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On-Line Spacecraft Environment Interactions Information System

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EnviroNET is a computerized text type data base that provides rapid access to the latest information on a variety of space environments and spacecraft interactions of importance to understanding anomalies. Although originally intended as a design guide for Space Shuttle users, it has grown into a valuable resource of information on spacecraft charging and near-Earth charging environments. Included in the services is interactive modeling, some of which are also of interest for diagnosing anomalies. A more recent development is the on-line expert system for diagnosing anomalies. The expert system combines algorithms with expert heuristic knowledge, and uses confidence factors in variables and rules to calculate results with degrees of confidence associated with them.

Introduction

ENVIRONET is a NASA service facility that has several features that make it an attractive reference for articulating spacecraft anomalies. It includes on-line, dial-up technical information to explain environmental interactions with spacecraft in both low-altitude and high-altitude (including geosynchronous) orbits or payloads carried aboard the Space Shuttle and Space Station Freedom. Initiated at the request of NASA to provide a centralized computer-based depository of natural and induced space environments, the service also provides a capability for interactive graphics and modeling of space environments. These are for the most part based on measured and empirical data. Intended for use by scientists and engineers in the design and analysis of flight hardware, it is maintained current by NASA through cooperative efforts of industry, government agencies, the European Space Agency, academia, and the greater NASA community. Features of EnviroNET are summarized as follows: 1) centralized computer-based information on natural and induced environment; 2) based on measured data and empirical models validated by discipline panels; 3) used in the design and data analysis of flight hardware by scientists and engineers; and 4) maintained current by NASA through cooperative efforts of industry, other government agencies, European Space Agency, and the NASA community.

The information consists of expository text and numerical tables totaling about 2×10^6 characters (bytes), plus Fortran programs that model the space environment. This text is under continuous review, correction, and augmentation by 10 standing panels made up of technical experts in the respective environments. A list of the environments is shown in Table 1. The modeling effort is an ongoing effort based on the recommendations of the natural environment panel.

The EnviroNET network server is an IBM RS/6000. The RS/6000 is UNIX based to comply with the new requirement for an open system mandated by Congress. In the past, one of the most popular ways to access EnviroNET was through the Space Physics Analysis Network (SPAN).[1] SPAN is now considered a distributed component of the NASA Science Internet Project Office (NSIPO) at Ames Research Center. The net result is that connectivity to networks has been improved. In addition to the DECnet protocol, access can also now be made via the TCP/IP (Internet) protocol suite (Internet address 128.183.104.16), via Sprintnet (Telenet) or by direct dial at up to 9600 BPS through the Goddard Space Flight Center modem pool. Access through any of these means is available on a 24-h per day basis. NSI also interconnects with other national networks including Nsfnet, Esnet, and Milnet. We are approaching a superhighway for communications. File transfer is supported via FTP, Kermit, X modem or Z modem.

The on-line feature provides the opportunity for the space community to communicate, which facilitates the transfer of technology for mitigation of anomaly techniques due to the environment. In this fashion, the gap between the research and development community and those who need the developed methodologies is bridged.

Background

Early in the development of the Space Shuttle, payload planners recognized the need for a detailed picture of environmental impacts on Shuttle payloads. The extreme complexity and size of the Shuttle made it very difficult to characterize these environ-

Table 1 Current topics

Thermal and humidity
Vibration and acoustics
Electromagnetic interference
Loads and low frequency dynamics
Microbial and toxic contaminants
Molecular contamination
Natural environment
Orbiter motion
Particulate environments
Surface interactions

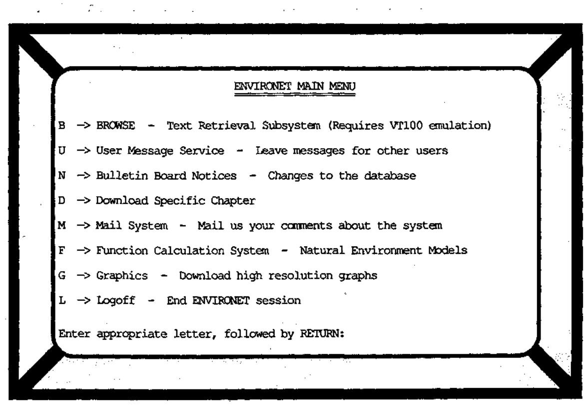

Fig. 1 EnviroNET main menu.

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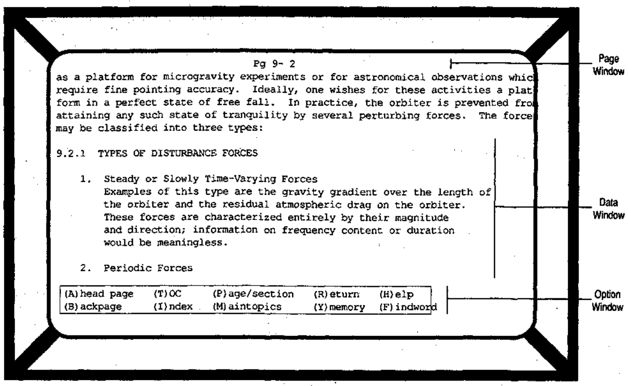

Fig. 2 Screen display showing "windows."

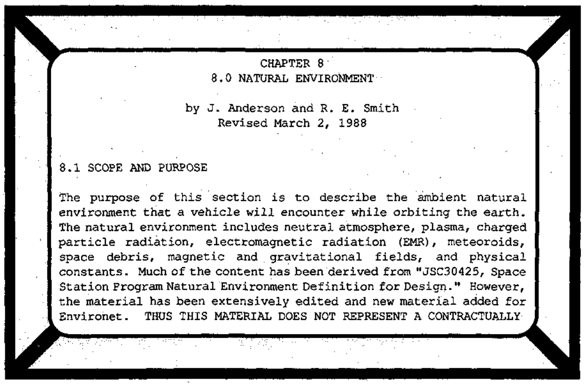

Fig. 3 Screen display for beginning of the natural environment chapter.

ments by computation. At the urging of the NASA payload community, the Shuttle program agreed to fly instruments (in early orbital flight tests) that would measure various elements of payload environment. In the fall of 1982, NASA conducted its first Shuttle environment workshop[2] to describe what had been learned from these measurements. This led to concerns voiced with regard to the need for information, on a continuing basis, about these and new concerns. To address the issues, NASA's Office of Space Science and Applications (OSSA) requested that a focal point be established for this environmental information, and that the activity be coordinated with other NASA centers, government agencies, and the user community. As might be expected, initial tests did not answer all of the questions and concerns raised by the payload community.

In mid-1983, the Shuttle Payload Engineering Division asked that Goddard Space Flight Center (GSFC) lead a NASA-wide effort to identify Shuttle environment data that could be used by Shuttle payload planners and developers. It also suggested that the data obtained from this activity be put into an electronic data base that could be accessed by any interested user. As a consequence, a multicenter Shuttle environment working group was organized through the efforts of OSSA and GSFC, with the working group establishing the charter and framework within which this group would function.[3] In due time the system became operational and with the communications advantage of SPAN, the growth has been steady world wide. The name EnviroNET was coined to relate to environment data on a network. With passing time it became obvious that EnviroNET should expand its data base to include application to spacecraft environment.

Browse

The main-menu system[4] that controls the EnviroNET activity is frequently updated in response to user suggestions and changing needs of the data base activity. This main menu (Fig. 1) allows one to run Browse, access the data files, download graphics and text, send mail to the system manager, read bulletin board notices, use the models, or exit the system. Browse is the name of the principal retrieval program. With Browse, simple command choices allow one to page through the EnviroNET data base sequentially or jump to points of interest. To use Browse, one must have a VT100-compatible terminal or emulation. Browse has three menus: main topics, data, and table of contents/index. One can move among the three menus to any part of the data base, or back to the EnviroNET main menu with a single keystroke. As you Browse about the data base and change menus, the information on the terminal screen will change, but the basic layout of the screen will remain the same. Information is displayed in three "windows": the page window at the top right, the data window at the center, and the option window at the bottom (Fig. 2).

Spacecraft Anomalies

The main topical areas appropriate for application to spacecraft anomalies are found in the chapters on the natural environment (Fig. 3) and surface interactions, respectively. A short summary of these chapters is presented in the following sections.

While orbiting the Earth, spacecraft encounter an environment that varies with time and location. As an aid to understanding anomalies it is important to be knowledgeable of this environment, in both its natural and induced aspects. This chapter includes tutorial information, theoretical and empirical models, measurements, and predicted conditions for the natural environment.

The neutral atmosphere is described in terms of composition, variation with time and geomagnetic activity, computer models, and predictive data for solar radio flux (F10.7) and the index of average daily geomagnetic activity (Ap). The chapter also covers plasma and the penetrating charged particles (trapped radiation and cosmic rays) that can cause damaging single-event upsets in semiconductors. Meteoroids and man-made space debris are also covered. The chapter also includes sun-Earth physical constants relating to gravity, pressure, and thermal radiation. It is important to note that many of the natural environments discussed in EnviroNET are strong functions of time, varying with the solar cycle and the strength of the Earth's magnetic field. For example, attempts are made to provide, wherever possible, specific instructions to the user on what is actually required and information on possible sources where day-to-day data are required.

Figure 4 shows the documentation on the Mass Spectrometer Incoherent Scatter (MSIS) model, a major code for predicting the neutral atmosphere. Figure 5 illustrates a user friendly screen display for the 1986 MSIS model.[5] The boundary conditions at the top are shown as input parameters. The output shown on the right is blank until the computer is asked to run the model (R) with keyed in values. In this part of the EnviroNET, the user can thus obtain estimates of the atmospheric density and temperature from the MSIS model. Such information would be valuable for drag calculations or estimating atomic oxygen erosion. Note, in particular, this capability of EnviroNET to provide graphical output in quasi-real time. For spacecraft charging studies, it is planned to add

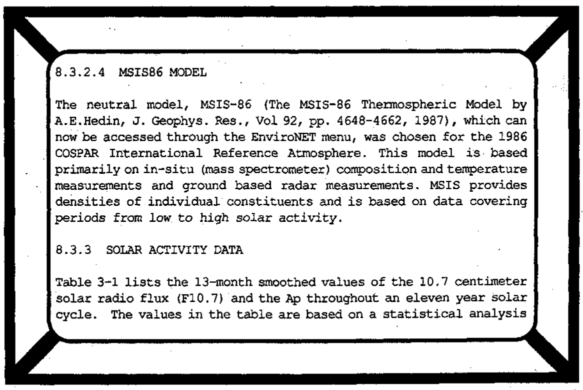

Fig. 4 Example of text on MSIS model in the natural environment chapter.

models of the geosynchronous plasma and of the aurora that can be used to estimate the currents to the vehicle in these environments. Currently available is the International Reference Ionosphere[7,8] (IRI) model which is required for computing charging at low altitudes. As in the case of MSIS, help screens, a program description, and plotting capability are available.

The spacecraft surfaces can also contribute to anomalies. The principal interactions with spacecraft surfaces discussed in this chapter are surface charging, $V \times B$ induced currents, high-voltage surface interactions, and ram/wake plasma variations.

These interactions are reviewed, sources of data identified, and future experiments recommended. The effects of these interactions are cataloged and potential solutions presented. Evidence from Air Force experiments on the Defense Meteorological Satellite Program (DMSP) have indicated that potentials as high as 1 kV may be observed in the auroral zone at low Earth orbit; hence, the justification for including spacecraft charging in the EnviroNET. $V \times B$ effects are probably the least serious of the "spacecraft charging" interactions included in EnviroNET. In addition to the sections on charging, $V \times B$, ram/wake effects, and high-voltage interactions, EnviroNET provides an additional service. Under the subsection on oxygen erosion, EnviroNET has stored up-to-date oxygen erosion rates for most common spacecraft surfaces. This information is critical in the selection of surface materials for charge control. Materials subject to rapid oxygen erosion should not be used for conductive outer coatings.

Cosmic Ray Effects on Microelectronics Model

For prediction of single event upset rates, the Cosmic Ray Effects on Microelectronics Model (CREME)[9–11] is available on line. CREME consists of a number of submodels, some of which require data files generated by other submodels. For example, if one wishes to consider the effects of trapped protons, one must first run GEOMAG and STASS. The CREME submodels are SPEC, which outputs the differential and/or integral energy spectra for a single element; LET, which outputs the differential and/or integral linear energy transfer (LET) spectra for a range of elements; Bendel, which outputs the upset rate due to nuclear reactions caused by protons; UPSET, which outputs the upset rate from directionization from particles outside the spacecraft; GEOMAG2, which computes the geomagnetic cutoff transmission function for a given orbit; and STASS, which is a user-produced input file of trapped proton energies (10 MeV and above) with corresponding fluxes.

Tsyganenko Geomagnetic Model

One of our newest graphic programs is an interactive model of the interaction between the solar wind and the Earth's magnetic field, which causes the magnetic field on the night side of the Earth to stretch into a very elongated structure known as the magnetotail.[12] A thin plasma sheet bifurcates the magnetotail which extends over 1000 Earth radii parallel to the flow velocity of the solar wind. The model computes Cartesian solar-magnetospheric components of the magnetic field produced by the extraterrestrial

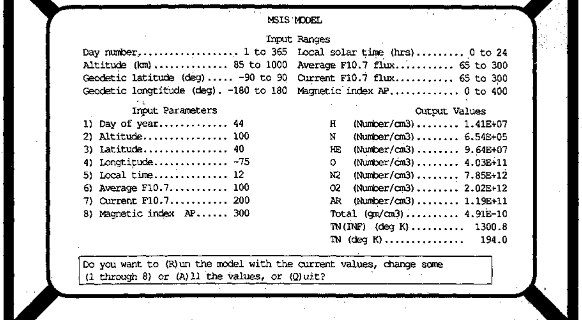

Fig. 5 User-friendly computer display for MSIS model.

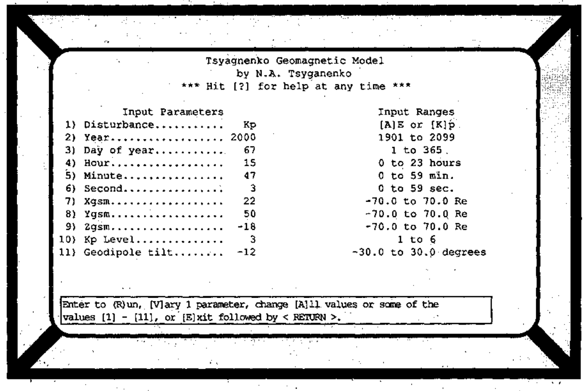

Fig. 6 User-friendly computer display for the Tsyganenko geomagnetic field model.

magnetic field in the range of distances from 1 to 70 Earth's radii (Re = 6371.2 km). This magnetotail stores magnetic energy that is converted from the interaction between the solar wind and the Earth's magnetic field. Magnetic substorms are created when the capacity to store this energy is exceeded. When this happens, substorms are produced that inject an energized plasma (5–20 keV) toward the Earth. This hot plasma can extend into geosynchronous orbits as a threat to charging of spacecraft. Figure 6 illustrates the screen display for the Tsyganenko model.

Updating EnviroNET

EnviroNET is a living system. This system includes much conventional text documentation, as well as computer-residing electronic text, and computer-based tools that both are being continually added to, as well as being refined. Thus, workshops are conducted periodically for the panel leaders and subpanels. The results of these workshops are printed as informal documents for the purpose of feedback of information essential to the improvement of the services to users. These documents are available upon request. As an example of this process, at the miniworkshop held by the Natural Environment Panel, recommendations were made to add models that would generate energetic electron and proton environment values for a point in space, calculate orbital integrations of particle fluence, provide magnetic field traces, and calculate ionospheric parameters. By adding orbiting programs to these models, the system will eventually simplify mission analysis for system engineers. A workshop held on environmentally induced spacecraft anomalies provided the nucleus of a coordinated effort for government agencies to address anomalies. Participants in the meeting included representatives from government and military labs, industry, and various weather services. Future plans include being a host for some of the historical data collected by the National Oceanic and Atmospheric Administration Anomalies Data Center. It is envisioned that if quasireal time data showed a potential problem (i.e., magnetic storm, proton event or x-ray flare) then the owner, user, or operator of the vehicle could access EnviroNET to see if it fits a previous pattern.

Development of an On-Line Expert System

The expert system for diagnosing spacecraft anomalies developed by the Aerospace Corp. for a personal computer using a Texas Instruments commercial expert shell[13] was handed off to EnviroNET to develop an on-line version.[14] NASA's C Language Integrated Production System (CLIPS)[15] was selected for development of the inference engine. CLIPS is compatible with both C and Fortran languages, and it has features which include the ability to compile rules and save them in a binary image file, thus allowing faster execution than a typical rule interpretive system. This feature qualifies CLIPS to be used as an expert shell, i.e., an environment where the rules can reside, be accessed, and manipulated. This system provides an effective method for saving knowledge, allowing computers to sift through large amounts of data, homing in on significant information. Most importantly, it uses heuristics in addition to algorithms, which allow approximate reasoning and inference and the ability to attack problems not rigidly defined.

The system output was verified by referring to historical case studies and historical data. The architecture of the system was designed to emulate the way the user normally looks at data to diagnose anomalies. Not only does it consolidate expertise in a uniform, objective, and logical way, but it also offers "smart" ways of accessing various data bases that are transparent to the user. Then by applying various rules in its knowledge base, the system can be queried, as appropriate, to arrive at a conclusion.

We have improved this system by porting it to the RS/6000. With the increased speed and the use of X Windows, the system features have been enhanced. For example, with X Windows the user could have one query window that prompts him/her for information, another separate window that displays which rules are being tested and fired, another showing that variables are being searched for, and yet another window for graphics. With these multiple windows the user can see the entire system working at once and be freed from having to change windows to see system information. The EnviroNET expert system combines the algorithmic capabilities of mathematical programs and diagnostic models with expert heuristic knowledge and uses confidence factors in variables and rules to calculate results with degrees of human confidence associated with them. Since the causes of environmentally induced spacecraft anomalies depend not only on algorithms, but also on environmental conditions, rules and information can rarely be known with 100% certainty. Based on present experiences, the role for the expert system is for either quasireal time or postanalysis. Because this program is still in a developmental state, it is available on-line only to privileged accounts of users interested in contributing to the program or interested in testing it.

Conclusion

Currently, a collection of validated working tools indigenous to spacecraft environment modeling are provided and more are being added as they become developed. The system endeavors to give visibility to the community working in this field. Although our ability to predict the environment to forecast satellite anomalies is a goal that is yet to be accomplished, a framework exists within which the development of such ways could be carried out. EnviroNET is providing substantial services for those interested in understanding and overcoming spacecraft anomalies.

Acknowledgments

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