Development of the Spacecraft Plasma Interaction Guidelines and Handbook

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Abstract

As part of ESA's programme to develop European capabilities in the field of spacecraft plasma interactions, a project is under way to develop a repository of useful information for spacecraft plasma interactions. This project is derived from and complementary to the development of an ECSS standard on spacecraft charging. Whereas the ECSS document is a quasi-legal document, the 'Guidelines and Handbook' is intended to be more readable and user-friendly and with wider scope. It is intended to include important design requirements and guidelines from the ECSS document and elsewhere. In addition, it collects together useful equations and tabular information from the general literature. These are often presented as figures for greater clarity. One goal is to show the ways in which requirements can be satisfied for common circumstances. The document also directs readers to relevant computational tools and laboratory facilities, so that more detailed investigations can be carried out. Through this it aims to promote the use and sharing of resources in Europe.

The contents include: general plasma parameters, spacecraft sheaths and wakes, tethers and electric propulsion, surface charging, internal charging and solar array effects.

The Guidelines and Handbook will exist in two forms; a hardcopy text and graphics version and an interactive electronic version. The content of both versions will be the same except that equations and figures of the text version will be able to be solved and dynamically generated in the interactive version. The emphasis is the rapid calculation of simple formulae.

Introduction

ESA has, for several years, sought to improve the knowledge and treatment of spacecraft plasma interaction issues through a number of projects. These have been co-ordinated through the mechanism of SPINE – the Spacecraft Plasma Interaction Network in Europe (http://dev.spis.org/projects/spine/home/). Through regular workshops, cross-fertilisation of ideas can occur and members of the scientific and applications community can hear about progress in a number of projects and influence the direction of future work. Current ESA-sponsored projects are shown schematically below.

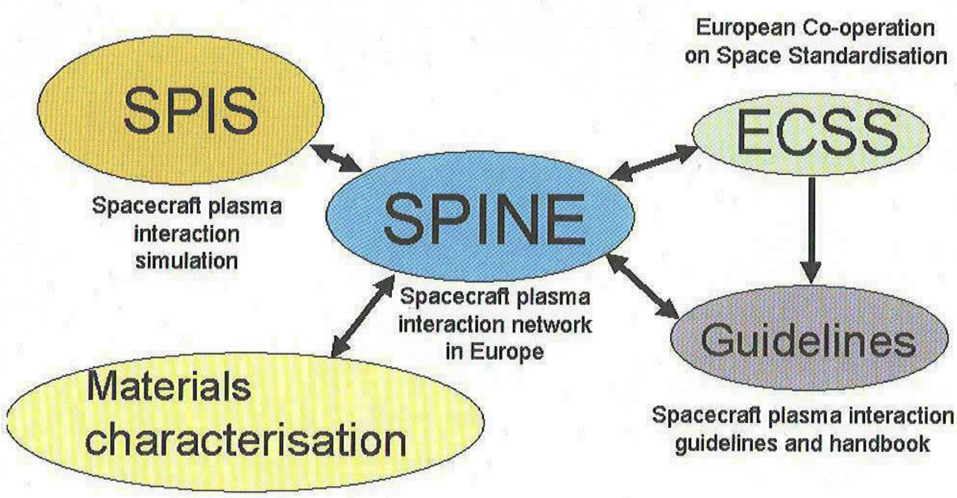


Figure 1 Schematic view of the interaction of ESA projects through SPINE.

Here, we describe in more detail the aims and outline of the ECSS-E-20-06 standard on spacecraft charging (subtitle: Environment-induced effects on the electrostatic behaviour of space systems) and the 'Spacecraft Plasma Interaction Guidelines and Handbook' (hereafter called the Guidelines and Handbook).

ECSS-E-20-06

ECSS, or European Cooperation on Space Standardisation (http://www.ecss.nl), is a joint initiative between ESA, European national space agencies and European space industry. It has the goal of progressively establishing a system of standards covering all aspects of space system development and operation, broadly divided into the fields of engineering, management and product assurance. It aims to improve the efficiency and quality of the procurement and engineering processes associated with space systems development and operation and to improve the competitiveness of European space industry. Under the framework of electric and electronic engineering standards, the E-20-06 standard has been under development to cover spacecraft charging and other spacecraft plasma interaction effects. During the drafting phase it has been made visible to European industry and has benefited from the feedback thus generated. At the present time it has completed the initial drafting phase and is about to be submitted for review by the ECSS authorities with the aim of adoption later in 2005.

This standard aims to provide a clear and consistent guide to the application of measures to assess and avoid/minimise hazardous effects arising from spacecraft charging and other environmental effects on a spacecraft's electrical behaviour. It also aims improve the efficiency of European space industry by ensuring that collaborative developments proceed on the basis of a common understanding of the processes and their effects and common requirements for their control. Its scope covers electrical effects occurring in space (i.e. from the ionosphere upwards).

Although this standard does include descriptions of effects and methods to quantitatively assess them, these sections are restricted to the extent that they ensure a consistent understanding of the concepts described in the requirements but are not intended as a comprehensive review of the field. The main section of the document is termed 'requirements' and here a minimalist, point-by-point listing of design and testing requirements is given. These cover: general issues of a protection programme; surface materials; secondary powered phenomena (e.g. solar array secondary arcing); high voltage systems; internal parts and materials; tethers; and electric propulsion The reason for the separation of requirements from other text and the terse style is that the standard is intended to form part of future contractual obligations. Hence clarity of what may be a legal requirement is essential.

Although references to specific tools and testing techniques is excluded from the main document, some guidance is provided in a set of informative annexes.

Guidelines and Handbook

This document is intended to be complementary to ECSS-E-20-06. However, its scope is wider, acknowledging that there are other standards and *de-facto* standards, as well as many aspects of spacecraft plasma interactions that do not form part of a specification. Sheath and wake effects are examples of this. By adopting a more informative and less legalistic approach, it is aimed to provide useful guidance and tools to help the user quantify effects and interpret requirements.

The main documents that provided guidelines and requirements are the following.

1. Space Engineering - Spacecraft Charging: Environment-Induced Effects on the Electrostatic Behaviour of Space Systems (Draft) 26 Jan 2005, ECSS-E-20-06 Draft v0.13
2. Space engineering - Space environment, 2000, ECSS-E-10-04A
3. Design Guidelines for Assessing and Controlling Spacecraft Charging Effects C.K.Purvis et al. 1984, NASA TP2361
4. Spacecraft surface charging handbook, V.A.Davis and L.W.Duncan, 1992, PL-TR-92-2232
5. Avoiding Problems Caused by Spacecraft On-Orbit Internal Charging Effects 1999, NASA-HDBK-4002
6. Space Environment for USAF Space Vehicles, 1991, MIL-STD-1809, (USAF)
7. Low Earth Orbit Spacecraft Charging Design Guidelines, D.C.Ferguson and G.B.Hillard 2003, NASA/TP-2003-212287

Areas covered include:

- General plasma parameters
- Sheath and Wakes
- Active electrostatic systems: (Tethers and electric propulsion)
- Surface Charging

- Internal Charging
- Solar Arrays

For each chapter, there is a review of the effects, a description of guidelines and requirements from various sources, a section on tools and equations and a section on simulation and test procedures. Equations are generally followed by graphs giving typical examples, e.g. a section on acoustic velocity is accompanied by the plot shown in Figure 2 below. This shows a typical variation of acoustic velocity versus altitude, based on the IRI2001 model [1], for 1st January 2003, with latitude 0°, longitude 0°, daily F10.7 radio flux of 70.0×10^{-22} W m^{-2} Hz^{-1} and 12-month average sunspot number of 50.

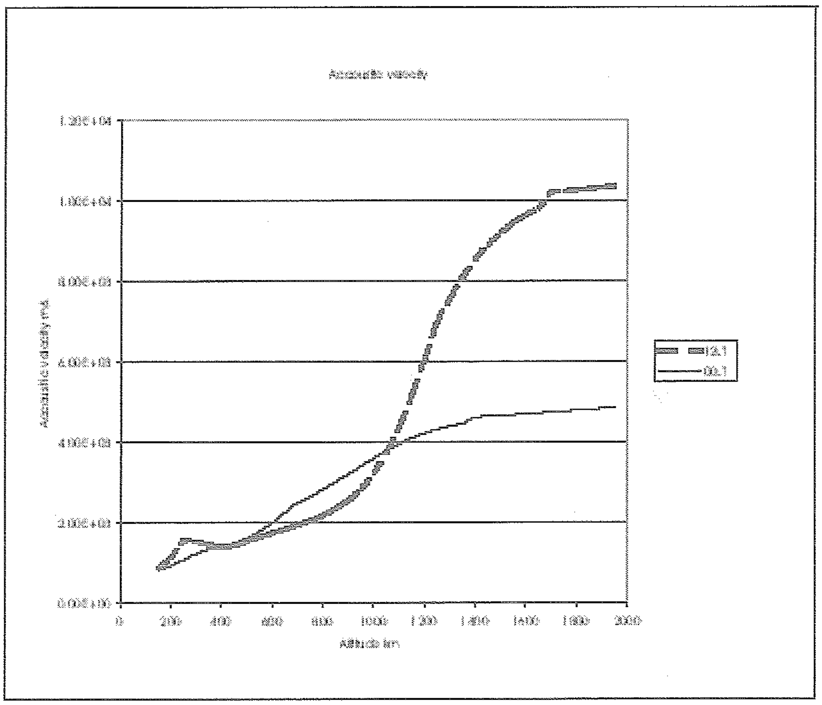


Figure 2 Typical acoustic velocity as a function of altitude for local noon and midnight

Where differences exist between authoritative sources, these are described, as shown in Figure 3 below. This gives different internal charging environment specifications. Figure 4 shows the result of passing these environments through a simple electron transport tool (DICTAT [6]) to calculate the current under different levels of shielding. In this case, this would allow a user to select the shielding necessary to keep the incident electron current below a specified level for control of internal charging.

Since one of the goals of the Guidelines and Handbook is to promote the use and sharing of resources in Europe, links are given to resources elsewhere, e.g. simulation codes and testing facilities.

Interactive Version

Although the document is intended to be useable in hard-copy form, it is being given additional capabilities by being implemented in an interactive version. This will be accessible through common web browsers and is expected to be distributed via CD-rom or via downloads for installation on the user's machine. In order to maintain the closest correspondence between the text and interactive versions of the document, a single pdf file is used to generate both the hardcopy and interactive versions. This contains links to web-based php plotting tools which are active when viewed with a browser but which do not interfere with the appearance or structure of the document when viewed as a hardcopy. For more complicated calculations and simulations, the user will be given links to appropriate tools, e.g. via SPENVIS (http://www.spenvis.oma.be/spenvis/).

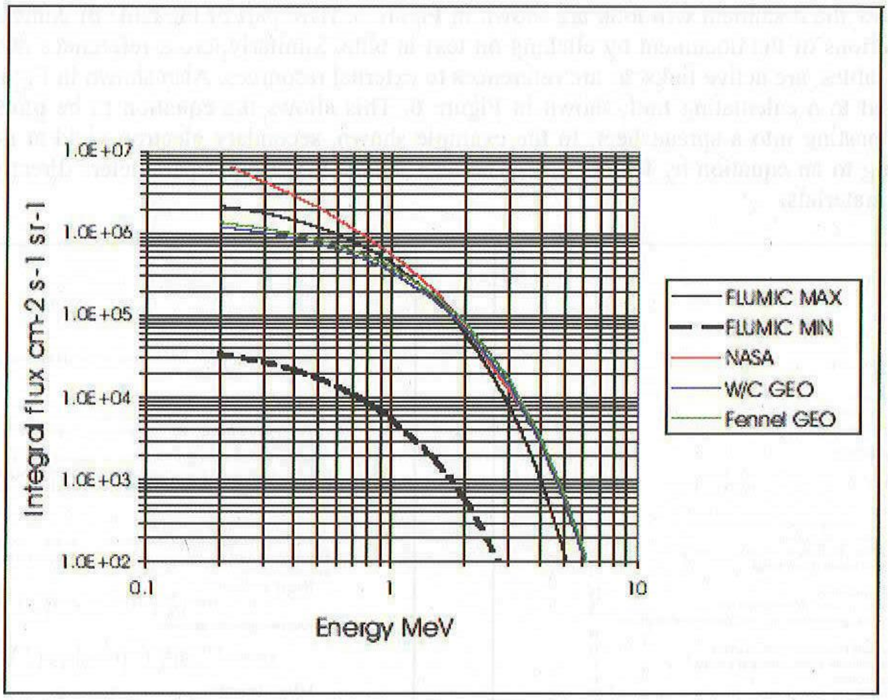


Figure 3 Worst case spectra for geostationary orbit, comparing FLUMIC [2] for L=6.9, the NASA worst case spectrum [3], Wrenn et al's' worst case' spectrum [3] and Fennell et al's [4] worst case environment. Approximate maximum and minimum values for FLUMIC correspond to 14th April 1994 and 21st December 1989 respectively.

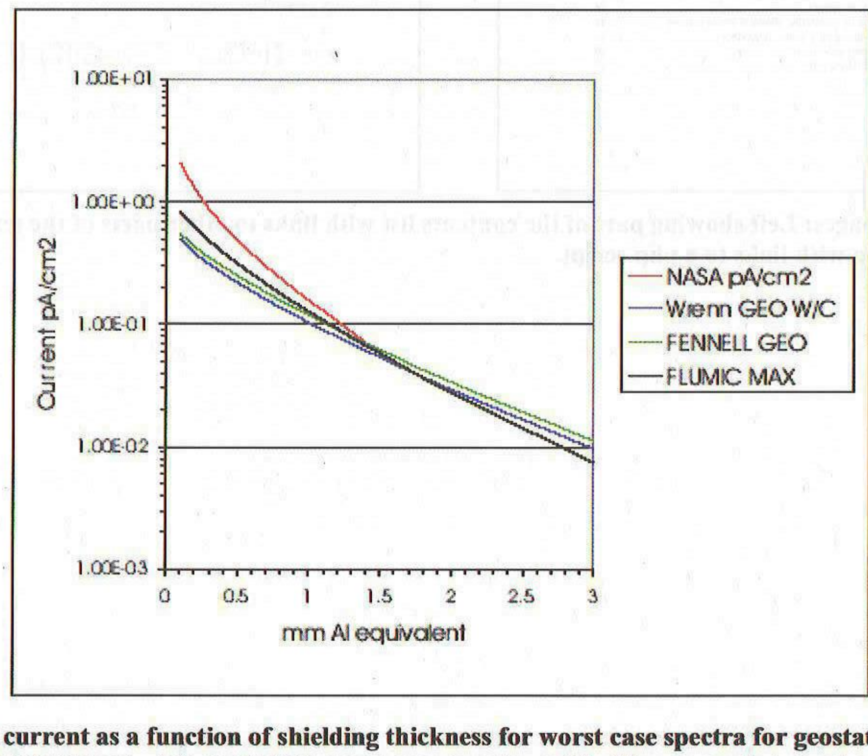
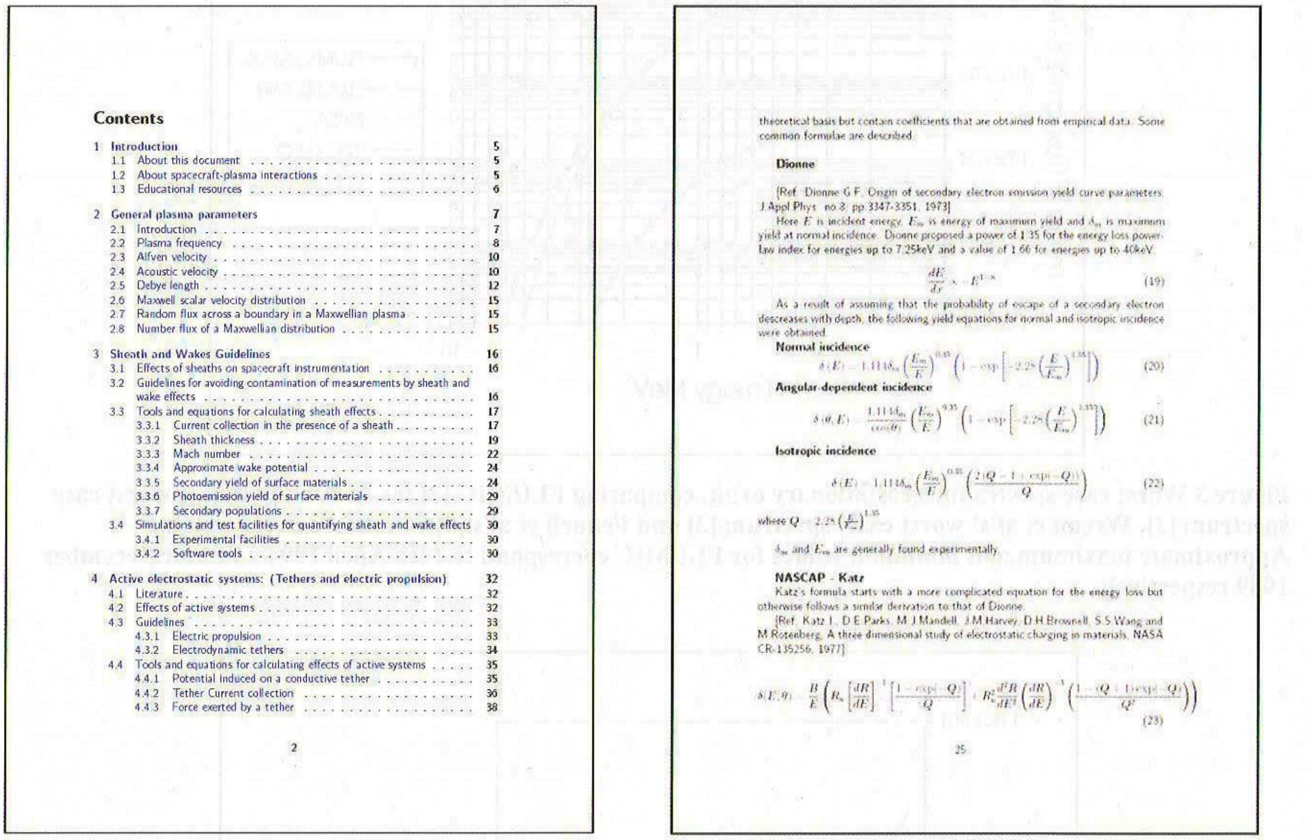


Figure 4 Incident current as a function of shielding thickness for worst case spectra for geostationary orbit, comparing FLUMIC [2] for L=6.9, the NASA worst case spectrum [3] , Wrenn et al's 'worst case' spectrum [2] and Fennell et al's [4] worst case environment. The FLUMIC spectrum was the maximum of the solar cycle, nominally 14th April 1994.

Examples of the how the document will look are shown in Figure 5. Here part of the table of contents is shown. Users can navigate to sections of the document by clicking on text in blue. Similarly, cross-references within the document, e.g. to figures and tables, are active links, as are references to external resources. Also shown in Figure 5 is an equation that has been linked to a calculating tool, shown in Figure 6. This allows the equation to be plotted and data to be extracted, e.g. for pasting into a spreadsheet. In the example shown, secondary electron yield at normal incidence is calculated according to an equation by Dionne [5]. The user is able to set input parameters directly, or select from a number of default materials.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theoretical basis but contain coefficients that are obtained from empirical data. Some common formulae are described.

Dionne

[Ref. Dionne G.F. Origin of secondary electron emission yield curve parameters. J.Appl Phys. no.8, pp.3347-3351, 1973]

Here E is incident energy, E_m is energy of maximum yield and δ_m is maximum yield at normal incidence. Dionne proposed a power of 1.35 for the energy loss power-law index for energies up to 7.25keV and a value of 1.66 for energies up to 40keV.

$$\frac{dE}{dx} \propto E^{1-n} \quad (19)$$

As a result of assuming that the probability of escape of a secondary electron descreases with depth, the following yield equations for normal and isotropic incidence were obtained.

Normal incidence

$$\delta(E) = 1.114\delta_m \left(\frac{E_m}{E}\right)^{0.35}\left(1-\exp\left[-2.28\left(\frac{E}{E_m}\right)^{1.35}\right]\right) \quad (20)$$

Angular-dependent incidence

$$\delta(\theta, E) = \frac{1.114\delta_m}{\cos(\theta)}\left(\frac{E_m}{E}\right)^{0.35}\left(1-\exp\left[-2.28\left(\frac{E}{E_m}\right)^{1.35}\right]\right) \quad (21)$$

Isotropic incidence

$$\delta(E) = 1.114\delta_m \left(\frac{E_m}{E}\right)^{0.35}\left(\frac{2(Q-1+\exp(-Q))}{Q}\right) \quad (22)$$

where $Q = 2.28\left(\frac{E}{E_m}\right)^{1.35}$

δ_m and E_m are generally found experimentally.

NASCAP - Katz

Katz's formula starts with a more complicated equation for the energy loss but otherwise follows a similar derivation to that of Dionne.

[Ref. Katz I., D.E.Parks, M.J.Mandell, J.M.Harvey, D.H.Brownell, S.S.Wang and M.Rotenberg. A three dimensional study of electrostatic charging in materials. NASA CR-135256, 1977]

$$\delta(E,\theta) = \frac{B}{E}\left(R_n\left[\frac{dR}{dE}\right]^{-1}\left[\frac{1-\exp(-Q)}{Q}\right] + R_n^2\frac{d^2R}{dE^2}\left(\frac{dR}{dE}\right)^{-3}\left(\frac{1-(Q+1)\exp(-Q)}{Q^2}\right)\right) \quad (23)$$

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Figure 5 Example pages: Left showing part of the contents list with links to other parts of the text in blue. Right showing an equation with links to a php script.

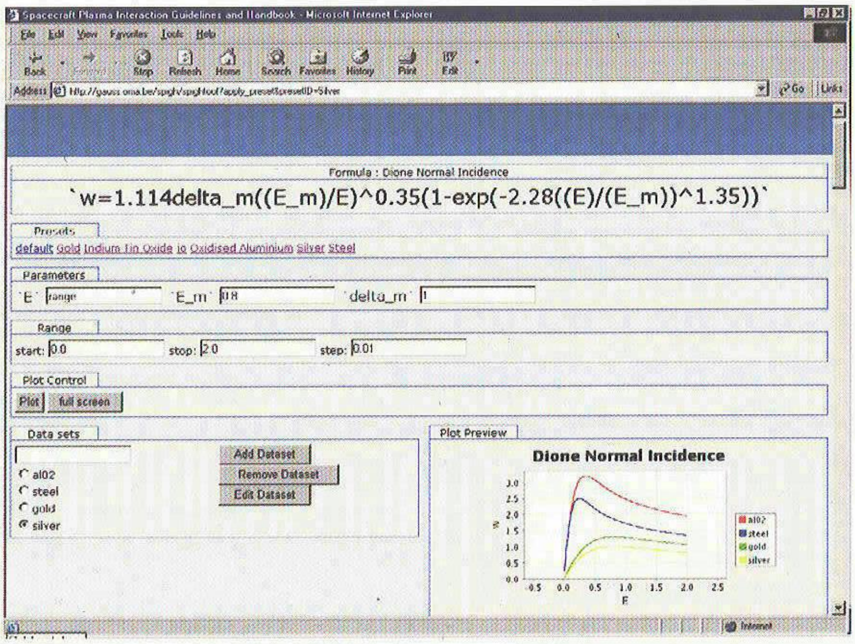

Figure 6 Example of calculation of a secondary electron yield using an equation by Dionne for normal incidence.

Summary and Conclusions

The 'Spacecraft Plasma Interactions Guidelines and Handbook' is complementary to the ECSS-E-20-06 standard on 'Spacecraft Charging: Environment-Induced Effects on the Electrostatic Behaviour of Space Systems'. The guidelines and handbook is intended to be less formal and more helpful. It has a wider scope, including many aspects of the space environment which do not lead to a requirements. At this time, the text version is largely complete and development is concentrating on introducing interactive capabilities.

References

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