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# Space environment (natural and artificial) — Guide to process-based implementation of meteoroid and debris environmental models (orbital altitudes below GEO + 2 000 km)

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

ICS 49.140

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# Foreword

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# Introduction

Every space systems in Earth orbit is exposed to a certain flux of micrometeoroids and man-made space debris. Collisions with these particles take place with hypervelocity. The impact risk shall be evaluated in design phases of space systems. There are many meteoroid and space debris environment models that are studied and developed; which describe populations of meteoroids and/or space debris. These models can be used as interim solutions for impact risk assessments and shielding design purposes. 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 the propagated environment onto spatial and temporal distributions of objects densities, transient velocities, and impact fluxes. Until a specific standard for the space debris environment is defined, the common implementation process of models should be indicated for impact risk assessment and spacecraft's design purpose.

# Space environment (natural and artificial) — Guide to process-based implementation of meteoroid and debris environmental models (orbital altitudes below GEO+2000km)

## 1 Scope

This International Standard specifies the common implementation process for the meteoroid and debris environment models for risk assessment of spacecraft and launch vehicle orbital stages. This standard identifies the guidelines of selection process of models for impact risk assessment; and assures the traceability of using models through design phases of space systems.

## 2 Normative reference

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 17666:2003, *Space systems – Risk management*

ISO 24113:2010, *Space systems – Space debris mitigation requirements*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 17666:2003, ISO 24113:2010 and the following apply.

**3.1**
**engineering model**
environment model that provides clear and concise information that engineers need

**3.2**
**geosynchronous Earth orbit**
Earth orbit with an orbital period equal to the Earth’s sidereal rotation period

**3.3**
**gravitational focusing**
force of the Earth’s gravitational field that attracts meteoroids, changes their trajectories, and therefore increases the flux

**3.4**
**impact risk**
risk of impact against meteoroids and debris on spacecrafts

**3.5**
**interplanetary**
applicable regime of the meteoroid environment model from Earth with AU

**3.6**
**low earth orbit**
Earth orbit with an apogee altitude that does not exceed 2 000 km

**3.7**
**mass density**
mass per unit volume

**3.8**
**meteoroid**
particles of natural origin and result from the disintegration and fragmentation of comets and asteroids which orbit round the sun

**3.9**
**meteoroid / (space) debris environment(al) model**
tool that simulates realistic descriptions of the meteoroid and debris environment of Earth, and performs risk assessment via flux predictions on user defined target orbit

**3.10**
**traceability**
ability to trace the history, application or location of that which is under consideration

**3.11**
**space system**
system which contains at least one element that is intended to be operated in space

## 4 Abbreviated terms

| | |
|---|---|
| AU | Astronomical Units |
| ESA | European Space Agency |
| GEO | Geostationary Earth Orbit |
| IMEM | Interplanetary Meteoroid Engineering Model |
| ISO | International Organization for Standardization |
| ISS | International Space Station |
| LEO | Low Earth Orbit |
| MASTER | Meteoroid and Space Debris Terrestrial Environment Reference |
| MEM | Meteoroid Engineering Model |
| MSFC | Marshall Space Flight Center |
| NASA | National Aeronautics and Space Administration |
| ORDEM | Orbital Debris Engineering Model |
| SSP | Space Station Program |

# 5 Guideline of implementation of meteoroid and Space debris environmental models

## 5.1 Overview of implementation concept

An impact flux assessment, including the methodology used and any assumptions made, shall be performed and documented in accordance with the Space Debris Mitigation Plan specified by ISO 24113:2010." And a risk management shall be performed and documented in accordance with the management process specified by ISO 17666:2003.

## 5.2 Impact fluxes estimation into a project

When space systems are designed or planed, the risk caused by impacts of meteoroids and space debris shall be evaluated. For the risk assessment, impact fluxes of meteoroids and space debris on the spacecraft and launch vehicle orbital stages shall be estimated.

## 5.3 Meteoroid and debris model implementation procedure

Impact fluxes on space systems are calculated using spacecraft's design data (ex. configuration, orbit), meteoroid environment model and space debris environment model. When meteoroid environment model and space debris environment model applies to space system's design; the following procedure should be followed.

### 5.3.1 Step 1: Model selection agreement

The model(s) which is (are) applied to space system's design is (are) selected by mutual agreement between the customer and the supplier of the space system. Moreover, the traceability of the model(s) application shall be assured.

### 5.3.2 Step 2: Model selection

The customer and the supplier should consider model capabilities and should select suitable environment model(s) for the mission of thespacecraft and/or launch vehicle orbital stages. Model capabilities are described in the sections 5.4. When model(s) selection is performed, it is recognized that the environment models have uncertainties and there are large differences in the flux values among each model. And it is recommended that the customer and the supplier prepare several models, and the comparison of flux values among models.

### 5.3.3 Step 3: implementation of meteoroid and space debris environmental models on a project

When impact fluxes are estimated for spacecraft design and/or component design, following approaches are recommended, in point of view of traceability of development of model, maintenance of model, and convenience of model user (design engineer).

a) Engineering models (analysis codes) which are institutionally maintained by national agencies are considered as candidates for applicable models for the design.

b) When a critical component is designed, the model which produces the maximum risk (the worst case) is selected among candidate models.

NOTE 1 Use of models other than models which are described in the sections 5.4 is NOT restricted.

NOTE 2 When the revised models listed in the sections 5.4 are published or a new model is published, the new models should be added to the list.

## 5.4 Capabilities of environment models

### 5.4.1 Meteoroid environment models

Capabilities of meteoroid environment models are described in Annex A. Comparison of impact fluxes among models are described in the bibliography [1].

### 5.4.2 Space debris environment models

Capabilities of space debris environment models are described in Annex B. Comparison of impact fluxes among three engineering models, which are published by NASA and ESA, is described in the bibliography [2]. And the maximum impact flux (worst case) among three models is described in Annex C for informative.

# 6 Traceability assurance

## 6.1 Overview of traceability concept

Traceability of the meteoroid and space debris model application process shall be guaranteed in all design phases of a spacecraft.

## 6.2 Assurance of traceability in a project

When risk assessments of meteoroid and space debris impacts are required, the following items shall be recorded in each design phase of the spacecraft. The contents of the items are evaluated by reviewers, in the Design Review (DR), in each design phase. Reviewers shall confirm the validity of contents of the items.

a) Reasons of the model selection which are used for risk assessments for the spacecraft

b) All input/output parameters and those values.

NOTE 1 Lists of input parameters of ORDEM2000, MASTER-2001 and MASTER-2005 are described in ANNEX D for informative.

c) Assumptions of input parameters on the design and reasons of the assumptions

e) When output parameters are corrected (ex. applying safety factor, life factor, margin of safety etc.), the reason and the assumption of the correction and details of correction methods and correction results.

NOTE 2 After publications of major engineering models of space debris environment (ORDEM2000, MASTER-2001 and MASTER-2005), many new events (ex. collision events, 2009) happened and those events increase space debris. Additionally, MASTER-2005 cannot calculate the flux of less than 1mm of space debris after May 1st, 2005. It is recommended that new information about debris population is considered when output parameters are corrected.

# 7 Remarks

For an international project, it is recommended that the following items are agreed among member bodies before the project starting.

a) applied environment model(s) to the project

b) method of maintenance of the environment model(s)

c) procedure of impact risk assessment.

# Annex A
(informative)

# Capability of meteoroid environment models

## A.1 Model overview (Scope)

- Grüen et al. [3]

Grüen model assumes that an isotropic meteoroid distribution which is based on lunar crater, zodiacal light and in-situ measurement data.

- Divine [4]

Divine model assumes a non-isotropic distribution which is based on five populations in particle mass, inclination, eccentricity and perihelion distance.

- Divine-Staubach [5]

Divine-Staubach model is a follow-up the Divine model using new data from GALILEO and ULYSSES dust detectors.

- NASA SSP-30425 [6]

SSP-30425,“Space Station Program Natural Environment Definition for Design”, describe space environment for ISS design.

- IMEM [7]

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).

- MEM [8]

Near 1 AU fluxes are calibrated from the Grüen model. A constant mass density of 1.0 $g/cm^3$ is assumed and the velocity distributions are independent from the particle sizes.

## A.2 Model specifications

**Table A.1 — Meteoroid Model Specifications**

| Model | Grüen et al. | Divine | Divine-Staubach | SSP 30425 (ISS) | IMEM (ESA) | MEM (MSFC) |
|---|---|---|---|---|---|---|
| Bibliography | [1] | [2] | [3] | [4] | [5] | [6] |
| Sporadic/stream | Sporadic | Sporadic | Sporadic | Sporadic | Sporadic | Sporadic |
| Interplanetary | no | 0.1 to 20 AU | 0.1 to 20 AU | no | 0.1 to 10 AU | 0.2 to 2 AU |
| Mass/size range | $10^{-18}$ to $10^{2}$ g | $10^{-18}$ to 1g | $10^{-18}$ to 1g | $10^{-18}$ to $10^{2}$ g | $10^{-12}$ to $10^{2}$ g | $10^{-6}$ to 10g |
| Near Earth | yes | yes | yes | yes | yes | yes |
| Gravitational focusing | 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",and interstellar dust(<$10^{-9}$g) | 6 radar/photographic meteor sources (Helion, Anti-Helion, North Apex, South Apex, North Toroidal, South Toroidal) |
| Velocity distribution | single value (20km/s) | yes | yes | yes (Kessler) | yes | yes |
| Mass density | single value (2.5g/cm$^{3}$ | 2g/cm$^{3}$ (m<$10^{-6}$g);<br>1g/cm$^{3}$ ($10^{-6}$ – $10^{-2}$g);<br>0.5g/cm$^{3}$ (m>$10^{-2}$g) | 2g/cm$^{3}$ (m<$10^{-6}$g);<br>1g/cm$^{3}$ ($10^{-6}$ – $10^{-2}$g);<br>0.5g/cm$^{3}$ (m>$10^{-2}$g) | 2g/cm$^{3}$ (m<$10^{-6}$g);<br>1g/cm$^{3}$ ($10^{-6}$ – $10^{-2}$g);<br>0.5g/cm$^{3}$ (m>$10^{-2}$g) | single value (2.5g/cm$^{3}$ | single value (1g/cm$^{3}$) |
| Primary data source | in situ experiments, zodiacal light, lunar crater record. Gruen et al. flux is identifical to the 1970 Zook flux for m>$10^{-7}$g | zodiacal light, Harvard Radio Meter Project (HRMP) data | Staubach re-fitted the probability densities, taking account into Ulysses and Galileo spacecraft | not identified explictly | in situ experiments (Ulysses, Galileo), COBER IR, luner crater record. No Zodiacal light data. Disregard | Canadian Meteor Orbit Radar (CMOR) data |
| Key assumptions | lux on Earth is isotropi | calibrated to the Grüen flux | calibrated to the Grüen flux | Grüen flux with Kessler's velocity distribution and modified mass | calibrated to the Grüen flux | calibrated to the Grüen flux |
| Release data | 1985 | 1993 | 1996 | 1994 (Rev) | 2004 | 2006 (MEM 1.6, EarthMEM 1.0) |

Bibliography [9]: It was found that the Divine-Staubach approach fits the requirements of the MASTER model best.Thus, only the Divine approach and the extensions introduced by Staubach are implemented in the model.

# Annex B
(informative)

# Capability of space debris environment models

This annex's scope is a guide an engineer in the selection and use of ones that are suitable for his specific mission needs.

In point of view of impact risk assessment, debris flux models (Annex B.1) should be considered for space system design. Debris propagation (evolutionary) models (Annex B.2) for study of the long-term debris environment, and should not be applicable for impact risk assessment in design phase.

## B.1 Debris flux models

### B.1.1 Model overview (Scope)

- DAMAGE [10-12]

DAMAGE model aims to account for the unique characteristics involved in modelling the full LEO to GEO environment.

- IDES [13-18]

IDES model is able to study the historical, current and future space debris populations, in addition to providing directional collision risk assessments for satellites in the full LEO to GEO debris environment.

- MASTER2001 [19]

MASTER2001 model is based on semi-deterministic analysis that includes orbit propagation of debris from all major debris sources, and MASTER2001 model can estimate the meteoroid environment. The applicable scope of MASTER2001 is the altitude between 186 km and 38 786 km and impact objects diameter between 1 um 100 m.

- MASTER2005 [20]

MASTER2005 model is an upgraded version of MASTER2001 as a tool for estimating debris environment for spacecraft design. The applicable scope of MASTER2005 is the altitude between 186 km and 36 786 km and impact objects diameter between 1 um 10 m.

- ORDEM2000 [21]

ORDEM2000 model is an empirical model based on ground-based observation data and surface inspection results of objects retrieved from orbit. The applicable scope of ORDEM2000 is altitude between 200 km and 2,000 km and debris diameter between 10 um and 1 m.

- SPDA [22-24]

SPDA is a semi-analytical stochastic model for medium- and long-term forecast of the debris environment (with size larger than 1 mm), for construction of spatial density and velocity distribution in LEO and GEO as well as for risk evaluation.

### B.1.2 Model specifications

**Table B.1 — Debris Flux Model Specifications**

| Item | | DAMAGE | IDES | MASTER2001 | MASTER2005 | ORDEM2000 | SPDA |
|---|---|---|---|---|---|---|---|
| Bibliography | | [1-3] | [4-9] | [10] | [11] | [12] | [13-15] |
| Source | | Southampton University | DERA | ESA | | NASA | RSA |
| Modeling approach | | statistical and near-deterministic methods | semi deterministic analysis | semi-deterministic analysis | | mesurement data | stochastic semi-analysis |
| Applicable regime | Minimum size | 1mm | ＞10μm | ＞1μm | | ＞10μm | ＞1mm |
| | Orbital regime | 120 - 37786 km | LEO to GEO | 186 - 36786 km | | 200 - 2000 km | 400 - 2000, 35300 - 36200 km |
| | Evolutionary period | long term | short and long term | 1958 - 2050 | 1957 - 2055 | 1991 - 2030 | medium and long term |
| Input parameter | | ・Target Orbit<br>Semi-major axis, Eccentricity, Inclination, Right asc. of asc. node, Argument of perigee | | ・Target Orbit Scenario<br>Semi-major axis, Eccentricity, Inclination, Right asc. of asc. node, Argument of perigee<br>・Inertial Volume Scenario<br>Geocentric distance, Right ascension, Declination<br>・Spatial Density Scenario<br>Lower/Upper alt. limit, Lowe/Upp | | Apo/Peri Altitude<br>Semi-major axis<br>Eccentricity<br>Inclination<br>Argument of perigee | |
| Output data | | Spatial density vs Altitude,<br>Spatial density vs Inclination,<br>Number of objects vs Time,<br>Cumulative number of collisions vs Time. | | ・Flux vs. Size, Mass, Semi-major axis, Eccentricity, Inclination, Altitude, Latitude, Impact velocity, Impact declination, Time, etc.<br>・Spatial density vs. Size, Mass, Altitude, Declination, Time | | Flux vs. Size,<br>Orbit position,<br>Altitude, Latitude | |
| Debris source terms | TLE background | yes<br>(or simulated from historical launch and fragmentation data) | | yes | | all soutces together | all sources together |
| | Fragments | yes | | yes | | | |
| | SRM dust/slag | TBC | | yes | | | |
| | NaK droplets | TBC | | yes | | | |
| | Paint flakes | no (TBC) | | yes | | | |
| | West ford needles | TBC (currently included if catalogued). | | yes | | | |
| Meteoroid | Background | none | none | Divine-Staubach | | none | none |
| | Streams | | | Jenniskens-McBride, Cour-Palais | | | |
| Primary data source / Validation | | DISCOS Database, IDES, MASTER, LEGEND | | LDEF, HST(SM1), EuReCa, *PROOF2001* | LDEF, CME, HST(SM1, SM3B), EuReCa, *PROOF2005* | SSN catalog, LDEF, Haystack radar, HST-SA, STS window and radiator, HAX radar, Goldstone radar | |
| Model features | | LEO-to-GEO (including GTO), mitigation and removal strategies, GUI. | | Flux to spheres, Oriented surf., GUI, Time browser | | | |
| Engneering model available for intentional use | | No engineering model, but Particles-in-a-box model (called FADE) is available (Further details can be provided upon request). | no | yes | yes | yes | no |
| Release data | | 2001, 2009 | 1996 | 2002 | 2006 | 2002 | 2001 |

## B.2 Debris propagation (evolutionary) models

### B.2.1 Model overview (Scope)

- LEGEND [25,26]

LEGEND model is capable of reproducing the historical debris environment as well as performing future debris environment projection. The applicable scope of LEGEND is the altitude between 200 and 40 000 km and outputs debris distributions in one-dimensional (altitude), two-dimensional (altitude, latitude), and three-dimensional (altitude, latitude, longitude) formats.

- LEODEEM [27,28]

LEODEEM calculates LEO debris evolution (less than 2 000 km altitude of perigee) taking into account collisions, and future launch traffic. It becomes possible to predict a long term LEO environment and investigate future mission hazard evaluation by using this model.

- GEODEEM [29]

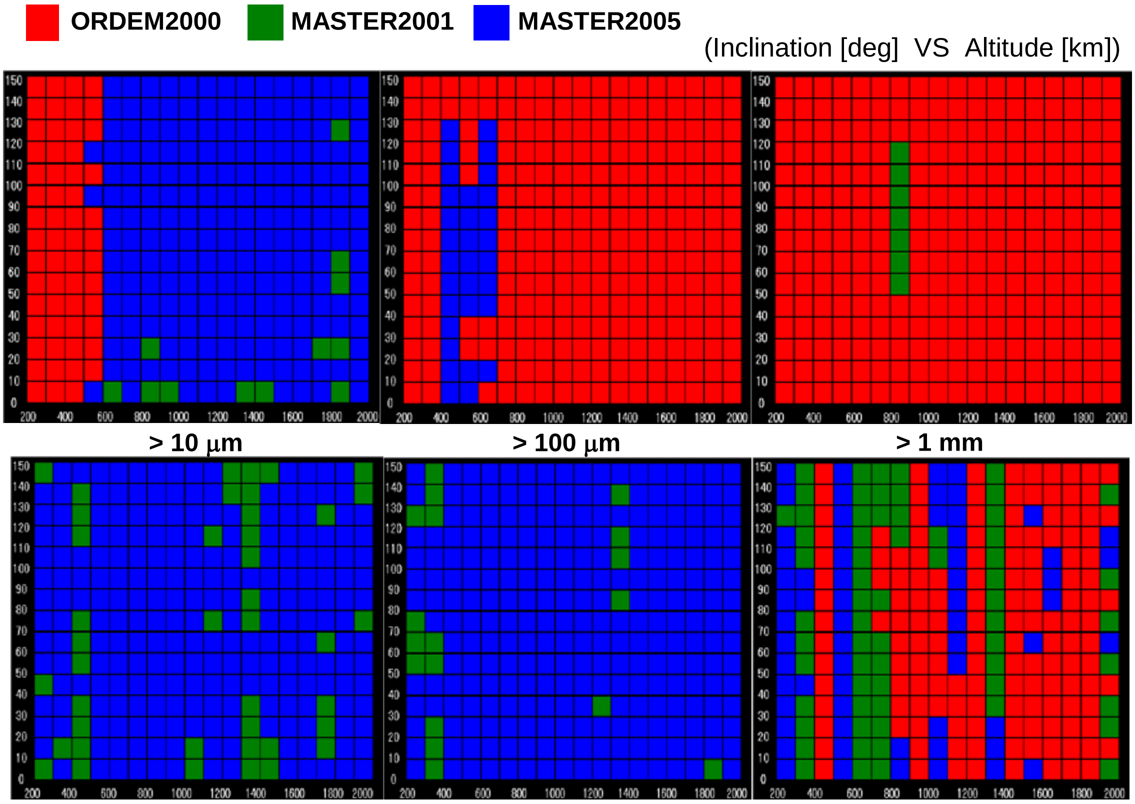
GEODEEM calculates GEO debris evolution taking into account collisions, and future launch traffic. Emphasis has been placed on the rate of collisions in the geosynchronous orbit and in the higher collection orbits and on the significance of cross-regime contamination.

NOTE The some models identified in B-1 (DAMAGE, IDES, SPAD) can also be used for long-term evolutionary analyses.

# Annex C
(informative)

## The Highest Debris Flux Values Among ORDEM2000, MASTER-2001 and MASTER-2005

Following figure indicates the highest debris flux model among three models (ORDEM2000, MASTER2001 and MASTER2005). The highest flux model was shown in different colours which classified by each space environment model [30, 31].



> 10 µm

> 100 µm

> 1 mm

> 1 cm

> 10 cm

> 1 m

**Table C.1 — The highest debris flux model among three models (ORDEM2000, MASTER2001 and MASTER2005)**

# Annex D
(informative)

# Examples of Input Parameters of ORDEM2000, MASTER-2001 and MASTER-2005

## D.1 Input parameters of ORDEM2000

**Table D.1 — Input parameters of ORDEM2000**

| | | | | |
|---|---|---|---|---|
| **Spacecraft Assessment** | Orbit Definition | by Apo/Peri Altitude | Apogee (km) | 200～100000 |
| | | | Perigee (km) | 200～2000 |
| | | | | |
| | | by SMA/ECC | Semimajor Axis (km) | 6578～100000 |
| | | | Eccentricity (km) | 0～1 |
| | | | | |
| | Inclination (deg) | 0～180 | | |
| | Year of observation | 1991-2030 | | |
| | | | | |
| | Argument of Perigee | Ramdom Arg.. of Perigee | on/off | |
| | | Argument of Perigee (deg) | 0～360 | |

## D.2 Input parameters of MASTER-2001

**Table D.2 — Input parameters of MASTER-2001**

| | | | | | |
|---|---|---|---|---|---|
| STANDARD application | Analysis Interval (yyyy/mm/dd hh) | Start period | 1957/10/04/00 | | |
| | | End period | 2050/05/01/00 | | |
| | | | [m] | [kg] | |
| | Size Interval | Min.size [m]/[kg] | 1.00E−05 | 1.00E−14 | |
| | | Max.size [m]/[kg] | 1.00E+02 | 1.00E+07 | |
| | Target orbit description | Semi−mjar axis [km] | 6565～43164 | | |
| | | Eccentricity [−] | 0～1 | | |
| | | Inclination [deg] | 0° ～180° | | |
| | | Right asc. of asc. Node [deg] | 0° ～360° | | |
| | | Argument of perigee [deg] | 0° ～360° | | |
| | | True Anomaly [deg] | 0° ～360° | | |
| | | Length of orbit arc [deg] | 0° ～360° | | |
| | Source Selection | Debris Sources | launch and mission related objects | | |
| | | | Fragments | | |
| | | | NaK−droplets | | |
| | | | SRM slag | | |
| | | | SRM Al203 dust | | |
| | | | Paintflakes | | |
| | | | Ejecta | | |
| | | | future explosions | | |
| | | | future collisions | | |
| | | Meteoroid Sources | core population | | |
| | | | asteroidal population | | |
| | | | A population | | |
| | | | B population | | |
| | | | C population | | |
| | Surface Definitions | Sphere | | | |
| | | Randomly Tumbling Plate | | Azi./R.Asc | Elev./Dec. |
| | | Oriented Surface | Earth oriented | −180° ～180° | -90° ～90° |
| | | | Sun oriented | 0° ～360° | |
| | | | Inertially fixed | 0° ～360° | |

## D.3 Input parameters of MASTER-2005

**Table D.3 — Input parameters of MASTER-2005**

| | | | | |
|---|---|---|---|---|
| **Analysis Interval (yyyy/mm/dd hh)** | Start period | 1957/11/01 12 | | |
| | End period | 2055/05/01 12 | | |
| | | [m] | [kg] | |
| **Size interval** | Min. size: lower diameter threshold | 1.00E−05 | 1.00E−14 | |
| | Max. size: upper diameter threshold | 1.00E+01 | 1.00E+06 | |
| **Target orbit desctiption** | Semi−major axis [km] | 6565～43,164 | | |
| | Eccentricity [−] | 0～1 | | |
| | Inclination [deg] | 0° ～180° | | |
| | Right asc. of asc. Node [deg] | 0° ～360° | | |
| | Argument of perigee [deg] | 0° ～360° | | |
| **Source Slection** | Debris Sources | Expl. Fragments | | |
| | | Coll. Fragment | | |
| | | Launch/Mission Related Obj. | | |
| | | NaK Droplets | | |
| | | SRM Slag | | |
| | | SMR Dust | | |
| | | Paint Flakes | | |
| | | Ejecta | | |
| | | All Debris Sources | | |
| | Meteoroid Sources | Core Population | | |
| | | Asteroidal Population | | |
| | | A Population | | |
| | | B Population | | |
| | | C Population | | |
| | Seasonal Meteoroid Streams | Jenniskens−McBride | | |
| | | Cour−Palais | | |
| **Surface Definitions** | sphere | | | |
| | randomly tumbling plate | | Azi./R.Asc. [deg] | Elev./Dec.[deg] |
| | oriented surface | earth oriented | −180° ～180° | −90° ～90° |
| | | sun oriented | 0° ～360° | |
| | | inertially fixed | 0° ～360° | |

# Bibliography

[1] Drolshagen.,G, Dikarev, V., Landgraf, M., Krag, H., Kuiper, W., "Comparison of Meteoroid Flux Models for Near Earth Space", Earth, Moon , and Planets, Vol. 102, No. 1-4, 2008, pp. 191-197.

[2] FUKUSHIGE, S., AKAHOSHI, Y., KITAZAWA Y., GOKA, T., “Comparison of Debris Environment Models; ORDEM2000, MASTER2001 and MASTER2005”, IHI Engineering Review Vol. 40 No. 1 February (2007), p.31-41

[3] Gruen, E.. et al., “Collisional Balance of Meteoritic Complex”, Icarus, Vol. 62, pp. 244-272, 1985.

[4] Divine, N., “Five Populations of Interplanetary Meteoroids”, Journal of Geophysical Research,Vol. 98, No. E9, pp. 17,029-17,048, 1993. "

[5] Dikarev, V. et al., “TOWARDS A NEW MODEL OF THE INTERPLANETARY METEOROID ENVIRONMENT”,Advances in Space Research, Vol. 29, No. 28, pp. 1171-1175, 2002."

[6] Kessler, D. J., “Space Station Program Natural Environment Definition for Design, International Space Station Alpha”, NASA SSP 30425, Revision B,National Aeronautics and Space Administration Space Station Program Office, Houston, TX, USA, 1994"

[7] Dikarev, V. et al., “The new ESA meteoroid model”, Advances in Space Research, Vol. 35, pp. 1282-1289, 2005.

[8] Mcnamara, H. et al., “METEOROID ENGINEERING MODEL (MEM): A METEOROID MODEL FOR THE INNER SOLAR SYSTEM”,Earth, Moon, and Planets, Vol. 95, pp. 123-139, 2004.

[9] Oswald, M. et al., “MASTER-2005 Final Report”, Institute of Aerospace Systems, April 2006.

[10] Lewis, H.G. et al., “DAMAGE: A DEDICATED GEO DEBRIS MODEL FRAMEWORK”, In: Proceedings of the Third European Conference on Space Debris, Darmstadt, Germany, 19–21March , 2001.

[11] Lewis, H.G. et al.,"ACTIVE REMOVAL STUDY FOR ON-ORBIT DEBRIS USING DAMAGE”, In: Proceedings of the Fifth European Conference on Space Debris, Darmstadt, Germany, 30 March –2 April 2009, ESA SP-672, July 2009.

[12] Nölke, D. and Reimerdes, H.-G. ,"RISK ANALYSIS AND DAMAGE PREDICTION OF SMALL SPACECRAFT”, In: Proceedings of the Fifth European Conference on Space Debris, Darmstadt, Germany, 30 March –2 April 2009, ESA SP-672, July 2009.

[13] Lewis, H.G. et al., “DEBRIS SPATIAL DENSITY DEPENDENCE ON CONTROL VOLUME RESOLUTION IN THE GEOSYNCHRONOUS ENVIRONMENT”, 35th COSPAR Scientific Assembly. Held 18-25 July 2004, in Paris, France, pp. 2912.

[14] Walker, R. et al., “ENHANCEMENT AND VALIDATION OF THE IDES ORBITAL DEBRIS ENVIRONMENT MODEL”, Springer Netherlands, Vol. 1, Number 1, 1999, pp. 1-19(19).

[15] Jehn, R. et al., “COMPARISON OF THE 1999 EXPERIMENT RESULTS WITH BEAM-PARK SPACE DEBRIS MODELS”, Advances in Space Research, Vol. 28, 2001, pp. 1367-1375.

[16] Walker, R. et al., “LONG—TERM COLLISION RISK PREDICTION FOR LOW EARTH ORBIT SATELLITE CONSTELLATIONS”, Acta Astronautica, Vol. 47, 2000, pp. 707-717.

[17] Walker, R. et al., “STUDYING THE MEO & GEO SPACE DEBRIS ENVIRONMENTS WITH THE INTEGRATED DEBRIS EVOLUTION SUITE (IDES) MODEL”, In: Proceedings of the Third European Conference on Space Debris, Noordwijk, Netherlands, 2001.

[18] Walker, R. et al., “A COMPARISON OF IDES MODEL PREDICTIONS WITH DEBRIS MEASUREMENT DATA”, Second European Conference on Space Debris, Organised by ESA, held 17-19 March, 1997, ESOC, Darmstadt, Germany, ESA-SP 393, pp. 239.

[19] Wiedemann, C. et al., “MASTER-2001 Final Report”, Institute of Aerospace Systems, December, 2002.

[20] Wiedemann, C. et al., “MASTER-2005 Final Report”, Institute of Aerospace Systems, April, 2006. http://www.master-2005.net/index.html

[21] Liou, J.-C. et al., “The New NASA Orbital Debris Engineering Model ORDEM2000”, NASA/TP—2002-210780, 2002. http://orbitaldebris.jsc.nasa.gov/model/engrmodel.html

[22] Sdunnus, H. et al., “Comparison of debris flux models”, Advances in Space Research, Vol. 34, 2004, pp. 1000-1005.

[23] Andrey, I. et al., “ENGINEERING MODEL OF SPACE DEBRIS ENVIRONMENT”, In: Proceedings of the Third European Conference on Space Debris, 19-21 March 2001, Darmstadt, Germany. Ed.: Huguette Sawaya-Lacoste. ESA SP-473, Vol. 1, Noordwijk, Netherlands: ESA Publications Division, ISBN 92-9092-733-X, 2001, pp. 293-298.

[24] Nazarenko, A.I., “COLLISION OF SPACECRAFT WITH DEBRIS PARTICLES ASSESSMENT”, In: Proceedings of 17th International Symposium on SPACE FLIGHT DYNAMICS, 16-20 June 2003 RUSSIA, MOSCOW.

[25] Liou, J.-C., “A statistical analysis of the future debris environment”, Acta Astronautica, Vol. 62, 2008, pp. 264-271."

[26] Liou, J.-C. et al., “LEGEND - a three-dimensional LEO-to-GEO debris evolutionary model”, Advances in Space Research, Vol. 34, 2004, pp. 981-986."

[27] Narumi, T. et al., “Space Debris Environmental Evolutionary Model in Low Earth Orbit”,The Japan Society for Aeronautical and Space Sciences, Vol. 7, 2008, pp. 1-17."

[28] Maniwa, K. et al., “Instability of the Current Space Debris Population inLow Earth Orbit”, The Japan Society for Aeronautical and Space Sciences, Vol. 58, No. 674, 2010, pp. 83-89."

[29] Hanada, T., “Consequences of Continued Growth in the GEO and GEO Disposal Orbital Regimes”, The Japan Society for Aeronautical and Space Sciences, Vol. 50, No. 577, 2002, pp. 48-55**.**

[30] TAHARA, N., KITAZAWA, Y., UCHINO, M., NAGAI, H., AKAHOSHI., Y. , GOKA. T, Comparison of Estimation Using Debris Environment Models for International Standardization, Preprint of The 27th International Symposium on Space Technology and Science, Tsukuba, JAPAN, 2009.

[31] JAXA Space Environment Standard, (Document No. JERG-2-141), JAXA,2009.