model Description

As an example of how NASCAP functions and what its capabilities are, a simplified model of the Spacecraft Charging At The High Altitudes (SCATHA) spacecraft was developed.[14,15] This spacecraft is shown in figure 4. For the NASCAP model only the cylindrical portion of the spacecraft was considered.

The NASCAP model is a quasi-cylinder 1.7 m diameter by 1.8 m long. The top and bottom of this cylinder is covered with aluminum and grounded to the structure. The cylindrical sides are primarily solar cells (quartz cover slides). There is a center band of aluminum which is grounded to the structure. Three 0.3m square patches of kapton are on the spacecraft to simulate one of the experiments, Spacecraft Surface Potential Monitors (SSPM). Two of these patches are on the cylindrical sides, 180° apart, while the third is on the top surface. This model is shown in figure 5. Note that the materials for each node have been coded to provide a visual display of the various surfaces. Each node represents a 10 cm by 10 cm area of the spacecraft.

3.2 Environmental Conditions

The environment used in this model evaluations corresponds to the substorm conditions of October 16, 1969.[3] This substorm, incidentally, was one of those used in the original reports on the spacecraft charging phenomenon. The conditions are:

Electron Temperature	5000 volts
Electron Density	0.5 e/cm^3
Proton Temperature	10,000 volts
Proton Density	1 p/cm^3

The Maxwellian approximation for the particle energies is used. This environment is considered to be constant throughout the computational period. No sunlight is considered.

This model, then, simulates an uncharged satellite in eclipse experiencing a constant substorm for a period of one hour. No attempt is made to determine the effect of a charging environmental flux nor in determining how the surfaces would be discharged.

It is recognized that satellites can also be charged while some surfaces are sunlit. This case is also of interest for electrostatic charging. While NASCAP can handle these conditions (i.e. geomagnetic substorm environment in sunlight), the subroutines have not yet been verified. The effects of sunlight as well as changing flux will be considered in future work.

3.3 NASCAP Results

Computer runs were started with all nodes at 0 volts. The substorm environment then charged the surfaces to their equilibrium potentials which were dependent upon the surface material properties. The charging of typical surfaces on the spacecraft is shown in figure 6.

Within seconds after the initial influx of substorm particles, the aluminum surfaces (representing the spacecraft electrical ground) reached their equilibrium potentials (about -4000 volts). All insulating surfaces followed this change to the same potential. The potential distribution around the satellite, at this time, is very uniform as shown in figure 7.

As the substorm continues, the insulator surfaces slowly moved towards equilibrium potentials. This process took about 20 minutes. This differential charging time is in agreement with predictions given in the literature.[16,17] Since the insulator surfaces have higher secondary yields, these surfaces became less negative than the aluminum.

Hence, differential charging developed around the spacecraft. The potential contours around the spacecraft at this time are shown in figure 8. Note the strong potential gradients that exist at regions where insulators and conductors come together.

It must be stressed that the potentials computed here are strongly dependent upon the material properties of the surfaces. While the most reasonable values from the literature have been incorporated in the program, they may be in error in this application. This error would influence the absolute magnitude of the surface potentials only. Differential voltages would still exist and would be similar to those shown in figure 8.

It is possible that the electric field arising from this differential charging of spacecraft surfaces might ionize the outgassing molecules and enhance contamination. In the SCATHA contamination experiment there is concern for molecule ionization when there is a few volt differential between the spacecraft and the space potential.[10] With this spacecraft model, there are voltage differences of kilovolts within 10 cm. Low energy particles will move more readily in the strong fields around the satellite and could increase contamination.

The NASCAP model was used to search for particle trajectories. Typical examples are shown in figure 9 for particles flowing from the aluminum center band and from the solar array cover slide. Areas in each region were arbitrarily selected as the starting points for the trajectory computations. The results indicate that electrons will escape from the satellite. The ions, however, will return to the structure. If these returning ions stay on the surfaces, then contamination will be significantly enhanced.

4.0 CONCLUDING REMARKS

The NASA Charging Analyzer Program (NASCAP) has been developed to determine the surface charging of spacecraft when encountering geomagnetic substorm conditions. Once a model of a spacecraft has been developed in the NASCAP code, the surface charging can be computed for any environmental input flux. With the surface charging available, charged particle trajectories can be computed to determine if it is possible for a particle to return to a satellite surface.

A preliminary model of the SCATHA spacecraft was developed and subjected to a one hour geomagnetic substorm condition without sunlight. It was found that, for these conditions, the grounded surfaces and insulators rose to the conductor equilibrium potential (-4 KV) within seconds. Then, the insulator surfaces each moved towards their less negative equilibrium potentials. This differential voltage distribution around the spacecraft will cause low energy particles to be attracted back to the spacecraft surfaces enhancing contamination.

These computer runs with the NASCAP code represent the first attempts to use a self-consistent program to study the behavior of spacecraft surfaces experiencing a geomagnetic substorm condition. While the results are enlightening, there is considerably more that must be done in order to understand the interactions between the spacecraft surfaces and the environment.

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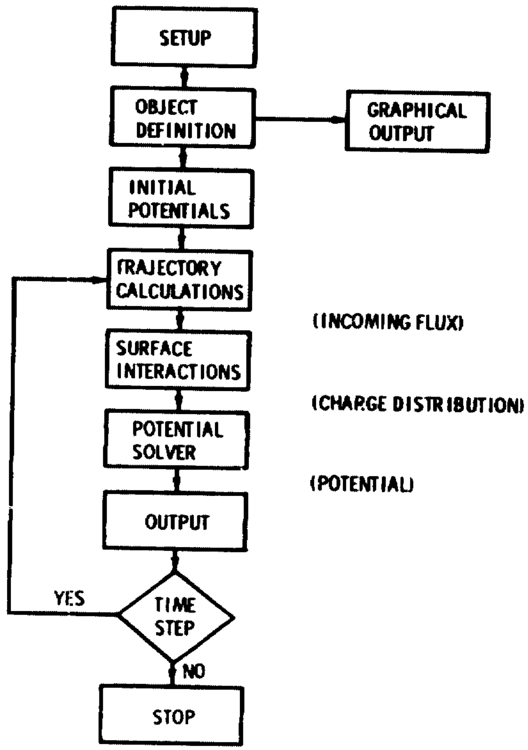


Figure 1. - NASCAP flow diagram.

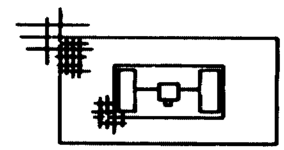


Figure 2. - Cross-section (y-z plane) of grid, showing first three embedded meshes.

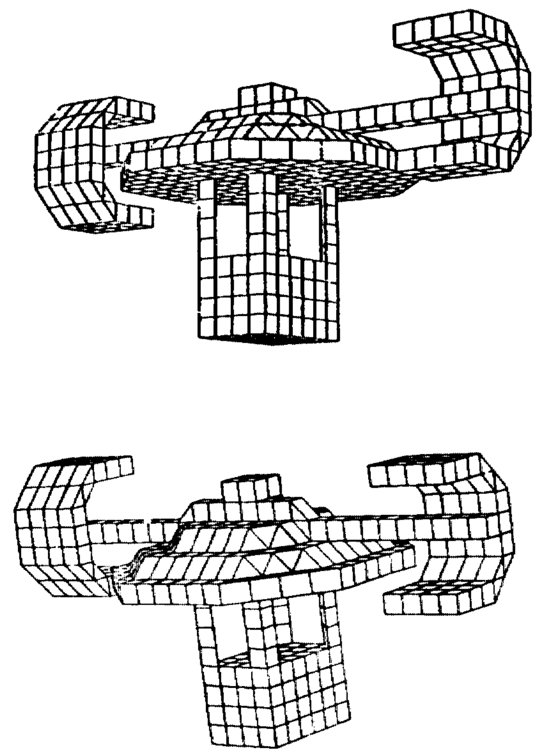


Figure 3. - NASCAP graphical output ATS-6 model.

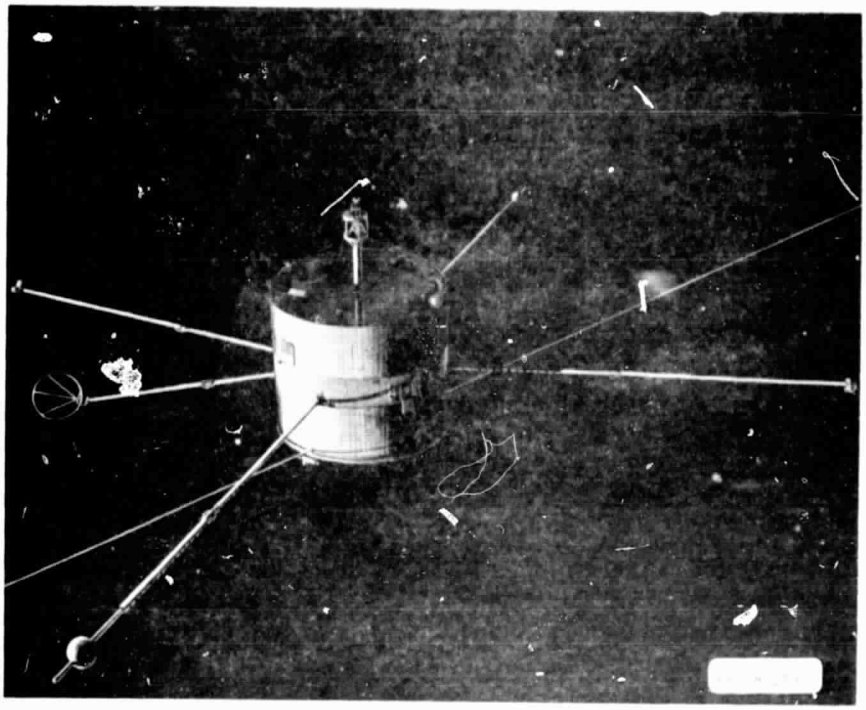


Figure 4. - Scatha Satelite.

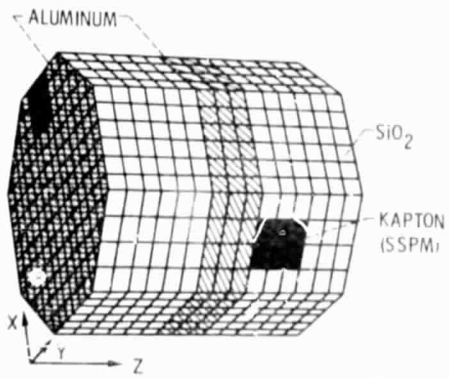


Figure 5. - NASCAP scatha model.

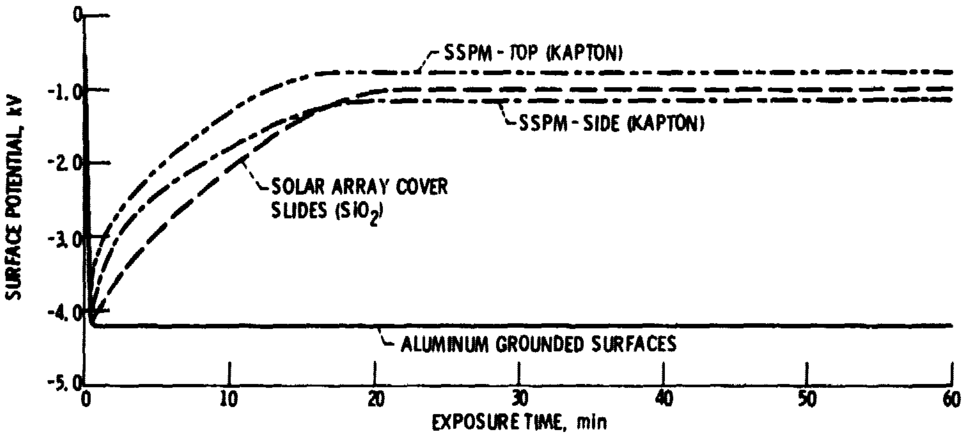


Figure 6. - Differential charging in substorm environment. Eclipse conditions. Scatha model.

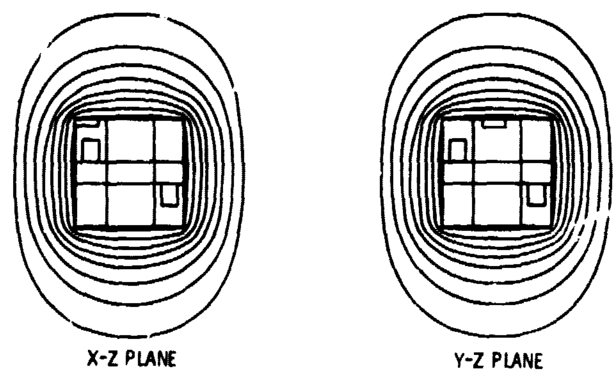


Figure 7. - Potential distribution around satellite after 1 minute in charging environment.

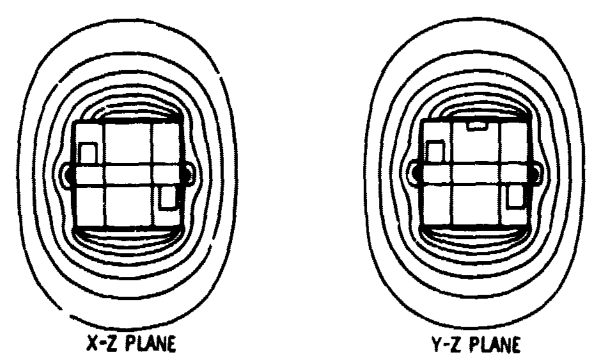
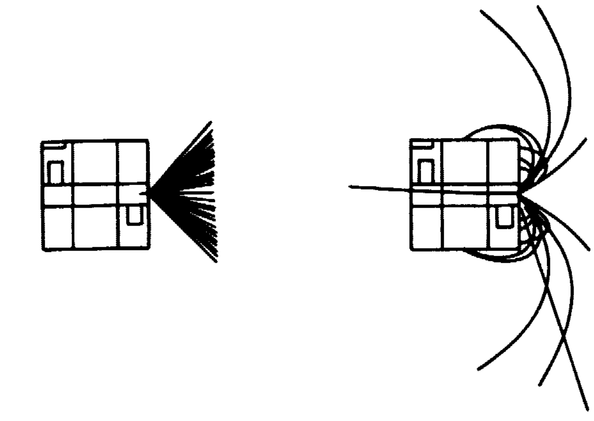
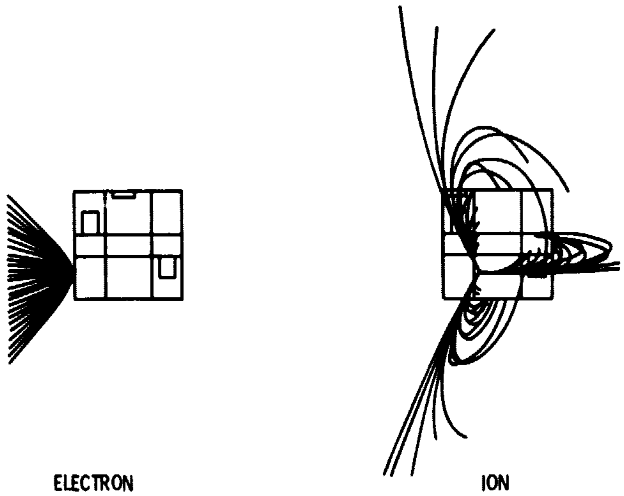


Figure 8. - Potential distribution around satellite after 1 hour in charging environment.



(a)

Figure 9. - Typical particle trajectories.



(b)

Figure 9. - Concluded.