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Space environment (natural and artificial) — Process-based implementation of meteoroid and debris environment models (orbital altitudes below GEO + 2 000 km)

Environnement spatial (naturel et artificiel) — Lignes directrices pour une mise en œuvre fondée sur les processus des modèles environnementaux des météoroïdes et des débris (altitudes d'orbite inférieures à GEO + 2 000 km)

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Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

This second edition cancels and replaces the first edition (ISO 14200:2012), which has been technically revised.

The main changes compared to the previous edition are as follows:

— removal of impact risk assessment requirements;

— in Annexes A and B, information on space debris environment models has been updated (SDEEM 2015 and SDEEM 2019);

— debris flux models: The latest version of each model is briefly described. Descriptions of historical models have been moved to NOTEs or deleted;

— since this document now focuses on models that have been developed primarily for impact flux assessment, those models whose main purpose is to study the long-term evolution of the space debris environment have been deleted.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Every spacecraft in an Earth orbit is exposed to a certain flux of micrometeoroids and man-made space debris. Collisions with these particles take place with hypervelocity. Many meteoroid and space debris environment models have been studied and developed which describe populations of meteoroids and/or space debris. Those models can be used for estimation the impact flux required when selecting the spacecraft operation orbit, evaluation the impact flux in a specific orbit, prediction of the frequency of collision avoidance operations, and estimate of the impact flux required for protection design. However, there are different methods in existence for reproducing the observed environment by means of mathematical and physical models of release processes, for propagating orbits of release products, and for mapping onto spatial and temporal distributions of objects densities, transient velocities, and impact fluxes. Until a specific standard for the space debris environment is defined, a common implementation process of models should be indicated.

This document specifies a common implementation process for meteoroid and space debris environment models. In the first edition, requirements were also included relating to impact risk assessment. However, with the publication of ISO 16126 in 2014, such requirements were no longer necessary in this document, and so they have been removed. The second edition now focuses on models used for estimating the impact flux.

Space environment (natural and artificial) — Process-based implementation of meteoroid and debris environment models (orbital altitudes below GEO + 2 000 km)

1   Scope

This document specifies a common process for selecting and implementing meteoroid and space debris environment models used in the impact flux assessment for design and operation of spacecraft and other purposes. This document provides guidelines and requirements for the process.

2   Normative reference

There are no normative references in this document.

3   Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
impact flux
number of impacts per unit area per unit time

3.2
mass density
mass per unit volume

3.3
meteoroid
small celestial body of natural origin

Note 1 to entry: Generally, a meteoroid is a solid, rocky object of a size considerably smaller than an asteroid and considerably larger than an atom.

Note 2 to entry: It is thought that most meteoroids result from the disintegration and fragmentation of comets and asteroids orbiting the sun, whereas others are collision impact debris ejected from bodies such as the Moon or Mars.

3.4
meteoroid environment model
type of analysis model that computationally simulates the *meteoroid* (3.3) population orbiting the sun

Note 1 to entry: Typically, this type of model is used to predict the flux of meteoroids on a target object in space, such as a spacecraft.

3.5
space debris
DEPRECATED: orbital debris
objects of human origin in Earth orbit or re-entering the atmosphere, including fragments and elements thereof, that no longer serve a useful purpose

Note 1 to entry: Spacecraft in reserve or standby modes awaiting possible reactivation are considered to serve a useful purpose.

[SOURCE: ISO 24113:2019,[1] 3.23]

3.6
space debris environment model
type of analysis model that computationally simulates the *space debris* (3.5) population

Note 1 to entry: Typically, this type of model is used to predict the flux of space debris on a target object in space, such as a spacecraft.

3.7
spacecraft
system designed to perform a set of tasks or functions in outer space, excluding launch vehicle

[SOURCE: ISO 24113:2019 3.25]

3.8
traceability
ability to trace the history, application or location of an object

[SOURCE: ISO 9000:2015[2],3.6.13, modified — Notes 1 and 2 to entry have been removed.]

4   Abbreviated terms

AU	astronomical units
CME	chemistry of meteoroid experiment
ESA	European Space Agency
EuReCa	European retrievable carrier
GEO	geostationary earth orbit
GUI	graphical user interface
HAX	haystack auxiliary radar
HST-SA	Hubble space telescope solar array
HST (SM1)	Hubble space telescope (service mission 1)
HST (SM3B)	Hubble space telescope (service mission 3B)
IMEM	interplanetary meteoroid engineering model
ISS	international space station
LDEF	long duration exposure facility
LEO	low earth orbit
MASTER	meteoroid and space debris terrestrial environment reference

MEM	meteoroid engineering model
ORDEM	orbital debris engineering model
NASA	National Aeronautics and Space Administration
PROOF	program for radar and observation forecasting
SDEEM	space debris environment engineering model
SSN	space surveillance network
SSP	space station program
STS	space transportation system

5 Procedures for the selection and implementation of meteoroid and space debris environment models

5.1 General

Meteoroid and space debris environment models can be used to estimate the impact fluxes of meteoroids and space debris on a spacecraft. This flux information can be used in

a)   the selection of the spacecraft operation orbit in mission analysis,

b)   the evaluation of the safety of specific orbit(s),

c)   the prediction of the frequency of collision avoidance operations, and

d)   the design of suitable impact protection, especially for critical components.

There is a variety of environment models available, each with its own set of characteristics and capabilities. 5.2 and 5.3 specify procedures that are available to guide a user in the selection and implementation of a suitable model.

5.2 Selection procedure

5.2.1   The customer and the supplier of the spacecraft shall coordinate in selecting the meteoroid and space debris environment models that are applied to their project and agree to the conclusion.

5.2.2   To select a suitable environment model, the capabilities of available candidate models should be considered.

NOTE   Annex A describes the capabilities of some meteoroid environment models and Annex B describes the capabilities of some space debris environment models.

5.2.3   Models other than those listed in Annexes A and B may be used.

5.2.4   When selecting an environment model, the following should be considered:

a)   transparency of the characteristics of the model;

b)   whether the model is used by a national space agency;

c)   whether the model is maintained on a regular and frequent basis;

d)   the format of the output flux data, including its suitability for transfer to another model, such as an impact risk analysis code;

e) the ease of use of the model.

5.2.5 When selecting an environment model, consideration should be given to the fact that there can be significant differences in the calculated fluxes among the available candidate models. The customer and/or the supplier should compare the fluxes of several models. See A.3 and B.3.

NOTE The choice of model to be applied depends on the mission objectives and requirements of the customer (and the supplier, if necessary). For example, to achieve adequate safety margin in the design of a spacecraft or its subsystems, it is reasonable to select the model with the highest flux values when analysing the risk caused by space debris and meteoroid impacts. This ensures that the worst-case scenario is evaluated. On the other hand, in the case of in situ debris sensor design, the worst-case scenario is achieved by using the model that generates the lowest impact flux values, since it results in the smallest observation opportunity. Finally, when selecting the operational orbit of a spacecraft by comparing the impact flux for each candidate orbit, the model can be chosen according to criteria other than the magnitude of its flux values. This is because the analysis involves relative fluxes.

5.3 Implementation procedure

5.3.1 Traceability of the implementation of the meteoroid and space debris environment models shall be assured, including during all design and operation phases, if applied to a spacecraft.

5.3.2 When applying a model to calculate meteoroid or space debris impact fluxes, a record of the following shall be kept:

a) the justification of the selected model;

b) all input and output parameters and their values for each analysis case;

c) any assumptions made regarding the input parameters and the technical justification for the assumptions;

d) any corrections and/or additional assumptions made to output parameters, their technical justification, and details of correction methods and their effects on the results.

NOTE Output parameters can be corrected by applying a safety factor, life factor or margin of safety. Such corrections can also be applied to the debris population, especially if there has been a sudden large increase in the population due to a debris generation event that has not yet been modelled.

e) The results of the impact flux assessment and the methodology used.

5.3.3 The records shall be evaluated and confirmed by reviewers during the appropriate review stages of a project.

6 International project

For an international project, the following items should be agreed amongst member bodies before starting the project:

a) the applicable meteoroid and space debris environment models for the project;

b) the method of maintenance of the meteoroid and space debris environment models.

Annex A
(informative)

Capability of some meteoroid environment models

A.1 Model overview

A.1.1 Gruen et al. model

The Gruen model[3] assumes an isotropic meteoroid distribution that is based on lunar crater, zodiacal light and in situ measurement data.

A.1.2 Divine model

The Divine model[4] assumes a non-isotropic distribution that is based on five populations in particle mass, inclination, eccentricity and perihelion distance.

A.1.3 Divine-Staubach model

The Divine-Staubach model[5] is a follow-up of the Divine model, using new data from GALILEO and ULYSSES dust detectors.

A.1.4 NASA SSP-30425 model

The SSP-30425 (Space Station Program Natural Environment Definition for Design) model[6] describes a space environment for ISS design.

A.1.5 IMEM model

Dikarev used an improved and controlled data set and applied refined mathematical methods in order to describe three-dimensional distributions of orbital elements (instead of the mathematically separable distributions of Divine)[7].

A.1.6 MEM model

Near 1 AU fluxes are calibrated from the Gruen model. A constant mass density of 1,0 g/cm^3 is assumed and the velocity distributions are independent from the particle sizes[8][9].

A.2 Model specifications

Table A.1 shows specifications of meteoroid models listed in A.1.

Table A.1 — Meteoroid model specifications

Model specifications	Model					
	Gruen et al.[3]	Divine[4]	Divine-Staubach[5]	SSP 30425[6]	IMEM[7]	MEM[8][9]
Sporadic or stream	Sporadic	Sporadic	Sporadic	Sporadic	Sporadic	Sporadic
a Force of the Earth's gravitational field that attracts meteoroids, changes their trajectories, and therefore increases the flux						

Table A.1 *(continued)*

Model specifications	Model					
	Gruen et al.[3]	Divine[4]	Divine-Staubach[5]	SSP 30425[6]	IMEM[7]	MEM[8][9]
Interplanetary	No	0,1 AU to 20 AU	0,1 AU to 20 AU	No	0,1 AU to 10 AU	0,2 AU to 2 AU
Mass/range	10^{-18} g to 10^2 g	10^{-18} g to 1 g	10^{-18} g to 1 g	10^{-18} g to 10^2 g	10^{-12} g to 10^2 g	10^{-6} g to 10 g
Near Earth	Yes	Yes	Yes	Yes	Yes	Yes
Gravitational focusing [a]	No	Earth only	Earth only	Earth only	Earth only	Earth only
Planetary shielding	No	Earth only	Earth only	Earth only	Earth only	Earth only
Sources of meteoroids	Not identified explicitly	-Asteroidal, -Core, -Halo, -Inclined, -Eccentric populations	-A, B, C , -Asteroidal, -Core, -Inter-stellar dust populations	Not identified explicitly	-Asteroids, "Jupiter-crossing comets", -Inter-stellar dust ($<10^{-9}$ g)	6 radar/photographic meteor sources (Helion, Anti-Helion, North Apex, South Apex, North Toroidal, South Toroidal)
Velocity distribution	Single value (20 km/s)	Yes	Yes	Yes (Kessler)	Yes	Yes
Mass density	Single value (2,5 g/cm³)	2 g/cm³ ($m < 10^{-6}$ g); 1 g/cm³ (10^{-6} g to 10^{-2} g); 0.5 g/cm³ ($m > 10^{-2}$ g)	2 g/cm³ ($m < 10^{-6}$ g); 1 g/cm³ (10^{-6} g to 10^{-2} g); 0.5 g/cm³ ($m > 10^{-2}$ g)	2 g/cm³ ($m < 10^{-6}$ g); 1 g/cm³ (10^{-6} g to 10^{-2} g); 0.5 g/cm³ ($m > 10^{-2}$ g)	Single value (2,5 g/cm³)	Single value (1 g/cm³)
Primary data source	-In situ experiments, -zodiacal light, lunar crater record. -Gruen et al. flux is identical to the 1970 Zook flux for $m > 10^{-7}$ g	-Zodiacal light, -Harvard Radio Meter Project (HRMP) data	-Staubach refit the probability densities, taking account into Ulysses and Galileo spacecraft	Not identified explicitly	-In situ experiments (Ulysses, Galileo), -COBER IR, -lunar crater record. -No zodiacal light data. -Disregard AMOR data	Canadian Meteor Orbit Radar (CMOR) data
Key assumptions	Flux on Earth is isotropic	Calibrated to the Gruen flux	Calibrated to the Gruen flux	Gruen flux with Kessler's velocity distribution and modified mass density	Calibrated to the Gruen flux	Calibrated to the Gruen flux
Release data	1985	1993	1996	1994 (Revision)	2004	2015 (Release 2.0)

[a]   Force of the Earth's gravitational field that attracts meteoroids, changes their trajectories, and therefore increases the flux

A.3   Model comparisons

Comparisons of the impact fluxes among several of the models are described in References [4],[5] and [10].

Annex B
(informative)

Capability of some space debris environment models

B.1 Model overview

B.1.1 SDEEM 2015

The SDEEM 2015[11] is based on a semi-deterministic analysis. A high-speed orbit propagator to include only the first-order solutions of orbit perturbations and an orbital elements discretization method to evaluate the spatial density and flux for targets are used in order to generate the space debris environment data in a highly efficient way. Spatial density and flux are the major outputs of the SDEEM 2015. SDEEM 2015 enables the calculation of flux for targets operating from 1959 to 2050, at altitudes of 200 km and 2 000 km.

B.1.2 SDEEM 2019

The SDEEM 2019[12][13] is an upgraded version of SDEEM 2015. The disintegration event can have a greater impact on the space debris environment in a short time. Updating the engineering model modelling data in time according to such events can effectively improve the model's responsiveness. Based on this, SDEEM 2019 software sets up a user interface to analyse user-defined space debris environment evolution data. For an emergency (or any debris group), users can generate space debris environment evolution data by themselves. Compared to its previous version SDEEM 2015, the modelling technology of SDEEM 2019 is largely improved, and the software is more flexible. Some of the major improvements include:

a) Extension of orbital range. The orbital range of SDEEM 2015 is 200 to 2 000 km, while for SDEEM 2019 it is 200 to 42 000 km.

b) Modelling technique improvement in GEO region. Spatial density and flux are presented under ECEF (Earth-centred Earth-fixed) coordinate system in GEO region, in order to enhance the pertinence in this particular region.

c) The effect of large constellations and unexpected breakups are analysed. The analysis process of the effect of large satellite constellation and unexpected breakup events on space debris environment is presented.

d) Interface design for user-defined space debris population. The SDEEM 2019 software is able to analyse any user-defined space debris population as long as the data form meets its specification, in order to present timely response to large satellite constellation and unexpected breakup events.

B.1.3 MASTER-8 model

The MASTER-8 model[14] is the successor of previously released models. The model is based on a semi-deterministic analysis of a reference population derived from the simulation of all major space debris source terms. Meteoroids, as the natural component of the Earth particulate environment, are modelled according to state-of-the-art approaches for both the sporadic background component and the meteoroid streams. The model consists of a flux and spatial density prediction tool that combines a quick assessment of spatial density characteristics with high resolution flux results and additional analytical capabilities, with an easy-to-use GUI. The model offers a full three-dimensional description of the terrestrial debris distribution reaching from LEO (perigee altitude above 186 km) up to lunar altitude (apogee altitude lower than 500 000 km). Flux results relative to an orbiting target or to an

inertial volume can be resolved into source terms, impactor characteristics and orbit, as well as impact velocity and direction.

NOTE 1   The MASTER-2005 model[15] is based on semi-deterministic analysis that includes orbit propagation of debris from all major debris sources and can estimate the meteoroid environment. The applicable scope of MASTER-2005 is an altitude between 186 km and 36 786 km and an impact object diameter between 1 μm and 10 m.

NOTE 2   The MASTER-2009 model[16] is an upgraded version of MASTER-2005. The applicable scope of MASTER-2009 is an altitude between 186 km and 36 786 km and an impact object diameter between 1 μm and 10 m.

B.1.4   ORDEM 3.1 model

The ORDEM 3.1 model[17] supersedes the previous NASA Orbital Debris Program Office models – ORDEM 3.0[18] and ORDEM2000.[19] The availability of new sensor and in situ data, re-analysis of older data, and development of new analytical techniques has enabled the construction of this more comprehensive and sophisticated model. The GUI of ORDEM 3.1 uses project-oriented organization and provides the user with graphical representations of numerous output data products. For example, these range from the conventional flux vs. average debris size (or altitude bin) for chosen analysis orbits (or views) to the more complex colour-contoured, two-dimensional directional flux diagrams in local spacecraft elevation and azimuth. The ORDEM 3.1 model contains debris populations covering low Earth orbit (up to 2 000 km altitude) to geosynchronous orbit (up to 40 000 km altitude) and can assess debris calculations up to year 2050.

NOTE   The ORDEM 2000 model and the ORDEM 3.0 model are empirical models based on ground-based observation data and surface inspection results of objects retrieved from orbit. ORDEM 2000 was released in 2002. ORDEM 3.0, which was released in 2014, includes material density classes of debris.

B.1.5   SPDA-E model

The SPDA-E model[20][21][22] is a semi-analytical stochastic model for medium- and long-term forecast of the debris environment (larger than 1 mm), for construction of spatial density, and velocity distribution in LEO and GEO, as well as, for risk evaluation. The model allows to calculate the following five characteristics of space debris: spatial density; cross-sectional area flux with respect to typical orbits of spacecraft; angular distribution of aforementioned cross-sectional area flux; angular dependence of the mean velocity of collisions; predicted values of cross-sectional area flux.

NOTE   Information on the last updates of the model is dated 2013 and the software is not freely available[22].

B.2   Model specifications

Table B.1 shows specifications of space debris environment models listed in B.1.

Table B.1 — space debris environment model specifications

Model specifications	Model				
	SDEEM 2005[11]	**SDEEM 2019**[12] [13]	**MASTER-8**[14]	**ORDEM 3.1**[17]	**SPDA-E**[20][21][22]
Source	Harbin Institute of Technology		ESA	NASA	RSA
Modelling approach	Semi deterministic analysis		Semi deterministic analysis	Measurement data	Semi deterministic analysis
Applicable regime					
a) minimum size	10 μm	10 μm	1 μm	10 μm	1 mm

Table B.1 *(continued)*

Model specifications	Model				
	SDEEM 2005[11]	SDEEM 2019[12][13]	MASTER-8[14]	ORDEM 3.1[17]	SPDA-E[20][21][22]
b) orbital regime	200 km to 2 000 km	200 km to 42 000 km	186 km (peri-gee altitude) to 500 000 km (apogee altitude)	100 km to 40 000 km (>10 µm) (LEO to GTO) 34 000 km to 40 000 km (>10 cm) (GEO)	400 km to 2 000 km, 35 300 km to 36 200 km
c) evolutionary period	1958 to 2050	1958 to 2050	1957 to 2036	2015 to 2050	Medium and long term
Input parameter	Target orbit scenario: -Semi-major axis -Eccentricity -Inclination -Argument of perigee	Target orbit scenario: -Semi-major axis -Eccentricity -Inclination - Right ascension of ascending node -Argument of perigee -Longitude (GEO targets)	Target orbit scenario: -Semi-major axis -Eccentricity, -Inclination, - Right ascension of ascending node -Argument of per-igee Inertial volume scenario: -Geocentric dis-tance, -Right ascension -Declination Spatial density scenario: -Lower/ upper altitude limit -Lower/ upper decline. Limit	-Apo/Peri -Altitude -Semi-major axis -Eccentricity -Inclination -Argument of perigee	—
Output data	Flux versus -Size -Relative ve-locity -Impact azi-muth -Impact eleva-tion	Flux versus -Size -Relative veloc-ity -Impact azimuth -Impact eleva-tion	Flux versus -Size -Mass -Semi-major axis -Eccentricity -Inclination -Altitude -Latitude -Impact velocity -Impact declination -Time, etc. Spatial density versus -Size -Mass -Altitude -Declination -Time	Flux versus -Size -Orbit position -Altitude -Latitude	—
Debris source terms					

Table B.1 *(continued)*

Model specifications	Model				
	SDEEM 2005[11]	**SDEEM 2019**[12][13]	**MASTER-8**[14]	**ORDEM 3.1**[17]	**SPDA-E**[20][21][22]
TLE background	Yes	Yes	Yes	(Density discrimination) (IN) Intacts (LD) Low-density (1,4 g/cc) fragments (MD) Medium-density (2,8 g/cc) fragments & microdebris (HD) High-density (7,9 g/cc) fragments & microdebris (NK) RORSAT NaK coolant droplets (0,9 g/cc)	All sources together
Fragments	Yes	Yes	Yes		
SRM dust and slag	Yes	Yes	Yes		
NaK droplets	Yes	Yes	Yes		
Paint flakes	Yes	Yes	Yes		
West ford needles	None	Yes	Yes		
MLI fragments	None	None	Yes		
Meteoroid					
Background	None	None	Diving-Staubach	None (Users should include MEM to calculate the total space particle impact environment for their spacecraft.)	None
Streams			Jenniskens-McBride, Cour-Palais		
Primary data source/ validation	—	—	-LDEF -CME -HST (SM1, SM3B) -EuReCa -PROOF 2009	-SSN catalogue -LDEF -Haystack radar -HST-SA -STS window and radiator -MOSEZT telescope -HAX -Goldstone radar	—