METEOROID AND DEBRIS FLUX ASSESSMENT ON ORIENTED SURFACES. APPLICATION TO EURECA AND HST SOLAR ARRAYS.

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ABSTRACT

Predictions from several space debris models are compared to measured impact fluxes on retrieved solar arrays.

A variety of different space debris models have been developed over the last few years to predict the number of impacts in orbit and to estimate the risk of loss, partial damage or performance degradation of satellites. Most of these models calculate the particle flux on randomly oriented surfaces and disregard the need for a more detailed analysis in order to provide adequate shielding.

The ESA/ESTEC implementation (ORIEN96) of the new NASA debris environment reference model (ORDEM96) is able to assess debris fluxes on surfaces oriented relative to the satellite flight direction. A new application is being developed which provides the possibility of flux assessments on Sun-pointing or inertially fixed surfaces in order to predict meteoroid and debris impacts on solar panels or optical instruments. This application interfaces to ORDEM96 as well as to the ESA Meteoroid and Space Debris Environment Reference model (MASTER).

1. INTRODUCTION

The retrieved solar arrays of the Hubble Space Telescope (HST) and the European Retrievable Carrier (EuReCa) offered a unique opportunity to investigate particle fluxes in low Earth orbit originating from man-made debris and meteoroids. The Hubble Space Telescope was launched in April 1990 and remained in a circular orbit of 600 km altitude and 28.5° inclination for 3.6 years until the exchange of its solar array. EuReCa began its mission in August 1992 and was retrieved after 324 days in a circular orbit at 500 km altitude and an inclination of 28.5°.

In the framework of ESA's Post Flight study program on space debris and meteoroids about $150 m^2$ total combined surface area of retrieved solar panels from the Hubble Space Telescope and the European Retrievable Carrier was subject to a detailed impact analysis.

The data gained from this survey provides an excellent opportunity to validate existing models. In order to adopt the model predictions to this specific problem, a procedure is being developed which fulfills the following requirements:

- Application of damage equations: The measured flux is given as a function of crater pit or conchoidal cracking diameter whereas the models apply to particle diameter. A conversion to crater diameters is therefore neccessary.
- Transformation of the modelled flux into a Sun-pointing coordinate frame: This transformation consideres the orientation of the surface under investigation.

This paper explains the procedures and presents results for the application of two space debris models:

- the new NASA model for spacecraft design and observations in low Earth orbit which was introduced in 1996 (Ref. 1) and
- the MASTER Analyst Application, released in 1995 by ESA/ESOC (Ref. 2).

2. MODELS FOR SPACE DEBRIS AND METEOROID RISK ASSESSMENT

Two models are used to assess the space debris flux on a target satellite. The new NASA space debris reference model (Ref. 1), here referred to as the NASA96 model, uses a semi-empirical approach. It devides the space debris environment into six different source inclination bands. All debris orbits from within one inclination band are further distinguished by their eccentricity family (either circular or elliptical) and six different source terms. The total debris population is represented by a set of functional terms containing a unique altitude and size dependant distribution for each source term and eccentricity family in each of the six inclination bands. NASA96 is valid for particle diameters down to 1 micron and it is restricted to circular target orbits for altitudes up to 2000 km.

The second debris model, the MASTER Analyst Application (Ref. 2) uses a semi-deterministic approach. Its basic population has been calculated by modelling the space debris history considering launches, explosions and collisions of spaceflight objects.

The 3-dimensional spatial density distribution of the population is stored using a spherical control volume surrounding the Earth devided into equidistant bins in

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radius, right ascension and declination. MASTER is capable of debris collision risk asessments for circular and elliptical target orbits reaching up to geostationary Earth orbit. The minimum debris particle diameter considered is 100 microns.

Additional to the two optional space debris models, the meteoroid model introduced by Gruen et. al.(Ref. 3) is used. This model uses an analytical approach to describe isotropic flux-mass distribution at 1AU distance from the Sun. A mean velocity of 20km/s is assumed.

3. COORDINATE TRANSFORMATION AND DAMAGE EQUATIONS

For the relation between the particle impact characteristics and the resulting crater pit and conchoidal cracking diameter, a set of damage equations developed by K. Paul and L. Bertoud is used (Ref. 4). These damage equations apply for semi-infinite targets on solar cell cover glass.

$$D_{Co} = 5 \cdot 10^{-4} \rho_t^{-0.5} \rho_p^{0.784} d^{1.076} V^{0.727} \cos^{0.601} \Theta \quad (1)$$

$$D_{pit} = 1.112 \cdot 10^{-4} \rho_t^{-0.5} \rho_p^{0.743} d^{1.076} V^{0.727} \cos^{0.15} \Theta \quad (2)$$

D_{co}	conchoidal cracking diameter	[cm]
D_{pit}	pit diameter	[cm]
ρ_t	target density	[g/cm^3]
ρ_p	particle density	[g/cm^3]
d	particle diameter	[cm]
V	Particle velocity	[cm/s]
Θ	encounter angle	[deg]

Constant particle mass densities were used for the crater size analysis: 2 g/cm^3 for meteoroids and 4 g/cm^3 for debris.

Both space debris models deliver directional flux information defined in a satellite fixed coordinate frame. The output of the meteoroid model is also converted into directional flux in the same coordinate system.

The flux on a Sun-oriented surface is obtained by transforming the fluxes encounter angle into a Sun-pointing coordinate frame. All transformations are integrated over one year due to the rotation of the Earth with respect to the Sun. The right ascensions of ascending nodes are being randomly distributed for both, target and impactors.

4. FLUX PREDICTIONS ON SUN-POINTING SURFACES

This paragraph shows the results of the predicted space debris and meteoroid flux on the solar arrays of HST and EuReCa. Where measurement data are provided, they are taken from the EuReCa (Ref. 5) and HST (Refs. 6, 7) meteoroid and debris post-flight analysis, respectively.

Fig. 1 shows an overview of the results of the NASA96 and MASTER space debris models and the GRUEN meteoroid model. The meteoroid model exceeds MASTER for particle diameters of less than 1 mm. NASA96 agrees well with MASTER above one mm diameter but exceeds it for lower sizes. Between 10 microns and 1mm diameter, it corresponds with the meteoroid data, but exceeds it for diameters lower than 10 microns.

The following plots show the predicted flux distributions for HST with respect to pit or conchoidal crater diameter. The MASTER model is not used here because it is limited to a minimum particle diameter of 100 microns whereas the damage equations apply for impact features on semi-infinite targets. Considering a cover glass thickness of 150 microns, damages from particles of 100 microns diameter should clearly be treated as impacts on finite targets.

As an impacting particle creates a crater with central pit larger than the particle diameter, the predicted fluxes (Fig. 2) are higher than in Fig. 1. The predicted debris flux raises more than the predicted meteoroid flux because the debris particles are denser (in this prediction by a factor of 2) and cause bigger craters. Therefore the main contribution of the predicted flux originates from debris.

In the framework of the post-flight analysis, the HST solar arrays were investigated using optical and electron microscopes (Scanning Electron Microscope, SEM) (Ref. 7). The results of this survey for the pit diameter are given in Fig. 3. It shows a good agreement with the total predicted flux from the previous figure. The total predicted flux curve touches the maxima of the measured curves, but continues below 5 microns with a higher gradient. Measurements and prediction diverge also for pit diameters greater than 500 microns.

The measured and predicted flux distribution with respect to the conchoidal cracking diameter are shown in Fig. 4. The agreement between measurements and prediction is not quite as good as in the previous example. Again the gradient at smaller crater sizes is higher for the prediction than in the measurements.

The result of the microscopic investigation of the EuReCa solar arrays (Ref. 5) is shown in Fig. 5. The measured fluxes are similar as for the HST except for the largest sizes were the HST fluxes were higher.

A comparison with predictions from the NASA96 and Gruen models show good agreement. The discrepancies between the two curves are small with a maximum difference for microns sized pit diameters, where the gradient of the predicted flux is again higher than the measurements.

5. SUMMARY

Particle flux predictions on Sun-pointing surfaces have been presented using different models. The flux predictions of the NASA96 space debris model and the Gruen meteoroid model have been compared with measurement data from the HST and EuReCa post-flight impact analysis. The comparison showed a good agreement between predictions and measurements, especially in the range of 10 to 100 microns pit diameter for HST and 100 microns to 1 mm pit diameter for EuReCa.

6. REFERENCES

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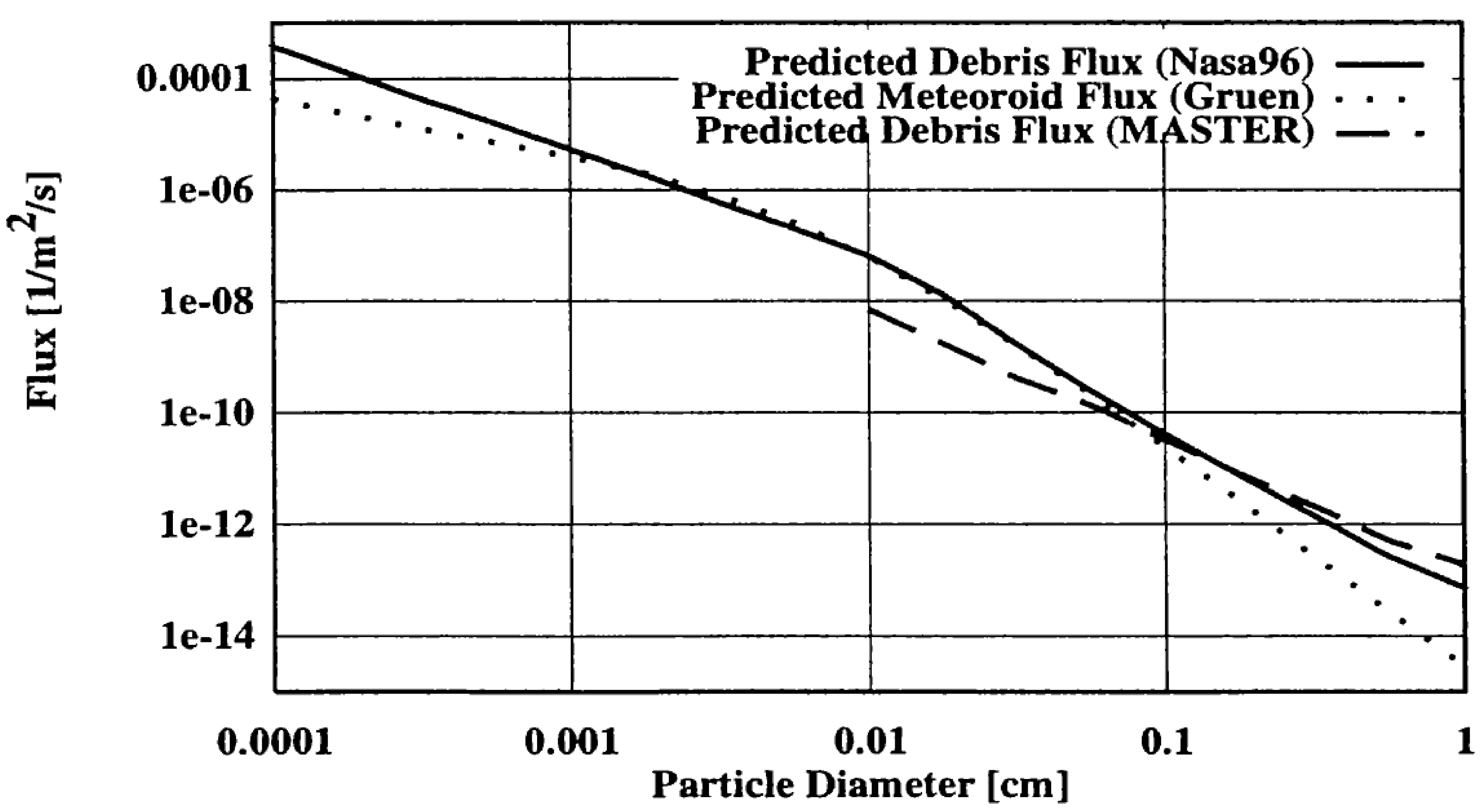

Fig. 1: Predicted Flux on HST solar array surfaces - particle diameter distribution

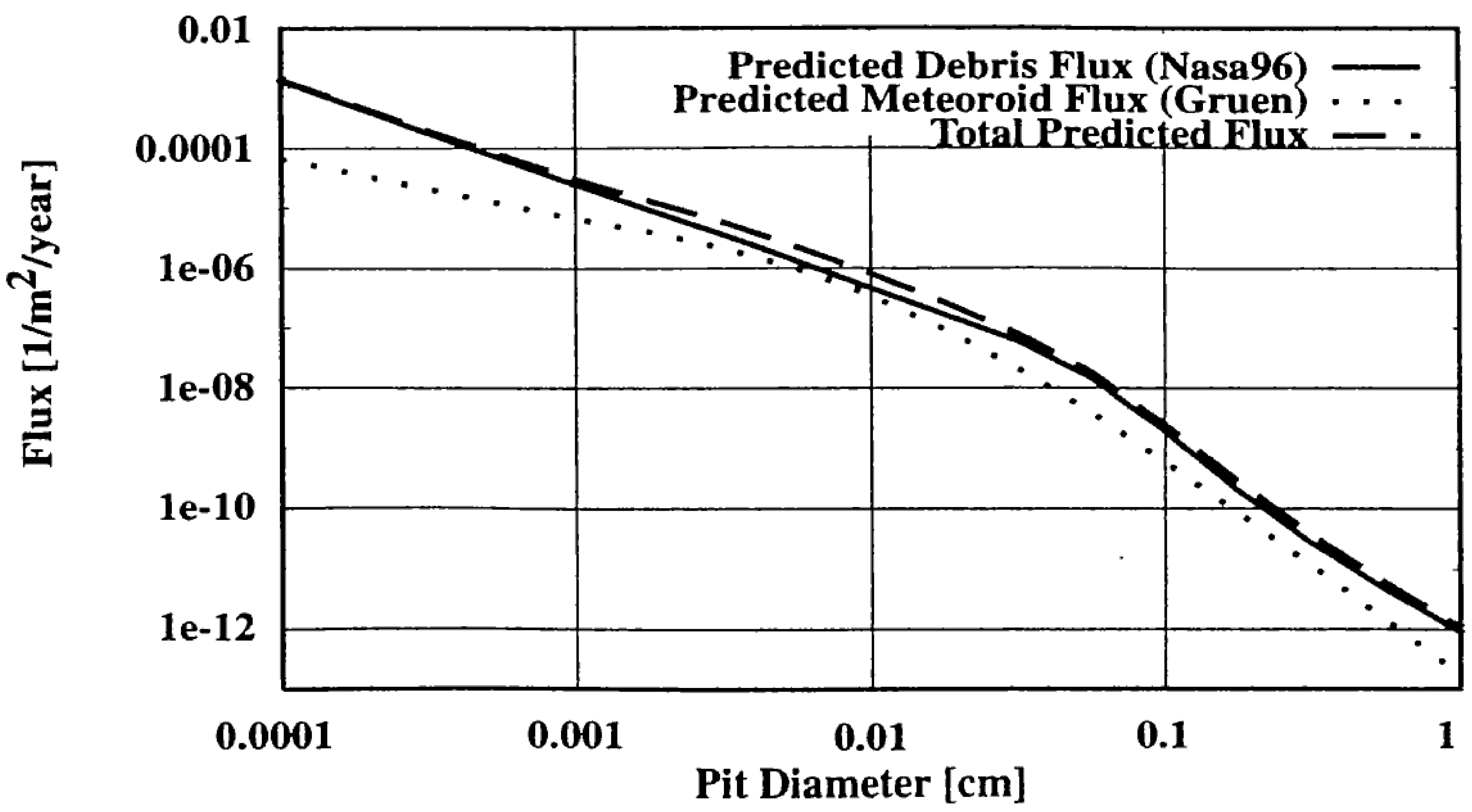

Fig. 2: Predicted Flux on HST solar array surfaces - pit diameter distribution

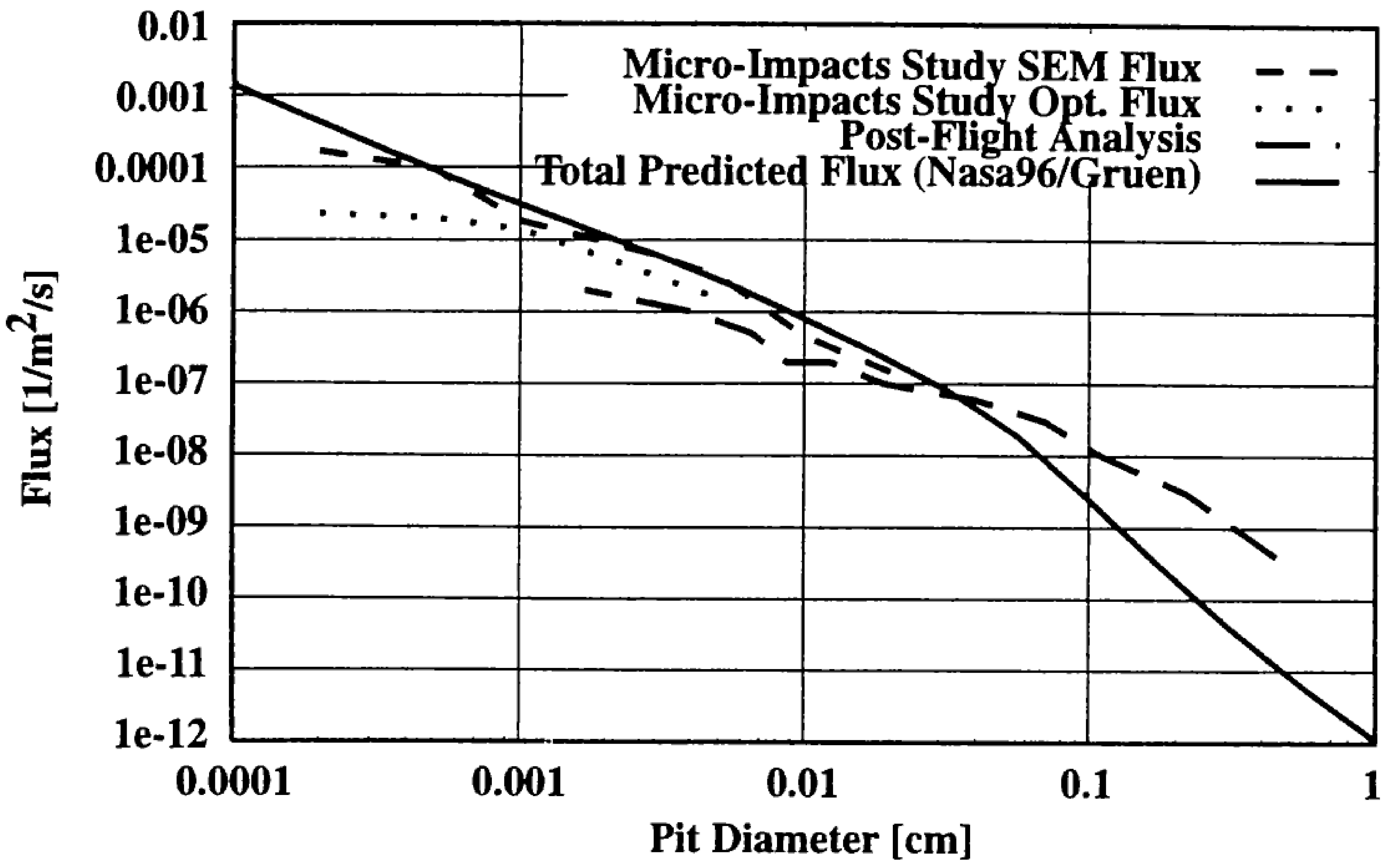

Fig. 3: Predicted and observed flux on HST solar array surfaces - pit diameter distribution

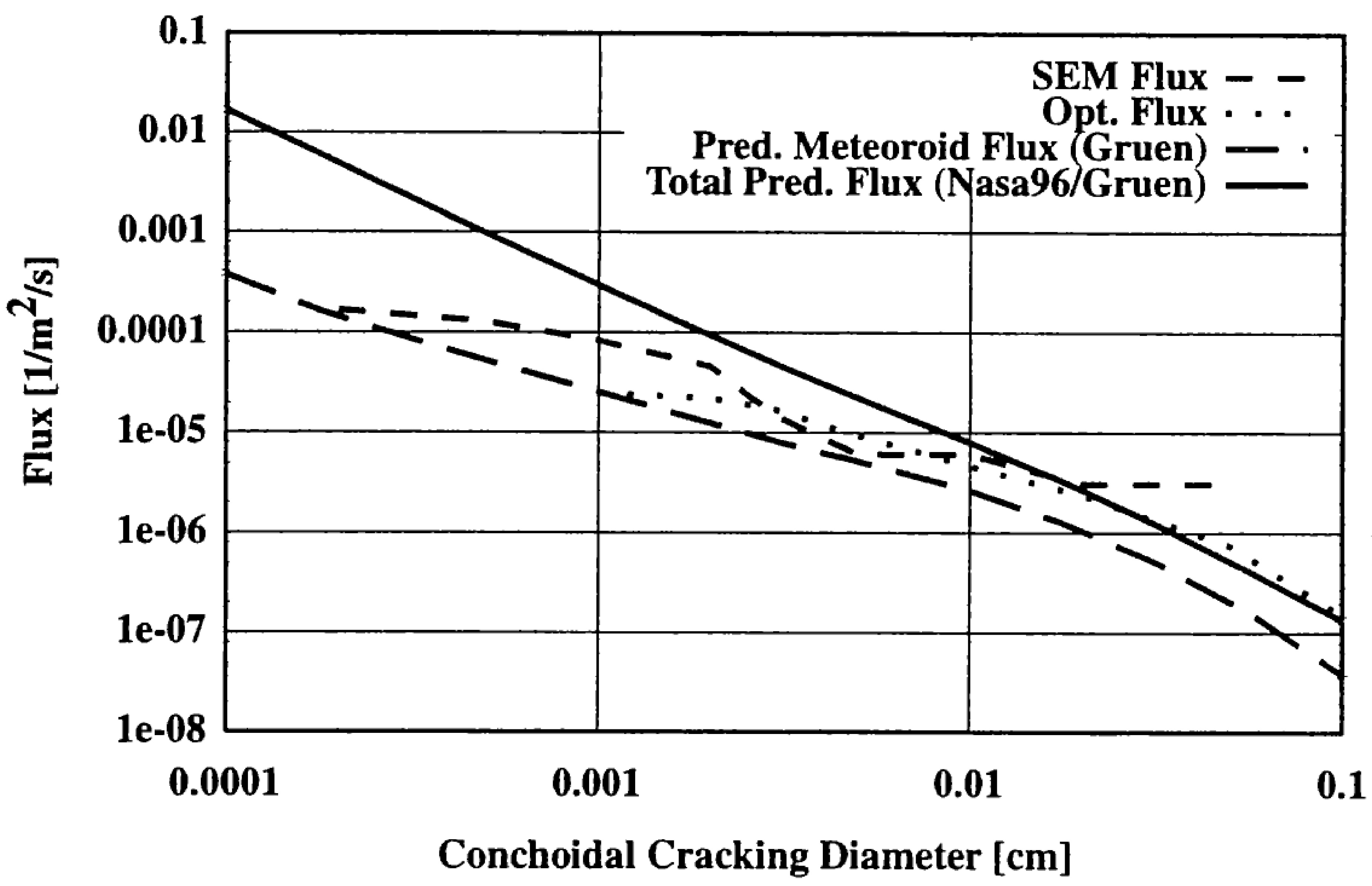

Fig. 4: Predicted and observed flux on HST solar array surfaces - conchoidal cracking diameter distribution

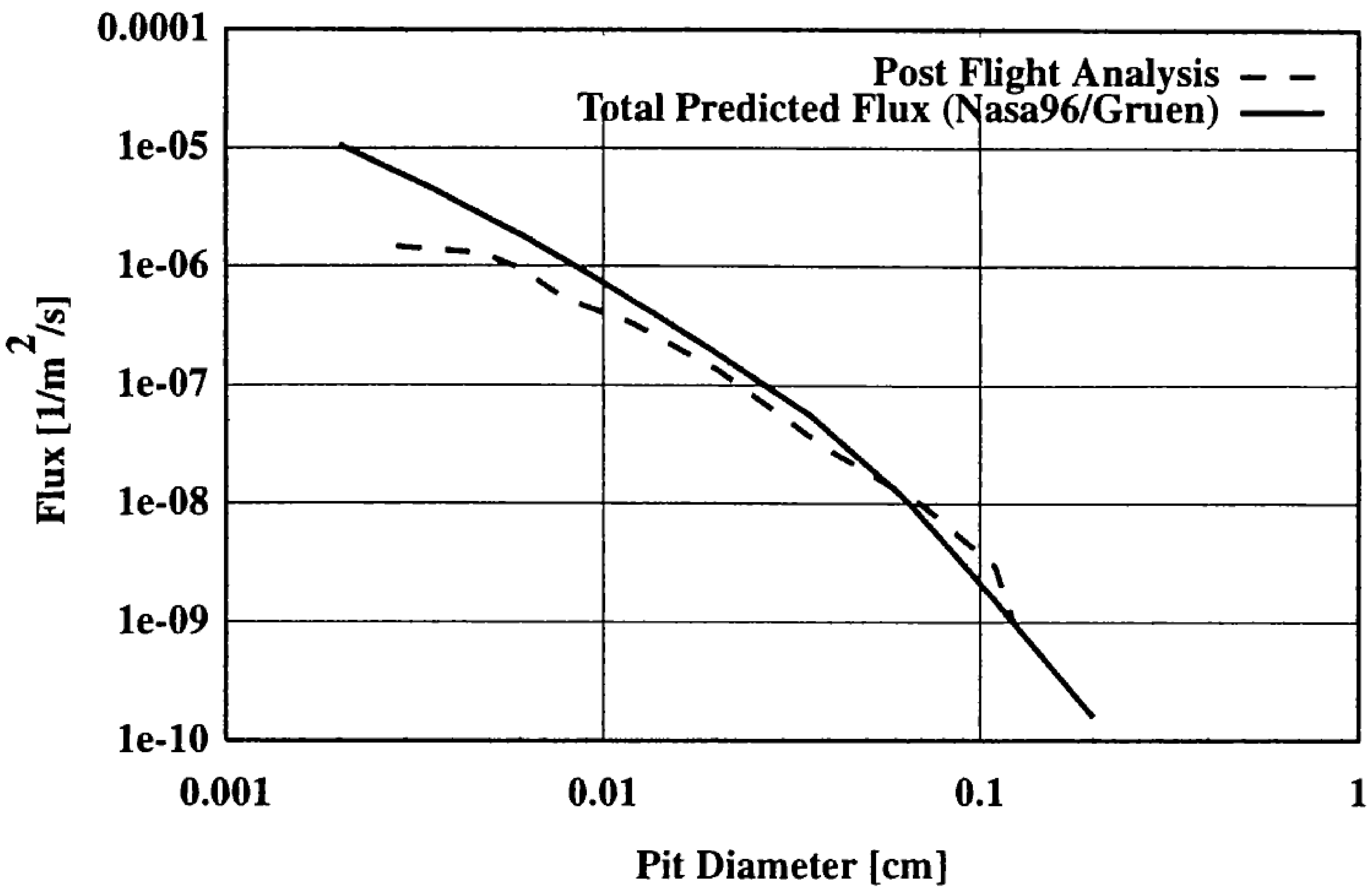

Fig. 5: Predicted and observed flux on EuReCa solar array surfaces - pit diameter distribution