

SPACECRAFT ENVIRONMENTAL INTERACTIONS: A JOINT AIR FORCE  
AND NASA RESEARCH AND TECHNOLOGY PROGRAM

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A joint Air Force/NASA comprehensive research and technology program on spacecraft environmental interactions is being undertaken to develop technology to control interactions between large spacecraft systems and the charged-particle environment of space. This technology will support NASA/Department of Defense operations of the shuttle/IUS, shuttle/Centaur, and the force application and surveillance and detection missions, planning for transatmospheric vehicles and the NASA space station, and the AFSC military space system technology model. The program consists of combined contractual and in-house efforts aimed at understanding spacecraft environmental interaction phenomena and relating results of ground-based tests to space conditions. A concerted effort is being made to identify project-related environmental interactions of concern. The basic properties of materials are being investigated to develop or modify the materials as needed. A ground simulation investigation is evaluating basic plasma interaction phenomena to provide inputs to the analytical modeling investigation. Systems performance is being evaluated by both ground-based tests and analysis. An environmental impact investigation to determine the effect of future large spacecraft on the charged-particle environment is planned. Finally, spaceflight investigations will verify the results of this technology investigation. The products of this research and technology program are test standards and design guidelines that will summarize the technology, specify test criteria, and provide techniques to minimize or eliminate system interactions with the charged-particle environment. The investigation is coordinated by a Spacecraft Environmental Interaction Program steering committee, which will incorporate into this investigation the requirements of both the Air Force and NASA.

STEERING COMMITTEE

The functions of this committee are to coordinate all phases of the investigation, to review progress, and to direct changes, as required, to satisfy the needs of the Air Force and NASA. The committee will meet annually to

review the program, to resolve pending action items, to form working groups as needed, and to issue required action items. The minutes of these meetings will be issued.

The committee will report to the NASA/Office of Aeronautics and Space Technology, Air Force Space Command/DL, and AFSTC through the Science and Technology Interdependency Group.

The steering committee consists of the following members:

Co-Chairpersons: Charles P. Pike, Air Force Geophysics Laboratory (AFGL); and Carolyn K. Purvis, NASA Lewis Research Center

Members: Wayne R. Hudson, NASA HQ; Henry B. Garrett, JPL; A. R. Fredrickson, Rome Air Development Center; D. A. Guidice, AFGL; and Lt. R. Cull, Air Force Weapons Laboratory

The steering committee will form working groups as needed to review, plan, and coordinate investigations in specific areas, to recommend new directions as required, and to make periodic progress reports to the steering committee. The working groups will function to keep the various organizations, both those within the formal program and others, coordinated in their various activities. The chairperson of each working group is appointed by the steering committee and is responsible for selecting members of the working group from the technical experts of the government, industrial, and university communities.

#### JUSTIFICATION —

Missions using very large spacecraft are planned for the remainder of the 1980's and the space station is scheduled for operation in the 1990's. The missions are planned to initially use equatorial and low-inclination orbits and then move to polar and geosynchronous orbits. Typical missions are communications platforms and space-based radar. The Air Force/NASA Spacecraft Charging Technology investigation showed that environmental charged-particle fluxes can act on spacecraft surfaces and influence system performance. These new, larger spacecraft can have potentially serious interactions at all altitudes and these interactions must be evaluated. Because the proposed structures have dimensions larger than characteristic plasma lengths, differential surface charging is possible. The motion of such a large structure in the Earth's magnetic field will induce electromagnetic forces on the structure. Since these structures are designed for low-density materials, electromagnetically induced stress can affect the mechanical design.

There is also a trend toward high-power modules for space applications. Plans have been established for 25-kW modules in the late 1980's, expanding to 500-kW modules, possibly nuclear, in the late 1990's. At these power levels the operating voltages will most likely be higher than the present range of 30 to 100 V for greater system efficiency. This elevation of operating voltages means that interactions between the biased surfaces, including thermal radiators for high-power systems, and the plasma environment are more probable.

Laboratory tests on small solar array samples have indicated that possible interactions include the establishment of parasitic current loops through the environment (resulting in power losses), arcing at negative potentials, and

disproportionate current collection through holes in insulation to biased surfaces underneath. These effects can adversely influence the operation of space power modules and must be understood before building high-power systems.

There is a growing concern for the influence that the very large structures proposed for future applications can have on the charged-particle environment. This influence may significantly alter the interactions between the structure and the environment.

Testing larger quantities and greater varieties of materials, including prolonged exposure to the space environment, is needed to determine performance reliability for extended-duration missions. As spacecraft become larger and more expensive, the reliability of specialized materials might become the limiting parameter for missions. To improve reliability, the space environment must be well characterized and the material responses to that environment must be determined.

### OBJECTIVES

The overall objective of this investigation is to develop the technology for controlling or mitigating spacecraft system interactions with the plasma, particle, and field environment of space. The technology developed in this investigation will support proposed Air Force/NASA space mission concepts into the 1990's.

### APPROACH

The initial emphasis in this investigation will be on low-Earth-orbit (LEO) altitudes. The proposed missions will be cataloged, engineering specifications for the charged-particle environment established, and possible interactions identified. The ground technology investigation will concentrate on determining and modeling plasma phenomena and then extrapolating these results to system interactions and performance in space. Applicable techniques available to the participants will be used.

The environmental interactions for large systems operating in altitudes out to geosynchronous conditions will be evaluated after the LEO study. The geosynchronous environmental investigation will use the LEO study results as well as applicable techniques from the Air Force/NASA Spacecraft Charging Technology investigation. In both the LEO and geosynchronous environmental interactions investigations, the effect of large systems on the environment will be evaluated as well as the effect of the environment on system performance.

Spaceflight experiments will be conducted to verify the results of the ground-based technology investigation of the environmental interactions. These space experiments will be coordinated with the ground-based study.

### PRODUCTS

The output of this investigation will be a series of test standards and design guideline documents. These will be issued in a preliminary form early

in the investigation and upgraded as the study continues. The major milestones for this investigation are shown in table I.

## TASKS

For each element of this investigation, the approach is summarized and the known tasks identified. The agency or agencies responsible for directing and coordinating the work under each task are given. Although the primary responsibility is assigned to one agency, the expertise of other agencies will be used.

### User Requirements

It is necessary to identify those missions or projects that could benefit from the technology that will be developed by this investigation and to incorporate their requirements. This will be done by maintaining close liaison with government funding sources and project offices. Potential applications of the technology have been identified as

- (1) Polar shuttle
- (2) Space station
- (3) Multikilowatt space power systems
- (4) Large, high-power communications satellites
- (5) Large surveillance satellites
- (6) Scientific spacecraft

The primary interactions to be evaluated have been tentatively identified as

(1) Large space system interactions. These interactions involve the possible effects due to the motion of a large body in the space environment and due to material reactions to the charged-particle fluxes.

(2) Biased-system/charged-particle interactions. These interactions include spacecraft systems that generate or use high voltage exposed to space. Communications satellites and spacecraft systems using high-voltage space power modules fall into this category.

(3) Scientific instruments and sensor interactions. The effect of electric fields surrounding a spacecraft on the behavior of scientific instruments and sensors will be evaluated.

(4) Large structure interactions on the environment. The presence of the proposed large structures may affect the environment. Such effects must be evaluated.

(5) Enhanced-particle environment interactions. These interactions involve spacecraft sources of particles that can be ionized and increase the charged-particle environment around the spacecraft. Close coordination will be maintained with the existing Air Force/NASA Spacecraft Contamination Investigation.

(6) High-energy particle interactions. Penetrating radiation effects will be evaluated in this study only insofar as they can influence charging

phenomena (e.g., internal spacecraft charging and radiation-enhanced conductivity in materials). Close coordination will be maintained with other groups conducting radiation damage evaluations.

(7) Charging response of spacecraft materials. This response depends on some basic material properties - conduction, prebreakdown streamer formation, photoconduction, and polymer degradation. These and other pertinent material properties will be studied in relation to space environmental interactions.

The specific tasks and responsible agencies are listed here.

Task 1: coordination and overview. - Coordinating user needs and incorporating these needs into the investigation will be the responsibilities of the steering committee.

Task 2: Air Force and NASA contacts. - Each agency will maintain a close relationship with the projects it manages in order to determine user needs and will report those needs to the steering committee for coordination and incorporation into this investigation.

#### Environment Specifications.....

The natural environment will be investigated and engineering specifications generated or updated as appropriate. The effect of large spacecraft on the environment will also be investigated and evaluated.

Task 1: Earth environment specification. - The available data for the low-Earth-orbit plasma, particle, and field environment will be reviewed. An engineering specification for this region will be generated and made available to all parties concerned with environmental interactions. This work will be the responsibility of AFGL and JPL.

Task 2: planetary environment specification. - The available data for planetary environments will be reviewed. An engineering specification for these environments will be generated and made available to all parties concerned with environmental interactions. This work will be directed by JPL.

Task 3: enhanced spacecraft environment specification. - The available data on possible outgassing or other sources, including arc discharges on the plasma wake and sheath that can enhance the charged-particle environment, will be reviewed. An engineering specification for this enhanced environment will be generated and made available to all parties concerned with spacecraft environmental interactions. Close coordination will be maintained with the Air Force/NASA Spacecraft Contamination Investigation, which is principally concerned with particulate contamination, and related programs to avoid duplication. This work will be the responsibility of JPL.

Task 4: environmental impact. - Using the environmental specifications and the proposed plans for large spacecraft, the possible alterations to the natural environment due to the presence of the spacecraft will be investigated and evaluated. This work is currently unfunded but is included as it is perceived as a future area of concern to support environmental impact assessments.

## Materials Investigation

The basic properties of typical spacecraft materials exposed to the space environment will be determined, and new or modified materials will be developed. The specific tasks and responsible agencies are listed here.

Task 1: material property determination. - The classical properties of typical spacecraft materials will be determined as a function of the material parameters and environmental fluxes. The properties to be determined are those that influence the surface potential of the material (e.g., secondary emissions, backscatter, conduction, deposition, and photoemission). Electron, proton, and photon fluxes as determined by the environmental specifications are to be considered. This work will be the responsibility of JPL, Lewis, and RADC.

Task 2: new or modified materials development. - Materials having selective properties will be developed as a means of controlling detrimental effects of spacecraft environmental interactions. The required properties for these materials, including advanced composite materials, will be defined from the interactions studies. The materials will be developed and tested to show that they will meet the requirements. This task will be the responsibility of AFWAL.

## Ground Simulation Investigation

Existing facilities will be used to simulate the space plasma environment, and the interactions will be studied experimentally. The specific tasks and responsible agencies are listed here.

Task 1: basic interaction studies. - This task will be divided into several subtasks each devoted to the study of a particular aspect of the interaction phenomena.

(1) Biased-system/charged-particle interactions will be investigated. Here the emphasis is on identifying key parameters (voltage levels, material properties, geometry, plasma temperature and density, and magnetic field strength and direction) affecting the interactions, which include collection of currents from plasmas and arcing in the presence of plasmas. Interactions to be investigated include those between systems and both the natural space environment and the enhanced environment resulting from the presence of large systems. This work will be conducted by Lewis.

(2) Plasma sheath growth will be investigated. Interactions between large structures moving through the environment will be investigated. Plasma wake and ram effects and sheath growth will be evaluated. Responsibility for this work will be assigned as resources become available.

(3) Discharges resulting from environmental interactions will be characterized. Both radiated and conducted characteristics will be determined. This work will be coordinated by JPL.

(4) Penetrating radiation studies will be conducted to evaluate radiation-induced charging interactions. RADC will be the contact point for this work.

Task 2: studies of large, high-voltage power systems. - In this task the basic interaction study results from section 5.4.1 (table I) will be applied to the design of large power systems for space applications. The interactions will be scaled to the size of a typical large power system, the environmental conditions will be scaled from ground conditions to space, and the effects of the environment on system performance will be evaluated. Means of controlling detrimental interactions will be devised. Wherever possible, experiments will be conducted to demonstrate that the interactions can be controlled. This work will be conducted by Lewis for NASA missions and by AFWAL for Air Force missions. AFWAL will also investigate the interaction of various weapons threat scenarios with the space environment and solar cell power systems. After these initial studies component hardware will be developed, tested, and integrated into a complete modular power system. Primary interactions are expected with the solar cell array and the radiators - both high temperature ( $\geq 600$  K) and low temperature (300 K). Where necessary, spaceflight experiments will be developed.

Task 3: mitigation techniques. - The environmental interaction in large, high-power spacecraft can be mitigated by techniques such as active charge control devices. Techniques will be evaluated to determine the extent to which they will alleviate detrimental system performance. This work will be conducted by AFGL.

### Analytical Investigation

Models of physical processes and engineering design tools will be developed. Models of individual interactions will be developed to identify critical parameters. These will be incorporated into a general engineering analytical tool (or tools) to aid in designing systems to withstand detrimental environmental interactions. The specific tasks and responsible agencies are listed here.

Task 1: basic plasma phenomenological modeling. - The basic plasma phenomena necessary to evaluate environmental interactions with spacecraft systems will be modeled. These phenomena will include ram/wake velocity effects, plasma sheath effects, and magnetic field effects. AFGL and Lewis will coordinate the respective efforts.

Task 2: discharge modeling. - Empirical models of discharge phenomena will be developed. Radiofrequency characterization and discharge modeling as a function of material and ambient plasma will be carried out. The work will be coordinated by JPL.

Task 3: system level analytical models. - Analytical models will be developed to support the design of mission spacecraft for the 1980's and 1990's. These design tools will incorporate the interaction models developed in section 5.5.1 (table I) and will be capable of evaluating the effect of environmental interactions and of assessing the means of minimizing detrimental interactions. The following models will be developed:

(1) Large space structures. This model will evaluate the interactions between large space structures, including the shuttle, and the space environment. It will be developed by AFGL.

(2) Large, high-voltage power systems. This model will evaluate the interactions that result from the operation of high-voltage systems on spacecraft. It will be developed by Lewis

Task 4: charging modeling. - Analytical models and empirical data will be developed to determine the level of charging induced in spacecraft materials. The work will be coordinated by RADC.

## SPACEFLIGHT EXPERIMENT PLANNING AND EVALUATION

The results of the ground-based technology program must be verified in the actual space environment. To accomplish this, spaceflight experiments have been conducted and are planned. Close liaison will be maintained with the NASA Shuttle Project Office, the NASA Space Station Office, and the DOD Space Test Program Office to maintain cognizance of flight opportunities. At this time it is not possible to completely specify the number and types of experiments that will be required; they will be the logical outgrowth of this technology investigation as it progresses. Space experiments funding is not included in the agreement.

## DESIGN GUIDELINES AND TEST STANDARDS

Design guidelines and test standards will be issued and updated as this program develops. These documents will summarize the state of the art of the various interactions being studied. Guidelines to be used in designing systems for space applications and test criteria for verifying conformance will be delineated. All participating agencies will submit their contributions for compilation by the steering committee. Lewis and AFGL will be responsible for issuing the design guidelines and test standards.

## ORGANIZATIONAL RESPONSIBILITIES

### Steering committee:

- (1) Overall planning, coordination, and reporting of the investigation
- (2) Incorporation of user requirements into the investigation
- (3) Coordination of basic plasma phenomena modeling
- (4) Coordination of spaceflight experiment options
- (5) Conduct of annual meeting, issuance of minutes, and formation of working groups

### AFGL:

- (1) Air Force point of contact
- (2) Coordination for Air Force
- (3) Development of test standards and military standards
- (4) Natural environment engineering specifications and basic interaction analytical studies: wake and ram
- (5) Techniques for mitigating system-limiting effects
- (6) Analytical modeling of large space structures



**AFWAL:**

- (1) Development of new or modified materials
- (2) Studies and development testing of high-voltage, high-power systems

**RADC:** Study of effects of penetrating radiation and charging on materials

**NASA HQ:** Ensurance of environmental interactions technology responsible to NASA needs

**Lewis:**

- (1) NASA point of contact
- (2) Coordination for NASA
- (3) Determination of material properties
- (4) Issuance of design guidelines document
- (5) Conduct of basic interaction experimental studies: biased-system - charged-particle interactions
- (6) Analytical modeling of high-voltage system

**JPL:**

- (1) Specification of Earth and planetary environments
- (2) Determination of material properties
- (3) Conduct of basic interaction experimental studies: discharges
- (4) Conduct of analytical discharge studies
- (5) Formulation of enhanced spacecraft environment specification

TABLE I. - SPACECRAFT ENVIRONMENTAL INTERACTIONS MILESTONE SCHEDULE  
 [Fiscal years 1983-91.]

TECHNOLOGY ELEMENT OPR/TITLE	83	84	85	86	87	88	89	90	91
5.2.1/AFGL/Earth Env Spec	Δ		Δ					Δ	
5.2.1/JPL/Earth Env Spec			Δ					Δ	
5.2.2/JPL/Planetary Env Spec									Δ
5.2.3/JPL/Enhanced Env Spec				Δ				Δ	
5.3.1/JPL/Mat Prop Det			Δ		Δ		Δ		Δ
5.3.1/Lewis/Mat Prop Det	Δ		Δ			Δ			
5.3.2/AFWAL/Mat Dev		Δ	Δ Δ	Δ	Δ				
5.4.1/Lewis/Inter Studies	Δ	Δ		Δ			Δ		
5.4.1/JPL/Inter Studies		Δ		Δ		Δ		Δ	
5.4.1/RADC/Inter Studies		Δ	Δ Δ	Δ Δ					
5.4.2/Lewis/Power Sys Study					Δ			Δ	
5.4.2/AFWAL/Power Sys Study		Δ			Δ			Δ	Δ
5.4.3/AFGL/Mitigation Tech			Δ	Δ		Δ			
5.5.2/JPL/Dischg Model			Δ		Δ		Δ		Δ
5.5.3/AFGL/Analytic Tools		Δ	Δ			Δ			
5.5.3/Lewis/Analytic Tools			Δ				Δ		
5.6/AFGL/Space Flt Exp Plan & Eval		Δ		Δ		Δ	Δ	Δ	Δ
5.7/Lewis/Dcs Guidelines					Δ			Δ	
5.7/AFGL/PHL STD-Test Spec			Δ		Δ	Δ		Δ	Δ
COMPLETION						Δ		Δ	Δ