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PLASMA AND ENERGETIC ELECTRON ENVIRONMENT AND EFFECTS

STATEMENT OF WORK

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1. Introduction

Most space missions need to cope with complex problems caused by the space environment. One aspect of this environment is the ambient plasma whose most hazardous component is electrons of medium and high energies which give rise to surface and internal electrostatic charging of spacecraft materials. Although much work has been done in attempts to make spacecraft safe from these effects, the continued occurrence of environmentally-induced anomalies on spacecraft and the expected increasing sensitivity of future ESA spacecraft, sometimes in very harsh orbits, means that we are not close to a solution of problems in this domain. Although efforts have been made at developing modelling capabilities for interaction predictions, the application of these in a real engineering environment is difficult: tools often lack validation by ground or space experiment, often operate with poor knowledge of input parameters and often contain simplifications to make problems tractable. Many problems in spacecraft charging investigations are related to lack of experiment/flight data.

The present study is directed towards the analysis of the actual environment at the origin of electrostatic charging on satellite surfaces and within dielectric materials and anomalies. The ability to determine what constitutes a hazardous environment and its probability to occur, and how data from different sources can be applied to predict anomaly or anomaly occurrence will also be investigated. This will include actual environmental data analysis, development of data processing tools and recommendations for the next generation of simulation tools dedicated to the effect of the plasma environment analysis.

2. Objectives

The principal objectives of this activity are to improve our current knowledge of the high energy electron environment as it is actually experienced by spacecraft, to check the validity of the existing tools and to prepare for the next generation of tools that would be able to take into account plasma effects for post-event analysis of anomaly events, spacecraft operations and mission analysis.

The work is divided in three equally divided parts: (i) Analysis of Freja charging data, (ii) development of an anomaly risk forecast system and (iii) tools development in geospace modelling and prediction.

2.1 Analysis of Freja charging events.

The Freja satellite is a scientific satellite on a polar elliptical orbit with apogee:1760 km, perigee: 600 km and inclination: 63 degrees. In several occasions it experienced high level negative charging (i.e. < -100 V). The satellite was equipped with many detectors for plasma measurements: e.g. electrons from a few eV to several keV, static and wave electric potential and fields. This therefore represents an exceptional opportunity to perform a detailed analysis of the charging process and to study in situ the associated plasma and electrostatic environment.

The output of this study should be particularly useful for ESA forthcoming missions since the environment at high latitudes, where freshly energized particle injections are a common occurrence, is still little documented despite the growing interest for orbits going through this region. Three work packages are devoted to Freja charging events. These include the detailed analysis of a sub-set of charging events, the construction of a statistical compendium of the charging environment and the comparison with the prediction of charging codes currently used at ESA.

2.2 Spacecraft anomaly forecast system.

Recent studies have shown that a large number of spacecraft anomalies are primarily driven by energetic electrons (in the energy range: 30 keV to 1 MeV) that can penetrate deep into dielectric materials and accumulate over several days. The role played by the other environment components, e.g., lower energy plasma, in the discharge triggering and propagation phase, though not elucidated yet, is thought to be nevertheless significant.

An index determining the risk of anomaly occurrence will be useful for spacecraft operators in order to avoid risky operation (e.g. thruster firing) when the anomaly risk index is high, or for users and customers to whom a quality coefficient determining a priori the risk of errors can be provided.

Given the difficulty for physically based tools to take into account the full complexity of the spacecraft systems and their interaction with the plasma environment, one possible approach is to rely on the use of space-based sensors coupled with non-linear filtering techniques to provide for such an index. In this way, service outage could be anticipated and efficiently coped with.

The method proposed is to train a neural network to predict one or several kinds of anomaly occurrence based on environmental data measured on-board or by other systems. The advantage of such a technique is that it should automatically capture the specificity of each system while avoiding any detailed modelling work. Three work packages are devoted to this study. Two of them are feasibility study via the simulation of the prediction of actually observed anomaly, either based on on-board sensor only or based on several space or ground environmental data sets. A last work package is devoted to the development of a small environment effects monitor able to provide for such an anomaly index.

2.3. Global Space Plasma Modelling Programme

Another approach to spacecraft plasma environment analysis is similar to the one used in aeronautics and that relies on weather forecasting and is therefore known as space weather.

The space plasma environment conditions leading to electrostatic charging are very variable in space and time. The present knowledge of the processes governing the dynamics of the plasma environment allows in principle to deduce, with a reasonable accuracy, the plasma conditions prevailing at a given position and a given time from "a few" input parameters that are currently monitored by spacecraft and ground based observatories.

Such a modelling capability would be useful for several purposes:

- (i) post-event analysis (to check, in the absence of an on-board plasma monitor, whether plasma processes or charging was at the origin of an anomaly);
- (ii) mission planning (one may, for example, determine the statistical occurrence of various potentials over a mission duration in order to assess the risk occurrence of anomaly and the contamination level due to charged contaminants);
- (iii) mission operations (if real-time simulation are possible, one can check whether a spacecraft is likely to be charged to such a level that critical operations like thruster firing should be avoided); In addition the dynamic model can be developed such as to simulate with more or less accuracy the dynamics of the cold plasma regions (ionosphere and plasmasphere) this would improve the surface charging prediction (since cold plasma is known to inhibit charging) but also will have application for
- (iv) radio-wave propagation effects.

Such programmes are currently under development in the US and in Japan. It is, however, not yet supported by any organisation in Europe. Three work packages are devoted to the first steps in the preparation of such a programme. This includes a review of the state of the art in space weather modelling an investigation including recommendations for a rationalized development of this activity in Europe, and the development of prototype tools for data set fusion based on the HTML language on a WWW server. Recommendations for the modular development of a magnetospheric simulator will also be provided in the form of a User Requirements Document.

3. Work Packages:

The detailed requirements are given below. For all work packages Technical Notes shall be produced, describing the background and methods used, and reporting the results.

3.1 Analysis of Freja charging events

WP.1.1 Charging events identification and case study of a subset of them

The contractor shall perform an extensive survey of the Freja data over a significant period of Freja life time (to be agreed with ESA) such as to cover the full altitude range and to gather enough charging events for a statistical study.

The contractor shall perform a detailed analysis of several Freja charging events (at least 10 events) preferentially including the lowest and the highest altitude observed events. This shall include at least a precise description of the electron and proton energy distribution and the lighting condition. The density of the cold plasma population which is a determinant parameter and which was not convincingly determined in previous studies, e.g. with, e.g. DMSP satellite, shall be accurately determined. The electrostatic environment shall also be properly characterized (e.g. identification of electrostatic potential barrier). Comparison with published information on ARCAD satellite which did not experience charging shall be performed. The relevant raw data and processed data shall be gathered in a data base which shall be delivered to ESA along with processing and access software. A Technical Note shall be prepared on the results of this work package.

WP.1.2 Comparison of the observation with the prediction of spacecraft charging codes

The contractor shall select a few of the charging events identified in WP.1.1 in agreement with ESA and make use of them as input to two spacecraft charging software available at ESTEC, NASCAP and POLAR, in order to test their ability to reproduce the Freja charging events. If the contractor does not possess the latest versions of one or both of these codes this study shall be done using ESTEC's versions either remotely or during a stay at ESTEC at the contractor expense.

This study requires a good knowledge of the materials used on the spacecraft surface. The relevant material properties (e.g. photo-emission rate, secondary electron emission shall be measured at the contractor expense when necessary). Changes of material properties after exposure to the space environment that may make useless the measurement of some of the material properties on ground shall be discussed and assessed (for instance by the measurement of the floating potential of the satellite with respect to other floating elements).

As an output to this study, the contractor shall provide a detailed list of the materials used on the spacecraft and of their characteristics relevant to the charging behaviour. He shall also make recommendations for improvement of the charging tools. In agreement with ESA the contractor shall develop prototypes to elucidate these points. A Technical Note shall be prepared on the result of this Work Package. It shall contain as a minimum:

- a detailed list of the materials used on the spacecraft and of their characteristics relevant to the charging behaviour;
- an analysis of the result provided by the simulation tools including a critical review of these tools aiming to identify their limits and shortcomings;
- the documentation related to the prototype developments.

WP.1.3. Statistical occurrence of charging events.

The contractor shall perform a statistical study of the distribution of the charging events and of the associated charging environments identified in WP.1.1. This shall include several entries such as the geomagnetic location, and some large scale geophysical parameters like Ap, Kp and the solar wind Bz the choice of which shall be made in agreement with ESA.

The output of this Work Package will be a database deliverable to ESA along with processing and access software. A Technical Note shall be prepared on the result of this Work Package.

3.2 Development of Spacecraft Anomaly Forecast Systems

The purpose of the three following work packages is to assess the probability of an anomaly in a given environment and the possibility of predicting the hazardous environment.

WP.2.1 Simulation of the prediction of spacecraft anomalies with on-board and/or local measurements

The contractor shall make use of an available anomaly data set together with the corresponding environmental data measured on the same satellite (including at least high energy electron measurements, i.e. > 100 keV, and, if possible, the orientation with respect to the sun). The data set shall be chosen in cooperation with ESA. A neural network shall be designed and trained to predict in advance. The probability of anomaly occurrence will be investigated using several time lags ranging from a few minutes to several days. ESA can provide the anomaly data set and the data environment of METEOSAT-3 satellite.

A technical note shall be produced as a result of this work package. It shall contain a description of the anomaly data set and of the environmental data set, a justification and a complete description of the training procedure, possible pre-processing of the input parameters and all other information necessary to reproduce the training procedure of the neural network. The final software consisting of the trained neural network shall be fully documented and delivered to ESA.

WP.2.2. Simulation of spacecraft anomalies forecasting with non-local measurements

Forecast of spacecraft anomaly using environmental data other than the ones measured onboard may provide information not easily accessible from local measurements alone. There is, however, a risk that such non-local data are only weakly related to the local environment giving rise to anomaly. The purpose of this work package is therefore to assess the quality of a forecast system of spacecraft anomaly making use of non-onboard measured data. The great interest in such a system is that it may be applied to provide a single anomaly risk index available for all spacerafts provided that most of the anomaly on spacecrafts are basically related to the same severe environments.

The contractor shall identify sources of data that are measured routinely, e.g., GOES particle data, geomagnetic indexes. The contractor shall make use of these environmental data, after agreement with ESA, to train a neural network to predict the risk of occurence of the spacecraft anomalies selected for WP.2.1 from the knowledge of the routinely measured environmental parameters, i.e. excluding onboard monitored data. This trained neural network will also be tested on one or several other spacecrafts anomaly data (to be agreed with ESA) in order to assess the generality of the forecast system.

A technical note shall be produced as a result of this work package. It shall contain, as in WP.2.1, a justification and a complete description of the training procedure, possible pre-processing of the input parameters and all information necessary to reproduce the training procedure of the neural network. The contractor shall discuss the possibility of using the neural network based forecast system trained on non-onboard measured data to produce an index assessing the risk of anomaly occurence on spacecrafts.

WP.2.3. Simulation of spacecraft anomalies forecasting with heterogeneous data sets

The purpose of this work package is to assess the efficiency of the forecast of spacecraft anomaly making use on a combination of both onboard and non-onboard measured data.

The contractor shall use some of the non-onboard measured data previously identified in WP.2.2. (in agreement with ESA) in combination with the on-board data of WP.2.1 to improve the neural network based forecasting system of the risk of anomaly occurence.

A technical note shall be produced as a result of this work package. It shall contain, as in WP.2.1, a justification and a complete description of the training procedure, possible pre-processing of the input parameters and all information necessary to reproduce the training procedure of the neural network. Based on the results of WP.2.1 and WP.2.2 and on a review of the literature on spacecraft anomalies the contractor shall also make recommendation for the development of onboard space environment monitors for anomaly prediction purposes. An approach based on the improvement and/or extension of existing ESA-sponsored space environment monitors (e.g., REM, SREM) shall be considered. Documention on REM and SREM will be provided by ESA at the start of this work package.

3.3 Global space plasma modelling and prediction

WP.3.1. Review of the state of the art in space weather modelling

In this work package, the contractor shall prepare a review of the state of the art in space weather modelling and forecasting. This shall include as a minimum:

- An analysis of the impact of the solar-terrestrial relations on space systems
- A review of the current modelling capabilities for the relevant space plasma and energetic electron environments and associated disturbances (e.g., geomagnetic storms and sub-storms).
- An analysis of the end-user requirements and of the implementation physics requirements for modelling improvements and a careful evaluation of the physics based limits of the predictibility of the space plasma environment.
- An analysis of the practical aspects for improvement of space weather modelling, e.g., data and observation tools requirements, software requirements.

The contractor shall prepare a technical note on this study. The contractor shall elaborate on the specific European capabilities in this field including recommendations for a rationalized development of this activity in Europe. The contractor shall also make suggestions for space weather studies making use of Cluster and Soho data.

This work package shall start at the kick-off of the contract.

W.P.3.2. Requirement for modelling tools for space weather programme

The contractor shall analyse the requirements for the development of computational tools for a space weather programme. Special emphasis shall be put on the possible prediction of the hazardous electron environment driving surface and deep dielectric charging. The purpose of this tool would be to derive the local environmental parameters known to be critical (e.g. plasma density and high energy electron fluxes between a few hundred eV to a few hundred keV) at any point in the inner magnetosphere from the input of parameters measured at other points in space (or planetary-averaged) and/or in time. This last tool must be primarily dedicated to the research of the cause of spacecraft anomalies by making it possible to assess whether or not hazardous environmental conditions were likely to exist at the time and place of a given anomaly, on the basis of partial, non-local measurements possibly including solar parameters. The output of this Work Package shall be the User Requirements and the Software Requirements Documents for the tools needed for the Space Weather Programme.

WP.3.3. Development of an easily accessible information server to coordinate in space weather forecasting and resources within ESA community and world-wide

As a purpose of illustration of the meaning of space weather programme, the contractor shall develop both at his premises and at ESTEC a WWW server providing information to any potential interested user of space weather. As a minimum this shall contain:

- detailed information on the existing European resources;
- pointer to other space weather servers (including non-European);
- means to retrieve basic data necessary to assess some of the anomaly risks (e.g. GOES data on high energy electrons);
- an anomaly data base based on data from this contract that can be consulted and updated remotely (e.g. by spacecraft project personnel at ESA);
- documents produced in this study (e.g. Technical Notes);
- any other items agreed between the contractor and ESA.

The software components for the WWW implementation shall be agreed with ESA. The software documentation and the resulting HTML pages are deliverable to ESA. The WWW server and the HTML pages shall be kept operational for two years after the end of the contract. During this period all changes of the HTML pages on the server shall be made in agreement with ESA and delivered to ESA under the conditions described section 5., Software Development. The activities related to the development of the WWW server shall be initiated at an early stage of the contract and shall run in parallel with the main research activities.

4. Management

The standard requirements for Management, reporting Meetings and deliverable (Appendix 3 to the contract) shall apply to the present activity, taking into account the following specific requirements, which shall prevail.

4.2 Reporting

Detailed technical notes shall be produced for each work package. Draft technical notes shall be provided to ESA, allowing for at least a 1-week review period.

4.3 Deliverables

- Para. 4.1.1 is not applicable.
- Para 4.4 is not applicable.
- Computer programs: All software and data bases developed or modified under this contract, together with the associated documentation, shall be delivered. Delivered software and associated documentation shall be guaranteed for a six-month period following the date of the final presentation.
- Further data, documentation, computer output, plots, graphs or drawings acquired or produced during the course of the contract shall be identified and kept available to ESA.

4.4 Commercial evaluation: not applicable.

5. Software Development:

All developed software shall conform to ESA Software Engineering standards as defined in the section ‘Applicable and Reference Documents’. Programming shall be performed either in ANSI Fortran-77 or Fortran-90 or in C. The target computer system shall be either a DEC-Alpha running the VMS operating system, a HP station running HP-UX operating system or a SUN station running Solaris system, linked to the Internet networks. The PV-Wave, IDL, HTML analysis and graphics packages may be used in parts of this work agreed with ESA.

Final versions of all developed software shall be installed at ESTEC by the Contractor at the time of the final presentation when a detailed instruction course of 1 day duration shall also be performed. Draft software developed shall be installed at ESTEC by the Contractor at the time of completion of each respective work package, when similar training of 1 day duration shall be given. As part of the software engineering process for each work package, software test plans shall be prepared by the Contractor and approved by ESA.

6. Applicable and Reference Documents:

The parts of document ‘ESA Software Engineering Standards’, ESA PSS-05-0 Issue 2, February 1991 concerning the production of URD, SRD and ADD documents shall apply, with the restriction that URD and SRD can be merged in one single document.