N89-23536

INFLUENCE OF CHARGING ENVIRONMENTS ON SPACECRAFT MATERIALS AND SYSTEM PERFORMANCE

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ENVIRONMENTALLY-INDUCED INTERACTIONS

The purpose of this paper is to present an overview of potential interactions that can occur on spacecraft operating in space environments. These interactions will be discussed in more detail in the accompanying papers.

The environment acts on spacecraft in such a way that charging of exterior surfaces occurs. The consequences from this charging then affect system operational performance. Hence, it is the coupling of this exterior charging to system performance that is of concern here. These interactions were first discovered in the spacecraft charging phenomena in which the geomagnetic substorms charged external surfaces to a level that discharges occurred. As a result of the discharge, electronic systems either changed logic state (anomalous switching) or failed.

These interactions can occur in all orbits. The type associated with geosynchronous orbits is called "passive" since the environment provides the charging mechanism (Reference 1). This type can also occur in polar orbits due to auroral charging environments. In low Earth orbits, the thermal plasma alleviates charging environment concerns, but system operations can induce similar effects ("active" interactions).

- o ENVIRONMENT ACTS ON SURFACE MATERIALS
  - RESULTS AFFECT SYSTEM PERFORMANCE
  - EXTERIOR SURFACE DISCHARGES COUPLE INTO ELECTRONIC SYSTEMS
- o INTERACTIONS OCCUR IN ALL ORBITS
  - ACTIVE: DUE TO SYSTEM OPERATION

    EXAMPLES: HIGH VOLTAGE OPERATIONS, EFFLUENT
  - PASSIVE: DUE TO ENVIRONMENT

    EXAMPLES: GEO AND POLAR-AURORAL CHARGING

GEO SUBSTORM CHARGING OF SPACECRAFT

This phenomena has been investigated for the past ten years (References 2-5). These studies have shown that there is a link between the exterior surface discharge and electronic system upsets (References 6, 7). The hazards with this spacecraft charging phenomena have been enhanced electrostatic contamination and plasma particle measurement disturbances. These studies have generated design guideline documents that provide guidance and suggested mitigation techniques (References 8, 9). The recommended mitigation techniques are to analyze to ascertain the extent of charging interaction, ground all exposed metallic surfaces to prevent discharge triggers, select minimal charging materials, filter sensitive system inputs, shield harnesses and control grounding techniques to minimize extraneous circuits. This document has been included in the revised edition of Military Standard 1541A (Reference 10).

- o HAZARDS ASSOCIATE WITH GEO SPACECRAFT CHARGING
  - DISCHARGES

    EMI, ELECTRONIC SWITCHING AND FAILURE, MATERIAL DAMAGE
  - ENHANCED ELECTROSTATIC CONTAMINATION
  - DISTURB SPACE SCIENCE MEASUREMENTS
- o MITIGATION TECHNIQUES
  - ANALYZE FOR CHARGING EFFECTS
  - GROUND EXTERIOR METALLIC SURFACES
  - SELECT MINIMAL CHARGING EXTERIOR MATERIALS
  - PROTECT INTERIOR SYSTEMS

    FILTER, SHIELD AND GROUND
- o INCORPORATED IN MIL STD 1541A

SPACECRAFT CHARGING IN FUTURE MISSIONS

The previous studies have resulted in the conclusion that the spacecraft charging issue has been settled. In the initial stages of the spacecraft charging investigation several companies claimed that "... there is no such thing as spacecraft charging, only bad design." These statements were wrong then just as this belief that all issues have been resolved is wrong now. The charging investigation covered only those materials and systems that were in use in the late seventies. The spacecraft of the future will not use those materials or systems. Charging anomalies arose because of the transition from relay to solid-state logic. This innovation reduced switching transients from long pulses at 15 volts to short pulses at less than 5 volts. The surface charging provided pulses which could switch and damage solid-state systems. The future missions want long mission duration at very high operating speed. In fact, the suggested operating speeds for future data buses correspond to the ringing frequency of todays standard structures. Hence, filtering is impossible. The future spacecraft will use new composites materials for structures. The behavior of these materials has not yet been determined. The only help that prior studies can provide is the recognition that the environment can cause interactions and that these must be assessed.

- FUTURE MISSIONS REQUIRE ADDITIONAL EVALUATION
  - ELECTRONIC SYSTEM SPEED INCREASING
    - OPERATIONS AT STRUCTURE RESONANT FREQUENCY
    - CAN'T FILTER OUT NOISE
  - MATERIAL SELECTIONS
    - COMPOSITE BEHAVIOR UNKNOWN
    - COATING SELECTION PROVIDENCE OF THERMAL DESIGN
    - LONG TERM AGING EFFECTS ON MATERIAL PROPERTIES UNKNOWN
- GUIDES EXIST BUT MAY NOT BE DIRECTLY APPLICABLE

LEO ORBIT INTERACTIONS

NASA is planning to build a very large Space Station* that will orbit at about 400 km. This Station will incorporate solar arrays that will generate 200 kw of power at a nominal operating voltage of 160 volts. This is the largest system yet conceived operating at a voltage larger than any previous satellite. This array voltage will determine the spacecraft floating potential relative to space. Whether or not this is serious has to be determined. Todays technology has trouble understanding its present data base of solar cell interactions obtained with 2 X 2 cm and 2 X 4 cm silicon cell segments tested only in limited areas of up to 1000 sq. cm. (References 11-13). The Station has baselined 8 X 8 cm solar cell for which there is no data on plasma effects.

The size of the Station also presents concerns for environmental interactions. There will be high voltage that may or may not be distributed over very large areas moving at orbital speeds through the Earth's magnetic field. The electronic systems must function at high operational rates. This Station is a complicated system and its interaction has to be understood in order to assure safe operations over the lifetime of the Station.

As complicated as the Space Station may appear, the SDI missions are far more complex. Here, the power levels rise to gigawatt levels which would be required instantaneously, anytime in their 10 year mission life. Clearly, this is a challenge to understanding complex interactions between space environments and spacecraft systems.

- o NASA SPACE STATION IN LEO
  - LONG MISSION LIFE (30 YEARS) AT HIGH POWER
    - 160 VOLT OPERATIONS
    - COMPLEX INTERACTION WITH ENVIRONMENT
- o TECHNOLOGY TO PREDICT BEHAVIOR UNPROVEN
  - NO LARGE SOLAR CELL DATA
  - NO LARGE STRUCTURE DATA
  - NO HIGH VOLTAGE DATA
  - NO LARGE COMPLEX STRUCTURE DATA
- o SDI MISSION AT HIGHER POWER LEVELS
  - VERY HIGH VOLTAGE PHENOMENA
    - EFFLUENTS FROM OPEN CYCLE OPERATIONS
    - LONG STORAGE TIME IN SPACE DIELECTRIC AGING

*Space Station Freedom

GROUND SIMULATION TECHNIQUES

Environmentally-induced effects have been studied in the past in ground simulation facilities (References 13-15). Such facilities allow a more complete testing of phenomena under controlled conditions. However, they suffer since they are normally poor simulations of the Earth's environment.

Geomagnetic substorm facilities normally operate with a monoenergetic electron beam irradiating a dielectric mounted on a grounded metal plate. Such tests can generate meaningful data on dielectric properties, but they can not be used to demonstrate space behavior. Floating or biasing the metal plate can be done, but this can influence the results.

Low Earth orbit simulation of the plasma environment also suffers in comparison to the actual environment. The space plasma temperature cannot be reproduced in chambers and the influence of the higher, ground simulation particle temperatures has not been determined. These facilities also limit the size of the sample that can be tested before the tank walls dominate the interaction.

Flight experiments provide the environment but the instrumentation is limited; the cost is high and the opportunities few.

The ideal situation would be to have the tools to model the interaction (engineering level as well as the more detailed techniques), conduct ground simulation tests to obtain needed information for the models, conduct flight experiments to validate the modeling technique and then use the models to predict the impact of the interaction on spacecraft systems behavior.

- SUBSTORM SIMULATORS
  - MONOENERGETIC ELECTRON BEAMS
  - SMALL AREAS EXPOSED
  - TANK GROUND POTENTIAL REFERENCE
- LEO SIMULATORS
  - POOR PLASMA ENVIRONMENT SIMULATION
  - SHEATH EFFECTS DOMINATE

    FACILITY SMALL FOR PROJECTED SPACECRAFT DIMENSIONS
  - EFFLUENT FLOW CONSTRAINED BY WALLS
- INTERPRETATION OF RESULTS DIFFICULT
- ANALYTICAL MODELING TECHNIQUES NEEDED
  - SUPPORTED BY GROUND AND FLIGHT EXPERIMENTS

SUMMARY

This paper is intended to present an overview of the possible interactions between spacecraft system and charging environment. Encounters with such environments have resulted in system upsets and failure in the past and it is naive to believe that future systems would be immune to these interactions. The state of the art is not as well developed as the technical community believes. All spacecraft interact with the environment, many have had system difficulties, but only a limited number of events have been reported. A program leading to an analytical modeling technique is required to ascertain the impact of interactions on system designs. This program must be supported by ground and flight experiments.

- SPACECRAFT SYSTEMS RESPOND TO ENVIRONMENTAL CONDITIONS
  - ELECTRONIC SWITCHING UPSETS, COMPONENT FAILURES AND MATERIAL DEGRADATION OCCURS
    - MOST SPACECRAFT HAVE ANOMALIES
    - FEW INCIDENTS ARE WELL-KNOWN
- FUTURE SPACECRAFT ARE LARGER, USE FASTER ELECTRONIC SYSTEMS AND HAVE LONGER MISSION LIFE
  - ANOMALOUS BEHAVIOR WILL INCREASE
  - TECHNIQUES FOR MITIGATION UNPROVEN
- DEVELOPMENT OF CONTROL TECHNIQUE REQUIRED
  - BASED ON UNDERSTANDING INTERACTION
  - DEMONSTRATED CAPABILITY TO PREDICT BEHAVIOR
  - DOCUMENTED MITIGATION TECHNIQUES

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