# Introduction to Trilateral S&MA Task Force "Space Sustainability"

Kumi NITTA
Japan Aerospace Exploration Agency
System Safety and Space Operations Safety Unit

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# 1. Introduction to the SSTF – (1) Background and History

## (1) Background

- An opinion was raised by a participant upon continuous Space Debris increase that;
  "Isn't there anything Trilateral S&MA could do against the worsening orbit situation?"
  (TRISMAC 2021; May 2021)
- We all agreed to form a TF dedicated to "Space Sustainability"
  (Trilateral Summit; June 2021)

## (2) History

- Kickoff meeting held in Oct. 2021
- Participants agreed on the understanding of the situation and the TF mission;
  - ✓ Requirements ("What to Dos") are available in various doc's but NOT properly implemented as expected
  - ✓ S&MA are the ones to provide "How to Dos" to realize "Space Sustainable" products/ services
  - ✓ Selected UNCOPUOS LTS Guideline as "Starting Point" as it brings a comprehensive agenda for Space Sustainability
  - ✓ TF to develop "Information Packages (IP)" to be used in development frontlines
- TF Charter was signed in Mar. 2022
- Developed an IP example and started (or "about to start") user feedback collection

# 1. Introduction to the SSTF – (2)
# Space Sustainability activities around the world

- There are many conferences and working groups around the world to discuss space sustainability. Here are some of the events and groups to look out for:

- ✓ UN/Portugal Conference: "Management and Sustainability of Outer Space Activities“
- ✓ Committee on the Peaceful Uses of Outer Space (COPUOS)COPUOS
- ✓ Secure World Foundation & Japanese government :The Summit for Space Sustainability
- ✓ European Space Forum
- ✓ UNOOSA: Working Group on the Long-Term Sustainability of Outer Space Activities
- ✓ The World Economic Forum: Global Future Council on Space Space Sustainability Monitor
- ✓ The Earth∞Space Sustainability Initiative
- ✓ Austria's Federal Ministry: Centre of Excellence for Space and Sustainability (CESS)

Etc………..

All of them are mainly guidelines and regulations, and there seems to be little technical discussion, so I felt that if our activities were more technical than technical, they would be more inclusive.

# 1. Introduction to the SSTF – (3) from TF Charter Outline

## (1) What should be implemented in this TF?

(a) Many regulations, guidelines, and recommendations related to space sustainability (including space debris mitigation) have been issued, and "What to Do" for Space Actors is becoming more apparent.

(b) However, consistent compliance with the regulatory framework above continues to be problematic. It is in the common interest of all Space Actors to establish and share possible approaches to meet the full intent of policy related to space sustainability.

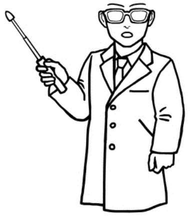
## (2) TF Mission

(a) S&MA will provide "How to Do" support to the operators (projects and businesses) inside and outside each agency by utilizing its accumulated technology, knowledge, and various networks.

(b) Specifically, we provide helpful information and technical support to assist operators to "implement" the requirements and recommendations (Shall, Should, Recommend) specified in various guidelines, ISO, and standard documents of each agency into their products, design, manufacturing, and operation technologies.

# 1. Introduction to the SSTF – (4) Expected Outcome

## <Before>



Specialists

ECSS-E-ST-xxxx

NASA-STD/ HDBK

JMR/ JERG

UNITED NATIONS
Office for Outer Space Affairs

IADC
Inter-Agency Space Debris Coordination Committee

WORLD ECONOMIC FORUM

Here are "**What to Dos**" **(partially How to Dos)**.
It's you to develop products to meet them.

Operators

Not sure which/ how to use support materials; Tools, Facilities, DBs, and Papers/ Documents

How to comply?

Whom to consult?

## <After>

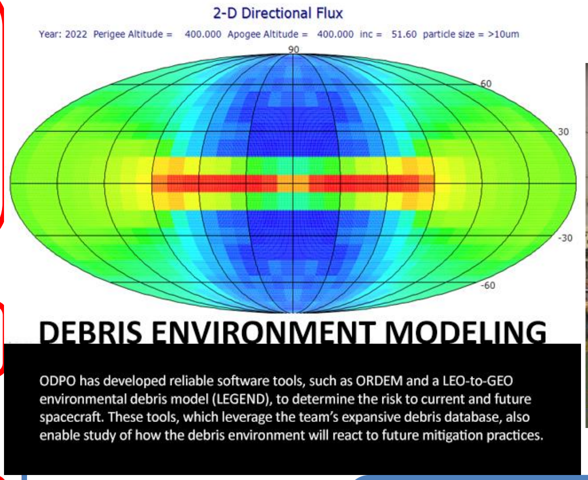
S&MA provides "**How to Dos**".

- Information Packages
- Lectures (Analysis Tools etc.)
- Consultancy
- Test Plans, etc.

Info. Packages


Lectures/ Consultancy

Analysis Tools




Test Facilities

Now, much clearer how to implement the whole requirements !!

# 2. Phase 1 Achievement – (1) Output

Starting from LTS B.8 high-level requirements, extracted technical keywords (Discussion Items; DI) for which "How to Dos" should be developed and shared.

Table 3s in the "Information Package" provide comprehensive information from three agencies.

**Step 1**
Extract and Breakdown of LTS B.8 Full Statements that require measures

→

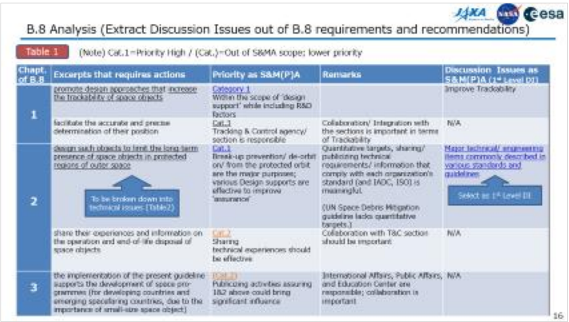
**Step 2**
**"Table 1"**
Select High-Priority 1st Level DI's

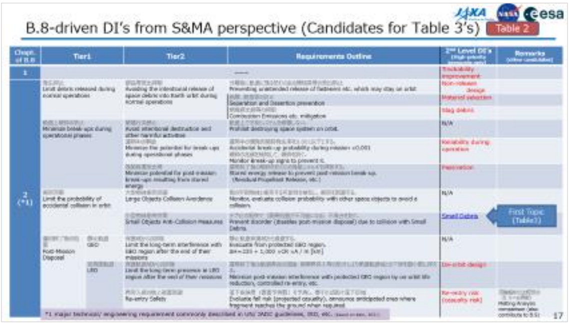
→

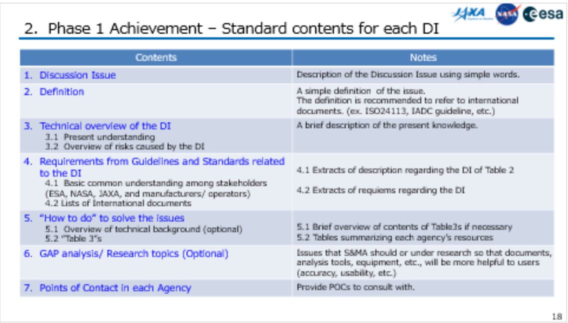
**Step 3**
**"Table 2"**
Select 2nd Level DI's (Technical Keywords)

→

**Step 4**
**IP incl. "Table 3s"**
Arrange available resources for the selected DI





2. Phase 1 Achievement – Standard contents for each DI

| Contents | Notes |
| --- | --- |
| 1. Discussion Issue | Description of the Discussion Issue using simple words. |
| 2. Definition | A simple definition of the issue. The definition is recommended to refer to international documents. (ex. ISO24113, IADC guideline, etc.) |
| 3. Technical overview of the DI<br>3.1 Present understanding<br>3.2 Overview of risks caused by the DI | A brief description of the present knowledge. |
| 4. Requirements from Guidelines and Standards related to the DI<br>4.1 Basic common understanding among stakeholders (ESA, NASA, JAXA, and manufacturers/ operators)<br>4.2 Lists of International documents | 4.1 Extracts of description regarding the DI of Table 2<br>4.2 Extracts of requiems regarding the DI |
| 5. "How to do" to solve the issues<br>5.1 Overview of technical background (optional)<br>5.2 "Table 3"s | 5.1 Brief overview of contents of Table3s if necessary<br>5.2 Tables summarizing each agency's resources |
| 6. GAP analysis/ Research topics (Optional) | Issues that S&MA should or under research so that documents, analysis tools, equipment, etc., will be more helpful to users (accuracy, usability, etc.) |
| 7. Points of Contact in each Agency | Provide POCs to consult with. |

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Standard IP Contents (Template)


Example Table 3 for "Small Debris"

# 2.Phase 1 Achievement – (2) Example IP for Small Debris

# 2. Phase 1 Achievement (3) – Small Debris IP publish plan

## (1) The joint Doc. development

The final draft was sent out for final review.
Agencies' internal Doc. authorization , Small Debris IP publish and HP uploads will follow.

Co-Authors;

- Kumi NITTA (JAXA; Leader)
- Yukihito KITAZAWA (JAXA)
- Shin TAURA (JAXA)
- Horoyuki HIRABAYASHI (JAXA)
- Frank GROEN (NASA)
- Matthew FORSBACCA (NASA)
- J.-C. LIEU (NASA)
- Rosario NASCA (EX-ESA)
- Paloma VILLAR (ESA)
- Sergio VENTURA (ESA)

Microsoft Word
文書


ESA-TECQ-RP-2024-001931
CAA-2023042
NASA/TM-20240003092

Tri-Agency S&MA Joint Report for Space Sustainability:
Information Packages Release 1, Small Debris

European Space Agency
European Space Research and Technology Centre
Keplerlaan 1, PO Box 299NL-2200 AG Noordwijk, The Netherlands
www.esa.int

Japan Aerospace Exploration Agency
Tsukuba Space Center
2-1-1 Sengen, Tsukuba, Ibaraki 305-8505, Japan
https://global.jaxa.jp/

National Aeronautics and Space Administration
NASA Headquarters
Washington, D.C. 20546
www.nasa.gov

June 2024

# 2. Phase 1 Achievement (4)- Summary

We're ready to listen to potential users.
We could develop better packages upon their voice and expand coverage along with the TF purpose.

| Planned Actions (based on the Charter) | Achievements | Comments |
|---|---|---|
| 1. Sort useful Knowledge Base<br><br>(1) Applicable documents and Websites (Standards, Handbooks, databases, etc.)<br>(2) Owned tools<br>(3) Available technologies and facilities | (1) Broke down LTS B.8 to extract technical keywords (DIs), which require comprehensive IPs<br>(2) Took "Small Debris" as a DI example and developed the draft IP<br>(3) Completed standard contents of IP<br>(4) Completed an example draft IP for Small Debris | (1) Draft IP comprehensively summarized required information<br>(2) Collecting feedback from potential users |
| 2. Develop the way of informing the operators | Not yet completed : Implemented an internal document approval process for each agency. It will be listed on the website of each Agency. | It need to prepare multiple IPs before informing. |
| 3. Develop action plans forward | The TF agreed on the outline of the Phase 2 plan and began to consider its contents. | |

# 3. Conclusion-(1) From the Team

1. The team believes the activity itself and the “Information Package” are worthwhile;
   (1) shows fully supportive attitude of the three agencies
   (2) comprehensive information
   (3) TBD

2. On the other hand, the achievement to date is limited;
   (1) Just started users’ voice on the Draft IP; subject to refinement
   (2) Only one DI has been covered; more DIs should be covered
   (3) Yet to be shared with public users

3. The team strongly recommends continuing the TF, along with the Charter.

# 3. Conclusion-(2) Phase 2 Plan Outline

"Phase 1" = Apr.2022 – Dec.2022; tried to develop an IP for "Small Debris" and now finalized.

"Phase 2" = Dec. 2022 (previous Trilateral Summit) until 2025(TBD)

- ✓ Publish a joint Doc. for Small Debris / Presentation @ TRISMAC
- ✓ Develop another IP for Uncontrolled Re-entry

## 1. Develop IPs for 'How to Do'

(1) Small Debris (@Phase 1)

(2) Uncontrolled Re-entry

(3) Others (To be Confirmed)

Main Stream

## 2. Publish/ Announcement

(1) Finalize the Joint Doc. for Small Debris

(2) Publish @HP sites

(3) Presentation at the TRISMAC, announcing new HP sites for users now.

(4) Others

User Feedback

Input

### Out-of-TF activities (upon agreement)

(1) Comparison Test
(ex. Hypervelocity impact facilities)

(2) Benchmark Evaluation
(ex. Impact Risk Analysis Tools)

(3) Design Guideline comparison
(ex. Protection Design)

HVIS TSUKUBA2024

# 17th HYPERVELOCITY IMPACT SYMPOSIUM

# HVIS 2024

2024
9.8 SUN – 9.13 FRI

Tsukuba, Japan

Tsukuba International Congress Center
2-20-3 Takezono, Tsukuba City, Ibaraki Prefecture 305-0032

https://hvis2024japan.jp/

## Key Dates

**Abstract Due**
~~November 30, 2023~~
December 15, 2023

**Abstract acceptance notification**
Late-January 2024

**Paper manuscripts due**
March 31, 2024

**Revised papers due**
July 30, 2024

Appendix

# B.8 Analysis (Extract Discussion Issues out of B.8 requirements and recommendations)

Table 1 (Note) Cat.1=Priority High / (Cat.)=Out of S&MA scope; lower priority

| Chapt. of B.8 | Excerpts that requires actions | Priority as S&M(P)A | Remarks | Discussion Issues as S&M(P)A (1st Level DI) |
|---|---|---|---|---|
| 1 | promote design approaches that increase the trackability of space objects | Category 1<br>Within the scope of 'design support' while including R&D factors | | Improve Trackability |
| | facilitate the accurate and precise determination of their position | Cat.3<br>Tracking & Control agency/ section is responsible | Collaboration/ Integration with the sections is important in terms of Trackability | N/A |
| 2 | design such objects to limit the long-term presence of space objects in protected regions of outer space<br>To be broken down into technical issues (Table2) | Cat.1<br>Break-up prevention/ de-orbit on/ from the protected orbit are the major purposes; various Design supports are effective to improve 'assurance' | Quantitative targets, sharing/ publicizing technical requirements/ information that comply with each organization's standard (and IADC, ISO) is meaningful.<br>(UN Space Debris Mitigation guideline lacks quantitative targets.) | Major technical/ engineering items commonly described in various standards and guidelines<br>Select as 1st Level DI |
| | share their experiences and information on the operation and end-of-life disposal of space objects | Cat.2<br>Sharing technical experiences should be effective | Collaboration with T&C section should be important | N/A |
| 3 | the implementation of the present guideline supports the development of space pro-grammes (for developing countries and emerging spacefaring countries, due to the importance of small-size space object) | (Cat.2)<br>Publicizing activities assuring 1&2 above could bring significant influence | International Affairs, Public Affairs, and Education Center are responsible; collaboration is important | N/A |

# B.8-driven DI’s from S&MA perspective (Candidates for Table 3’s)

Table 2

| Chapt. of B.8 | Tier1 | Tier2 | Requirements Outline | 2nd Level DI’s (High-priority keywords only) | Remarks (other candidates) |
|---|---|---|---|---|---|
| 1 | ――― | | | Trackability improvement | |
| 2 (*1) | 発生抑止<br>Limit debris released during normal operations | 部品等放出抑制<br>Avoiding the intentional release of space debris into Earth orbit during normal operations | 分離後に軌道に残る恐れのある締結具等の放出防止<br>Preventing unintended release of fasteners etc. which may stay on orbit | Non-release design | |
| | | | 剥離、脱落等の防止<br>Separation and Desertion prevention | Material selection | |
| | | | 燃焼排出物等の抑制<br>Combustion Emissions etc. mitigation | Slag debris | |
| | 軌道上破砕の防止<br>Minimize break-ups during operational phases | 破壊行為禁止<br>Avoid intentional destruction and other harmful activities | 軌道上で宇宙システムを破壊しない。<br>Prohibit destroying space system on orbit. | N/A | |
| | | 運用中の事故<br>Minimize the potential for break-ups during operational phases | 運用中の偶発的破砕発生率を0.001以下とする。<br>Accidental break-up probability during mission <0.001<br>破砕の兆候を検知して、破砕を防ぐ。<br>Monitor Break-up signs to prevent it. | Reliability during operation | |
| | | 残留推薬放出等<br>Minimize potential for post-mission break-ups resulting from stored energy | 運用終了後の破砕を防ぐため残留エネルギを排除する。<br>Stored energy release to prevent post-mission break-up.<br>（Residual Propellant Release, etc.） | Passivation | |
| | 衝突対策<br>Limit the probability of accidental collision in orbit | 大型物体衝突回避<br>Large Objects Collision Avoidance | 他の宇宙物体と衝突する可能性を検知し、衝突を回避する。<br>Monitor, evaluate collision probability with other space objects to avoid a collision. | N/A | |
| | | 小型物体衝突対策<br>Small Objects Anti-Collision Measures | デブリとの衝突で（廃棄処置が不可能になる）不具合を防ぐ。<br>Prevent disorder (disables post-mission disposal) due to collision with Small Debris. | Small Debris | ⇐ First Topic (Table3) |
| | 運用終了後の処置<br>Post-Mission Disposal — 静止軌道<br>GEO | 保護域からの排除<br>Limit the long-term interference with GEO region after the end of their missions | 静止軌道保護域から退避する。<br>Evacuate from protected GEO region.<br>ΔH＝235 + 1,000 ×CR ×A / m [km] | N/A | |
| | 低高度軌道<br>LEO | 保護軌道域からの排除<br>Limit the long-term presence in LEO region after the end of their missions | 運用終了後は軌道寿命の短縮、制御再突入等の処分により保護軌道域との干渉を最小限に抑える。<br>Minimize post-mission interference with protected GEO region by on-orbit life reduction, controlled re-entry, etc. | De-orbit design | |
| | | 再突入時の地上被害回避<br>Re-entry Safety | 落下危険度（傷害予測数）を予測し、要すれば破片落下区域<br>Evaluate fall risk (projected casualty), announce anticipated area where fragment reaches the ground when required. | Re-entry risk (casualty risk) | 溶融解析の比較照合（B.９へも貢献）<br>Melting Analysis comparison (also contribute to B.9) |

*1 major technical/ engineering requirement commonly described in UN/ IADC guidelines, ISO, etc. (based on Kato, 2021)

# 2. Phase 1 Achievement – Standard contents for each DI

| Contents | Notes |
|---|---|
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| 6. GAP analysis/ Research topics (Optional) | Issues that S&MA should or under research so that documents, analysis tools, equipment, etc., will be more helpful to users (accuracy, usability, etc.) |
| 7. Points of Contact in each Agency | Provide POCs to consult with. |

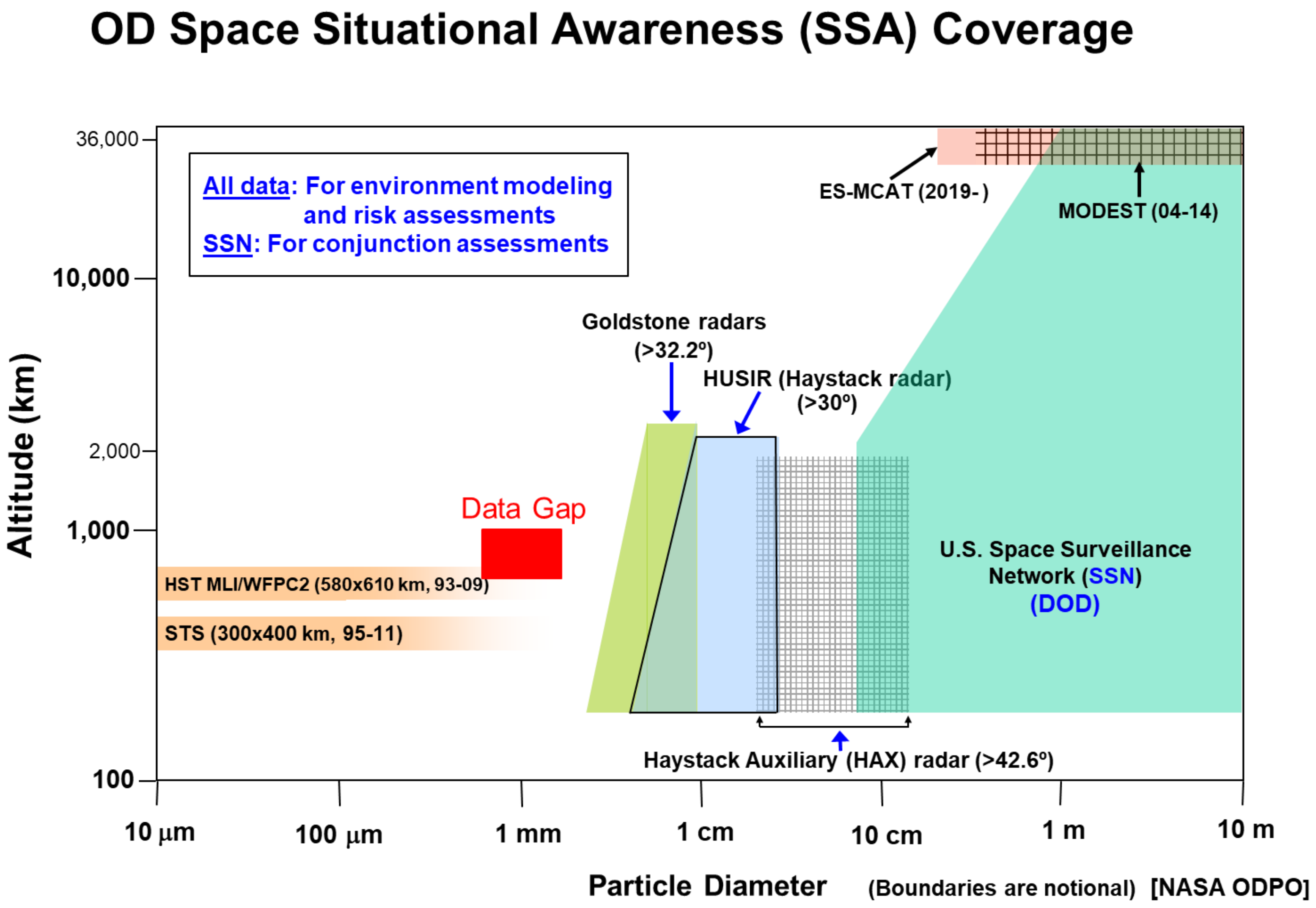
# Trilateral S&MA joint Activity on Space Sustainability

## Information Package for “Small Debris”

# 3. Technical overview of “Small Debris”

(Including 1. and 2.)

# 3.1 Present understanding




Small Debris Definition: smaller than 1cm in this DI. The threshold is defined for two reasons.

**First**, in impact risk analysis models, it is difficult to characterize the penetrative damage accurately inside a spacecraft from a space debris impactor larger than one centimeter in size.
**Second**, it is difficult for current shielding technology to protect a spacecraft against a space debris impactor larger than one centimeter.
[ISO16126]

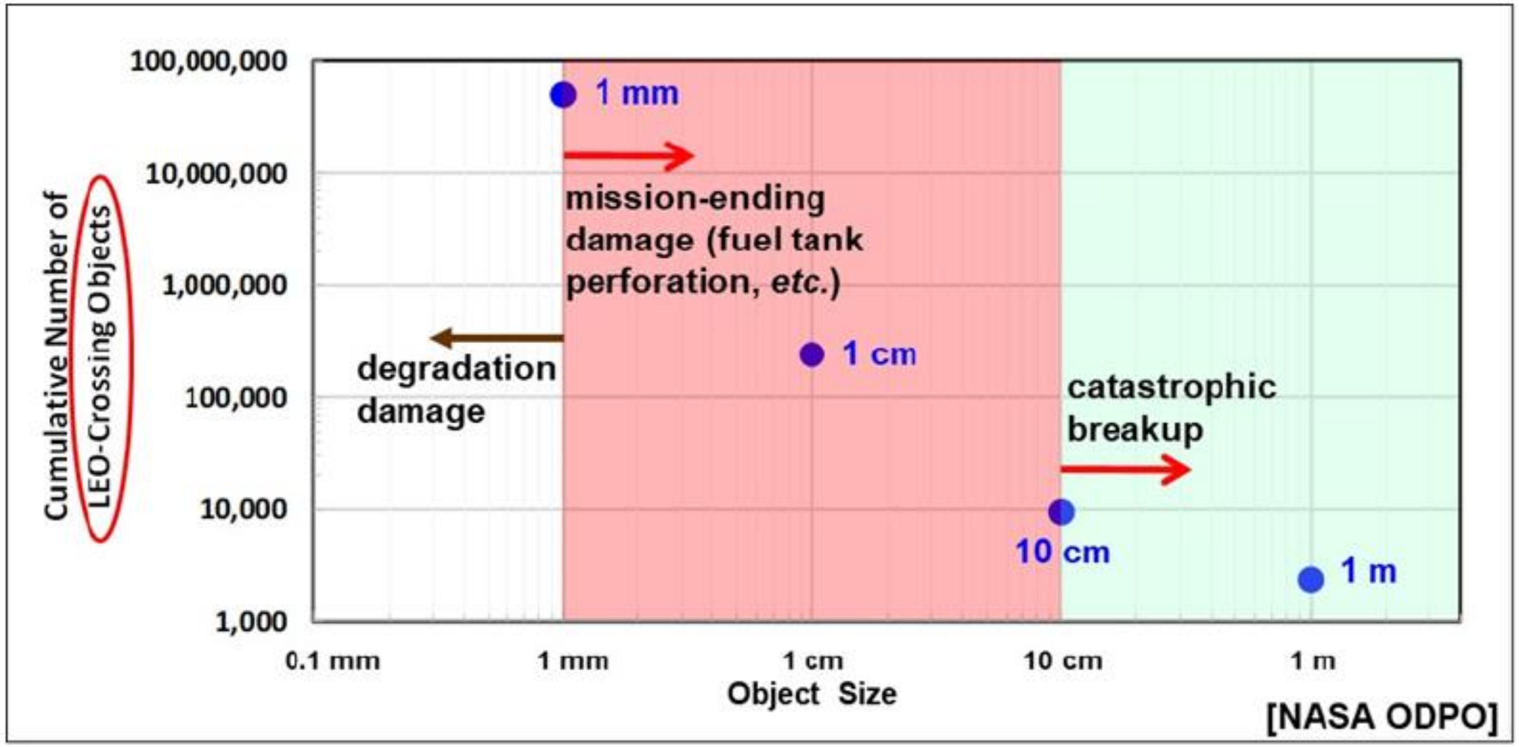
Main Sources: (1) Solid rocket motors (SRM) from µm-order dust up to cm-order slugs, (2) Ejects, (3) Paint flakes

Data Gap: The collision rate of micro-debris with a size of 100 µm to several mm is hard to predict due to a lack of knowledge.

# 3.2 Overview of risks caused by “Small Debris”

## Risk from Small Debris

- **There is far more small debris than large debris**
  - Mission-ending risk is driven by millimeter-sized debris in LEO, but there is a lack of direct measurement data on such small debris
  - Conjunction assessments and collision avoidance against the large (≥10 cm) tracked objects only address <1% of the mission-ending impact risk



# 3.2 (Cont.) Effects of Different Space Debris Sizes on Spacecraft

Two options for eliminating spacecraft damage: avoidance or protection

| Size | -- |
|---|---|
| ～ 0.1 mm | ・Very high collision frequency but low risk<br>・Peeling off the harness covering when it hits |
| 0.1 to 1 mm | ・High collision frequency<br>・Cause serious damage depending on the location<br>・Several methods of protection are proposed |
| 1 mm to 1 cm | ・Middle collision frequency<br>・Potential to cause serious damage |
| 1 cm to 10 cm | ・Low collision frequency but high risk<br>・Tracking and avoidance ( 2 cm ～)<br>・Note that High uncertainty in tracking and incomplete coverage |
| 10 cm ～ | ・Tracking and avoidance |

Untrackable

**Critical size range**

・much more numerous than larger trackable debris
・still large enough to cause significant damage

Trackable ＝ Avoidance

# 4. Requirements from Guidelines and Standards related to “Small Debris”

# 4.1 Basic common understanding among stakeholders on "Small Debris"

## Extracted description regarding the "Small Debris" from Table 2

Note: Stakeholders = ESA, NASA, JAXA, and manufacturers/ operators

Table 2

| Chapt. of B.8 | Tier1 | Tier2 | Requirements Outline | DI's (High-priority keywords only) | Remarks (other candidates) |
|---|---|---|---|---|---|
| 2 (*1) | Prevention of accidental collision in orbit | Large Objects Collision Avoidance | Monitor and evaluate collision probability with other space objects to avoid a collision. | N/A | |
| | | Protection for Small Objects Anti-Collision | Prevent damage to critical systems (disables post-mission disposal) and catastrophic hazard due to collision with Small Debris. | Small Debris | |

# 4.2 Overview of primary top-level international documents for "What to do."

| Org. | Doc. No. | Doc. Title | Section (Clauses) | Description (requirements) | Last rev./date |
|---|---|---|---|---|---|
| UN | ――― | Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space | ――――― | No specific description for small debris. However, the UN endorsed IADC guidelines as follows.<br>"For more in-depth descriptions and recommendations pertaining to space debris mitigation measures, Member States and international organizations may refer to the latest version of the IADC space debris mitigation guidelines and other supporting documents, which can be found on the IADC website (www.iadc-online.org)" | 2010 |
| IADC | IADC-02-01 | Space Debris Mitigation Guidelines | 5.4 Prevention of On-Orbit Collisions | Spacecraft design **should** also limit the probability of collision with **small debris** which could cause a loss of control, thus preventing post-mission disposal. | Rev. 3 June 2021 |
| IADC | IADC-15-03 | Statement on Large Constellations of Satellites in Low Earth Orbit | 3. Considerations for large constellations of satellites | Spacecraft design **should** limit the consequences of collision with **small debris**, which could cause a loss of control, thus preventing post-mission disposal. | July 2021 |
| ISO | ISO 24113 :2019 | Space systems — Space debris mitigation requirements | 6.1 Avoiding the intentional release of space debris into Earth orbit during normal operations | 6.1.1.1 Spacecraft **shall** be designed so as **not to release space debris** into Earth orbit during normal operations, other than space debris from pyrotechnics and solid rocket motors. | Edition : 3 July 2019 |
| | | | 6.2 Avoiding break-ups in Earth orbit | 6.2.3.4 During the design of a spacecraft an assessment **shall** be made of the risk that a **space debris or meteoroid** impact will cause the Spacecraft to break-up before its end of life. | |
| | | | 6.3 Disposal of a spacecraft or (...) | 6.3.1.2 During the design of a spacecraft for which a disposal manoeuvre has been planned, an assessment **shall** be made of the risk that a **space debris or meteoroid** impact will prevent the successful disposal | |

# 4.3.1 Overview of JAXA's requirement documents

| Organization | Document No. | Document Title | Section (Clauses) | Description (requirements) | Last revised date | Remarks |
|---|---|---|---|---|---|---|
| JAXA | JMR-003D | Space Debris Mitigation Standard | 5.1.2 Limitation of combustion products from pyrotechnics and solid rocket motors<br><br>5.3.1.1.8<br><br>Effect of space debris impact and protection design | (1) Pyrotechnic devices, except for solid rocket motors and igniter devices, shall be designed and used so as not to release combustion products and fragments larger than 1 mm in their largest dimension into Earth orbit.<br>(2) Solid rocket motors shall be designed and operated so as not to release slag sized 1 mm or larger into GEO protected region and LEO protected region. It is evaluated on a case-by-case basis when the effect on GEO protected region by released products is limited due to its trajectory such as the moon, planetary and other missions with a highly elliptical orbit.<br><br>Probability of the loss of disposal functions shall be calculated against impacts by space debris and meteoroid. Critical components and cables shall be in the calculation then protection measures, redundancy and layout change should be considered if the risk is unacceptable. The acceptable criteria shall be defined for each mission taking into account for the technical maturity of collision risk calculation and protection methods. Refer to "Micro-debris Impact Survivability Assessment Procedure (JERG-2-144)" about the collision risk calculation and protection design. | Sep.9, 2020 | |

# 4.3.2 Overview of ESA's requirement documents

| Organization | Document No. | Document Title | Section (Clauses) | Description (requirements) | Last revised date | Remarks |
|---|---|---|---|---|---|---|
| ESA | ESA/ADMIN/IPOL(2014)2 | Space Debris Mitigation Policy for Agency Projects | | ESA policy defining the applicable standards, the implementation and verification procedure for Projects, and the certification of compliance from the ESA Technical Authority (independent from the Projects) | 2022 | https://technology.esa.int/page/space-debris-mitigation |
| ESA / ECSS | ECSS-U-AS-10C, Rev. 1 | Adoption Notice of ISO 24113: Space systems - Space debris mitigation requirements | | European standard for Space Debris Mitigation requirements | 2019/12/03 | https://ecss.nl/standard/ecss-u-as-10c-adoption-notice-of-iso-24113-space-systems-space-debris-mitigation-requirements-2/ |
| ISO | ISO 24113:2019 | Space Debris Mitigation Requirements | | International standard for Space Debris Mitigation requirements | 2019/07 | https://www.iso.org/standard/72383.html |
| ESA | ESSB-ST-U-004 | ESA Re-entry Safety Requirements | | ESA standard for re-entry safety requirements, including requirements for both uncontrolled re-entry and controlled re-entry (e.g. based on 5 successful ATV controlled re-entries) | 2017/04/12 | Distribution upon request: (space.debris.mitigation@esa.int) |
| ESA | ESSB-HB-U-002 | ESA Space Debris Mitigation Compliance Verification Guidelines | | ESA handbook explaining to Project Manager and Engineers how the requirements are implemented and verified (e.g. how to perform analysis, etc.) | 2015/02/19 | Issue 2 expected in Q3 2022<br><br>https://technology.esa.int/page/space-debris-mitigation (or upon request: space.debris.mitigation@esa.int) |

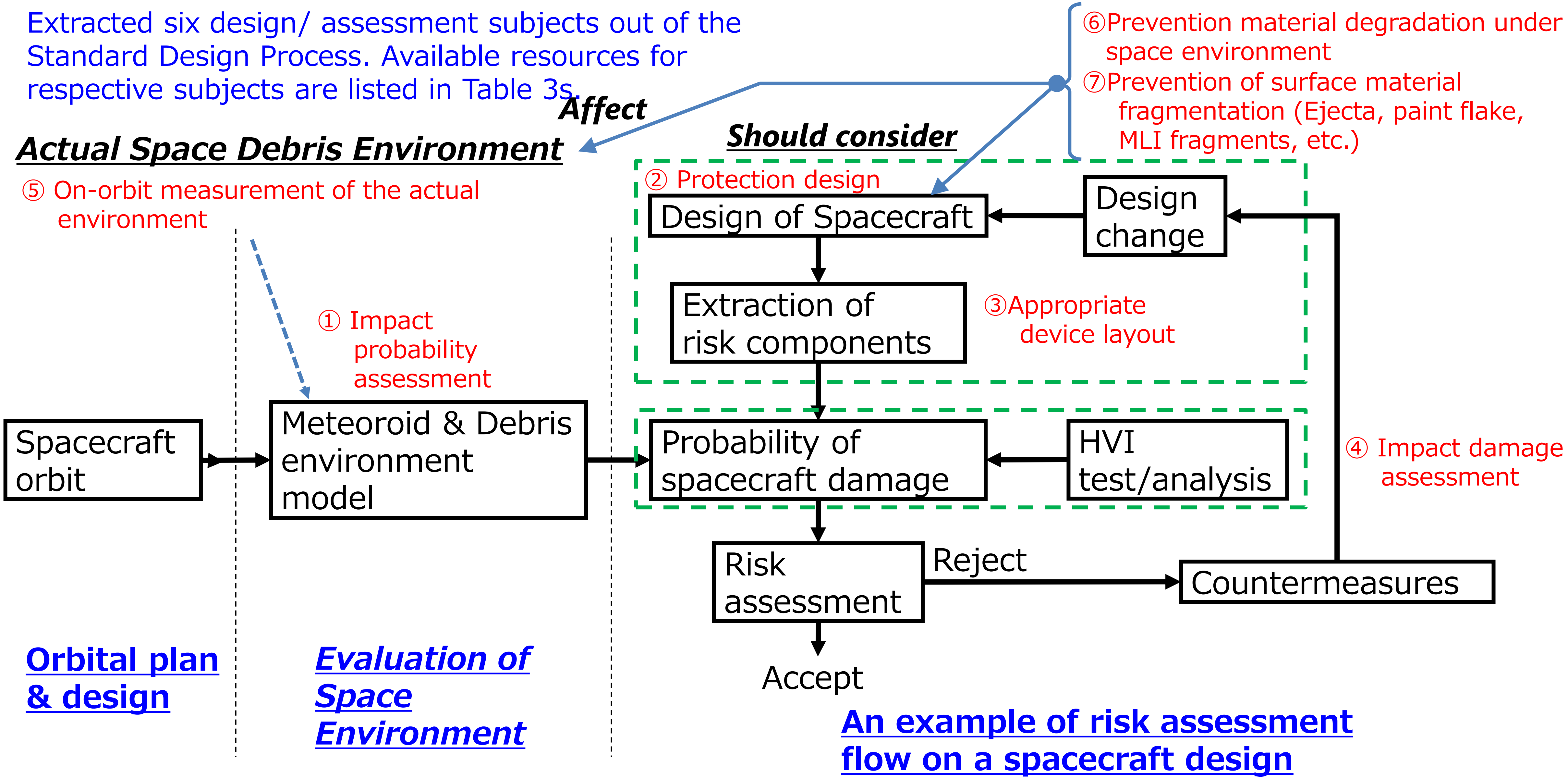
# 4.3.3 Overview of NASA's requirement documents

| Organization | Document No. | Document Title | Section (Clauses) | Description (requirements) | Last revised date | Remarks |
|---|---|---|---|---|---|---|
| NASA | NPR 8715.6B | NASA Procedural Requirements for Limiting Orbital Debris and Evaluating the Meteoroid and Orbital Debris Environments | All | This is a top-level policy document. It defines the purpose of orbital debris mitigation, applicability of the orbital debris mitigation requirements, and roles/responsibilities of affected organizations. | 16 February 2017 | Available at: https://www.orbitaldebris.jsc.nasa.gov/reference-documents/ |
| NASA | NS 8719.14C | Process for Limiting Orbital Debris | Section 4 | This technical standard document establishes detailed orbital debris mitigation requirements and the technical rationale behind each requirement. | 5 November 2021 | Available at: https://www.orbitaldebris.jsc.nasa.gov/reference-documents/ |

# 5. “How to do” to solve the issues

# An Example of Risk Assessment Flow Based on JERG-2-144

Extracted six design/ assessment subjects out of the Standard Design Process. Available resources for respective subjects are listed in Table 3s.




Modified and simplified flow based on JERG-2-144 Micro-debris Impact Survivability Assessment Procedure (Kitazawa,*et al.*,2016)

# Table 3a(JAXA) for Small Debris (1/3)

| Individual Risk | Required Measures | Knowledge of three agencies S&MA could provide | | |
|---|---|---|---|---|
| | | Applicable doc's/websites (Standards, Handbooks, Databases, etc.) | Analysis Tools | Technologies／Facilities |
| **Spacecraft damage due to small debris collision** | **① Impact probability assessment** | ✓ JERG-2-141 Space Environment Standard (written in Japanese)<br><br><Section 10 "Meteoroid and Space Debris" describe meteoroid/debris environment models, selection procedures of models, and those applying process to spacecraft design phases are explained. This process coincides with ISO 14200:2012 (Process-based implementation of meteoroid and debris environment models). In addition, ISO 14200 was revised, and a new version of ISO 14200:2021 was published. JERG-2-141 is also under revised proses in 2022.> | ✓ TURANDOT<br><br>It analyzes spacecraft damages from collisions with space debris.<br>MASTER8、ORDEM3 and MEM3 are handled for debris flux database in analyses.<br><br>Ref: http://astro-muse.com/contents_en_products.html | Impact risk assessment is done using the tool |

# Table 3a(JAXA) for Small Debris (2/3)

| Individual Risk | Required Measures | Knowledge of three agencies S&MA could provide | | |
|---|---|---|---|---|
| | | Applicable doc's/websites (Standards, Handbooks, Databases, etc.) | Analysis Tools | Technologies／Facilities |
| **Spacecraft damage due to small debris collision** | **② Protection design**<br>**③ Appropriate equipment layout**<br>**④ Impact damage assessment** | ✓ JERG-2-144 Micro-debris Impact Survivability Assessment Procedure<br><br>the assessment procedure for verifying the validity of the protection design of satellites and probes against risks of impact with micro-debris and meteoroid which are 1 mm or less in size and whose impact probability and impact damage is not negligible<br><br>✓ JERG-2-144-HB001 Micro-debris Impact Survivability Assessment Procedure Handbook<br><br>Data provision of Various Impact Tests and numerical simulation results.<br>Examples of spacecraft protection design<br>(written in Japanese) | ✓ LS-DYNA<br>✓ Autodyne<br><br>Using E.O.S., which is suitable for collision phenomena to determine the penetration threshold of debris such as protection materials and space materials, it is possible to approximate not only the liquid phase but also the solid and gas phases, and sometimes even the plasma state, to simulate highly dynamic and nonlinear behavior of materials. | ✓ Hyper velocity impact Test: 2-stage-light gas gun: ISAS projectile diameter 0.3-3.2mm velocity ~ 7km/sec<br><br>✓ Ballistic limit derived from hypervelocity impact testing and hydrocode simulations |

# Table 3a(JAXA): for Small Debris (3/3)

| Individual Risk | Required Measures | Knowledge of three agencies S&MA could provide | | |
|---|---|---|---|---|
| | | Applicable doc's/websites (Standards, Handbooks, Databases, etc.) | Analysis Tools | Technologies／Facilities |
| **Damage impact assessment error due to Small Debris information shortage (*2)** | **⑤ On-orbit real-time measurement of the actual space environment** | ✓ On-Orbit Impact DB<br>(Under recovery coordination; Ref: https://matdb.jaxa.jp/main_e.html) | N/A | ✓ Space Debris Monitor for onboard Spacecraft<br><br><For in-situ measurement of debris flux in the size range of 100 um to a few mm. Measurement parameter: Debris size and Impact time><br><br>©JAXA,IHI,iQPS<br>https://www.kenkai.jaxa.jp/eng/pickup/sdm.html<br>https://www.kenkai.jaxa.jp/pickup/kasper.html |
| **Pollution due to Small Debris out of Spacecraft (Paint flake, MLI fragment, ejecta, etc.)** | **⑥ Prevention material degradation under space environment**<br>**⑦ Prevention of surface material fragmentation (Ejecta, paint flake, MLI fragments, etc.)** | ✓ JERG-2-143 Space Environment Effects Mitigation; Ref: https://sma.jaxa.jp/en/TechDoc/Docs/E_JAXA-JERG-2-143.pdf<br>✓ JMR-003D-HB001 Space Debris Prevention Design and Operation Manual; Ref: https://sma.jaxa.jp/TechDoc/Docs/JAXA-JMR-003-HB001.pdf<br>✓ Material DB<br>(Under recovery coordination; Ref: https://matdb.jaxa.jp/main_e.html) | N/A | ✓ Material characteristics test data for space environment; Material degradation data due to AO, UV, Electron<br>✓ Hyper velocity impact test for ejecta assessment based on ISO11227:2012<br>✓ Space environment testing facilities at TKSC facilities<br>https://jaxa.repo.nii.ac.jp/?action=repository_action_common_download&item_id=2565&item_no=1&attribute_id=31&file_no=1 |

# Table 3b(ESA) for Small Debris (1/2)

| | | Knowledge of three agencies S&MA could provide | | |
|---|---|---|---|---|
| | | Applicable doc's/websites (Standards, Handbooks, Databases, etc.) | Analysis Tools | Technologies／Facilities |
| Spacecraft damage due to (small) debris collision | ① Impact probability assessment | ✓ ECSS-U-AS-10C / ISO 24113:2019 (https://ecss.nl/standard/ecss-u-as-10c-adoption-notice-of-iso-24113-space-systems-space-debris-mitigation-requirements-2/)<br>✓ ESSB-HB-U-002<br>✓ (https://technology.esa.int/page/space-debris-mitigation) | ✓ ESA DRAMA/ARES/MIDAS<br>✓ MASTER-8 available at: https://sdup.esoc.esa.int/master/ | ✓ Models computational tools |
| | ② Protection design<br>③ Appropriate equipment layout<br>④ Impact damage assessment<br><br>Unable to download; sign-in with an organization account is required. Instead, can download it from; https://www.iadc-home.org/documents_public/view/page/2/id/120#u | ✓ ECSS-U-AS-10C / ISO 24113:2019 (https://ecss.nl/standard/ecss-u-as-10c-adoption-notice-of-iso-24113-space-systems-space-debris-mitigation-requirements-2/)<br>✓ ESSB-HB-U-002 (https://technology.esa.int/page/space-debris-mitigation)<br>✓ IADC-04-03 (Protection Manual) (https://iadc-home.org/documents_public/view/id/81#u) | ✓ ESA DRAMA/ARES/MIDAS (https://sdup.esoc.esa.int/drama/)<br>✓ ESABASE2 (https://esabase2.net/)<br>✓ LS-DYNA<br>✓ Smoothed-Particle Hydrodynamics (SPH) codes | ✓ Ballistic Limit Equations (BLEs)<br>✓ Hypervelocity impact tests/facilities (e.g. Fraunhofer) English - Fraunhofer EMI<br>✓ Lessons learnt from past spacecraft |

# **Table 3b(ESA)** for Small Debris (2/2)

| **Individual Risk** | **Required Measures** | **Knowledge of three agencies S&MA could provide** | | |
|---|---|---|---|---|
| | | Applicable doc's/websites (Standards, Handbooks, Databases, etc.) | Analysis Tools | Technologies／Facilities |
| **Damage impact assessment error due to Small Debris information shortage (*2)** | **⑤ On-orbit real time measurement of the actual space environment** | ✓ Flight operation manuals/procedures to manage in-flight anomalies | ✓ Housekeeping parameter monitoring/analysis (e.g. unit parameters degradation recorded by the Operator and assessed during Anomaly Review Boards) | ✓ Ground station operations<br>✓ Collision probability assessments |
| **Pollution due to Small Debris out of Spacecraft (Paint flake, MLI fragment, ejecta, etc.)** | **⑥ Prevention material degradation under space environment**<br>**⑦ Prevention of surface material fragmentation (Ejecta, paint flake, MLI fragments, etc.)** | ✓ Space qualified processes/products (https://ecss.nl)<br>✓ Design/product assurance standards (https://ecss.nl) | ✓ Analysis with respect to degradation agents (e.g. radiation, thermal, outgassing, atomic oxygen, etc.)<br>✓ Tests<br>✓ Inspection | ✓ Best knowledge/practice basis<br>✓ Orbit propagation analysis from identified debris cloud events |

# Table 3c(NASA) for Small Debris (1/2)

| Individual Risk | Required Measures | Knowledge of three agencies S&MA could provide | | |
|---|---|---|---|---|
| | | Applicable doc's/websites (Standards, Handbooks, Databases, etc.) | Analysis Tools | Technologies／Facilities |
| Spacecraft damage due to (small) debris collision | ① Impact probability assessment | ✓ U.S. Government Orbital Debris Mitigation Standard Practices (2019), available at: https://www.orbitaldebris.jsc.nasa.gov/reference-documents/<br>✓ NASA Technical Standard 8719.14C (2021), available at: https://www.orbitaldebris.jsc.nasa.gov/reference-documents/ | ✓ ORDEM (https://software.nasa.gov/software/MSC-25457-1)<br>✓ ORDEM Cloud (https://ordem.appdat.jsc.nasa.gov/ )<br>✓ DAS (https://software.nasa.gov/software/MSC-26690-1)<br>✓ BUMPER (NASA internal) | ✓ Impact probability assessments are done using the tools listed to the left |
| | ② Protection design<br>③ Appropriate equipment layout<br>④ Impact damage assessment | ✓ U.S. Government Orbital Debris Mitigation Standard Practices (2019), available at: https://www.orbitaldebris.jsc.nasa.gov/reference-documents/<br>✓ NASA Technical Standard 8719.14C (2021), available at: https://www.orbitaldebris.jsc.nasa.gov/reference-documents/<br>✓ NASA TP-2003-210788, Meteoroid/Debris Shielding, available at: https://hvit.jsc.nasa.gov/reference-documents/<br>✓ NASA TM-2009-214785, Handbook for Designing MMOD Protection, available at: https://hvit.jsc.nasa.gov/reference-documents/<br>✓ DebriSat database for fragment characterization (shape, density, etc.) to improve damage assessments | ✓ DAS (https://software.nasa.gov/software/MSC-26690-1)<br>✓ BUMPER (NASA internal) | ✓ Ballistic limit equations derived from hypervelocity impact testing (primarily at NASA WSTF) and hydrocode simulations (WSTF: https://www.nasa.gov/centers/wstf/testing_and_analysis/hypervelocity_impact/home.html )<br>✓ Failure criteria defined by missions or hypervelocity impact testing/simulations |

# Table 3c(NASA): for Small Debris (2/2)

| Individual Risk | Required Measures | Knowledge of three agencies S&MA could provide | | |
|---|---|---|---|---|
| | | Applicable doc's/websites (Standards, Handbooks, Databases, etc.) | Analysis Tools | Technologies／Facilities |
| **Damage impact assessment error due to Small Debris information shortage (*2)** | **⑤ On-orbit real time measurement of the actual space environment** | ✓ On-orbit anomalies reported by operators<br>✓ On-orbit anomalies documented in Spacecraft On-orbit Anomaly Report (SOAR) database (NASA internal) | ✓ Anomalies: investigation tools vary, depending on the nature of anomalies | ✓ Anomalies: investigation technologies vary, depending on mission requirements and resources<br>✓ Dedicated in-situ measurement sensor technologies under development |
| **Pollution due to Small Debris out of Spacecraft (Paint flake, MLI fragment, ejecta, etc.)** | **⑥ Prevention material degradation under space environment**<br>**⑦ Prevention of surface material fragmentation (Ejecta, paint flake, MLI fragments, etc.)** | ✓ NASA TP-2003-210788, Meteoroid/Debris Shielding, available at: https://hvit.jsc.nasa.gov/reference-documents/<br>✓ NASA TM-2009-214785, Handbook for Designing MMOD Protection, available at: https://hvit.jsc.nasa.gov/reference-documents/ | ✓ Different testing and analysis tools | ✓ Hypervelocity impact testing (primarily at NASA WSTF)<br>✓ Space environment testing facilities at different NASA Centers. For example, the environmental testing facilities at JSC include vibration, vacuum, thermal, and thermal-vacuum chamber test operations for human spaceflight and robotic missions and provide the following services:<br>▪ Materials outgassing evaluations<br>▪ Accelerated Electrical/Electronic components burn-ins and life cycle testing<br>▪ Environmental cycling (thermal/humidity) for materials survivability<br>▪ Materials and hardware testing in extreme environments (manned/unmanned) |

# 6. GAP analysis/ Research topics

NOTE: GAP Analysis does NOT aim to select one superior method for users but to provide the differences between available methods comprehensively.

# GAP analysis/ Research topics candidates and Priorities

An example of GAP analysis (among 3 agencies) / Research Topics

| # | A. Technologies／Facilities | Outline/ Perspective of the comparison | Priority | Remarks |
|---|---|---|---|---|
| A1 | Hypervelocity impact facilities | Specification of each facility | #1 | |
| A2 | | | | |

| # | B. Analysis Tools | Outline/ Perspective of the comparison | Priority | Remarks |
|---|---|---|---|---|
| B1 | Debris Environment Models | Capability of each model | #2 | ORDEM, MASTER, etc. |
| B2 | Meteoroid Environment Models | | Low | MEM, Grün, etc. |
| B3 | Impact Risk Analysis Tools | Quantitative comparison in condition(s) where the most significant differences found | #3 | DRAMA, Turandot, DAS, etc. |
| B4 | Hydrocodes | | | Autodyne |

| # | C. Applicable doc's/websites (Standards, Handbooks, Databases, etc.) | Outline/ Perspective of the comparison | Priority | Remarks |
|---|---|---|---|---|
| C1 | Documents related to protection design | Are there any differences in estimating/defining" Critical minimum size" and actual design methods for "Protection " among each applicable documents | #4 | |

# Specification of each facility

**A1 Hypervelocity impact facilities**

No notable differences among the three agencies' facilities

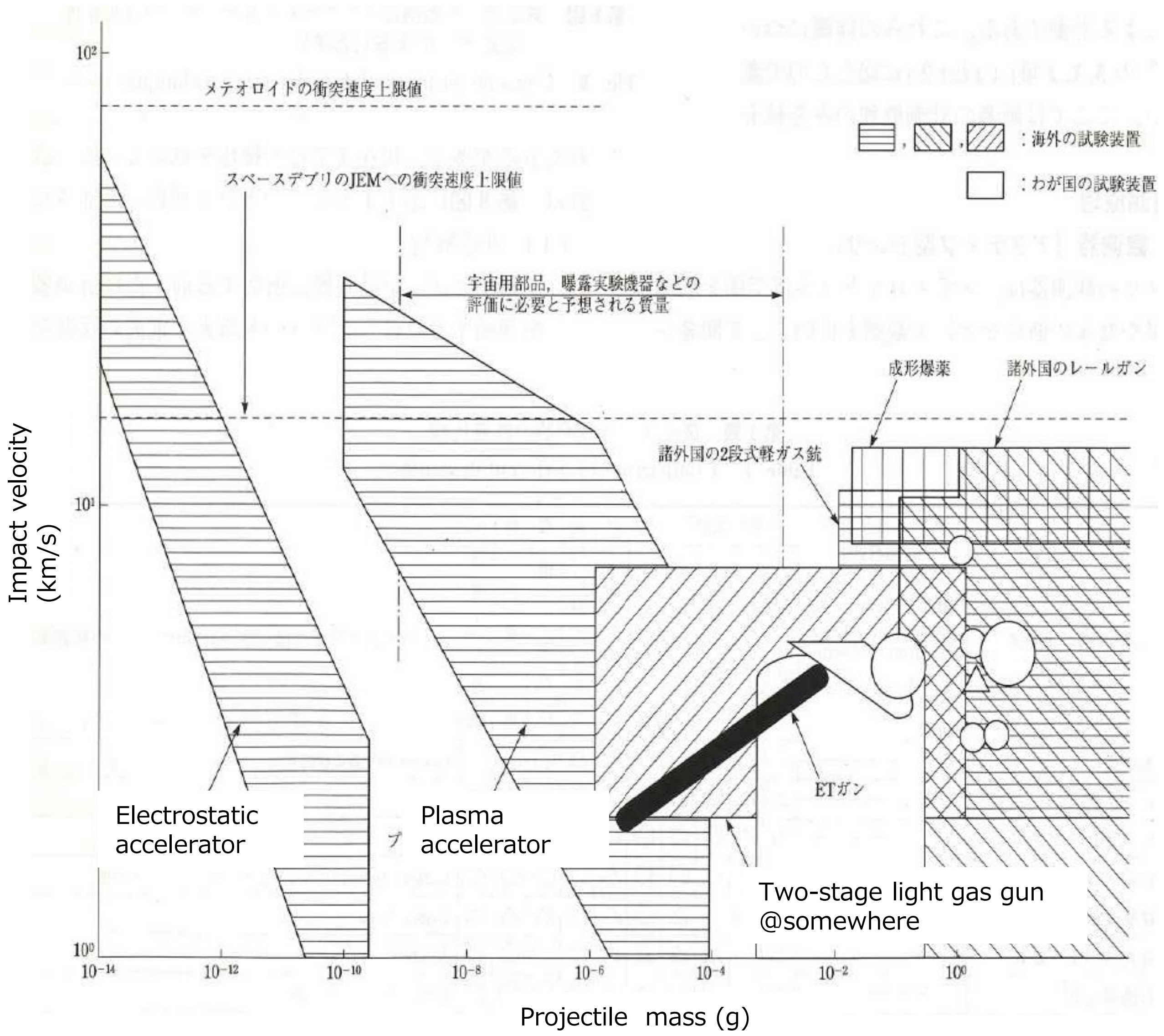
| # | Org. | Location (Site) | Accelerator Type | Single Projectile Size Range | Velocity Range | Diagnostics Available | Velocity Measurement | Target Accommodations | Target Capabilities | Others | Bibliography and/or website address |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | JAXA | ISAS (Sagamihara) | Ex. 7/30mm horizontal Two-stage light gas gun (PAI)<br><br>4.7/15mm vertical Two-stage light gas gun (PAI) | 0.3 -7.0mm (Ability of projectile sizes) 0.03-0.5mm (Multiple particles)<br><br>1.0 -4.8mm (single particle) (Ability of multiple shots (ex. Using sabot) also mentioned) | 0.5-7.0 km/s<br><br>0.8-7.0 km/s | +High-Speed Video Camera<br>-HPV-X (Shimadzu)<br>-HPV-1 (Shimadzu)<br>-Phantom V2512 (Vision Research)<br>-KIRANA (Specialized Imaging)<br>-Fast M3K (Telops)<br>+spectrograph<br>-maya2000 (Ocean)<br>-Time-resolved spectrum system (Hamamatsu) | - laser-photodetector system | 100cm×200cm or 45cm×30cm (Size and/or Capacity of target chamber)<br><br>100cm×200cm or 45cm×30cm | - 1Pa (Ability to pressurize and/or heat/cool targets) | -Optical, laser, electron microscopes and laser profiler for target inspection<br>-Compression testing machine<br>-Sound velocity measurement system | https://stage.tksc.jaxa.jp/pairg/spf/ |
| 2 | ESA (collaboration example) | EMI Fraunhofer (Freiburg, Germany) | Two-stage light gas gun (different sizes) | 100 g | 7.8 km/s | - Accelerometers<br>- Pressure gauges<br>- High-speed spectroscopy<br>- High-speed photo/video | - Laser vibrometers<br>- Flash/impact light detectors<br>- X-ray film track | 5.5m x 3.5m x 3.5m (target chamber) | 1 GPa max pressure | | https://www.emi.fraunhofer.de/en/business-units/space/equipment.html |
| 3 | NASA | White Sands Test Facility | Horizontal Two-stage light gas guns | Projectile shapes range from spheres, cylinders, disks, and cubes to multiple projectile "shotgun" shots. Single projectiles range in diameter from 25.4 mm down to 0.4 mm. Multiple projectiles down to 0.05 mm. | Up to 7 km/s | High speed data acquisition (100 million samples per second) and imaging systems (up to 200 million frames per second) capture projectile, environment, and target data for results analysis. | Laser break-beam stations<br><br>Photo diode flash detectors | Target chambers range from 107 cm diameter x 213 cm long to 274 cm diameter x 914 cm long, accommodating targets with different dimensions | Ability to pressurize and/or heat/cool targets | Laser microscope for target inspection<br><br>Ultra-high-speed imaging system cameras to capture projectiles in flight immediately prior to impact | https://www.nasa.gov/centers/wstf/testing_and_analysis/hypervelocity_impact/index.html |

# (Cont.) Launch Capability comparison

**A1 Hypervelocity impact facilities**

★TBD

Sample




To be updated

# Debris Environment Model comparison

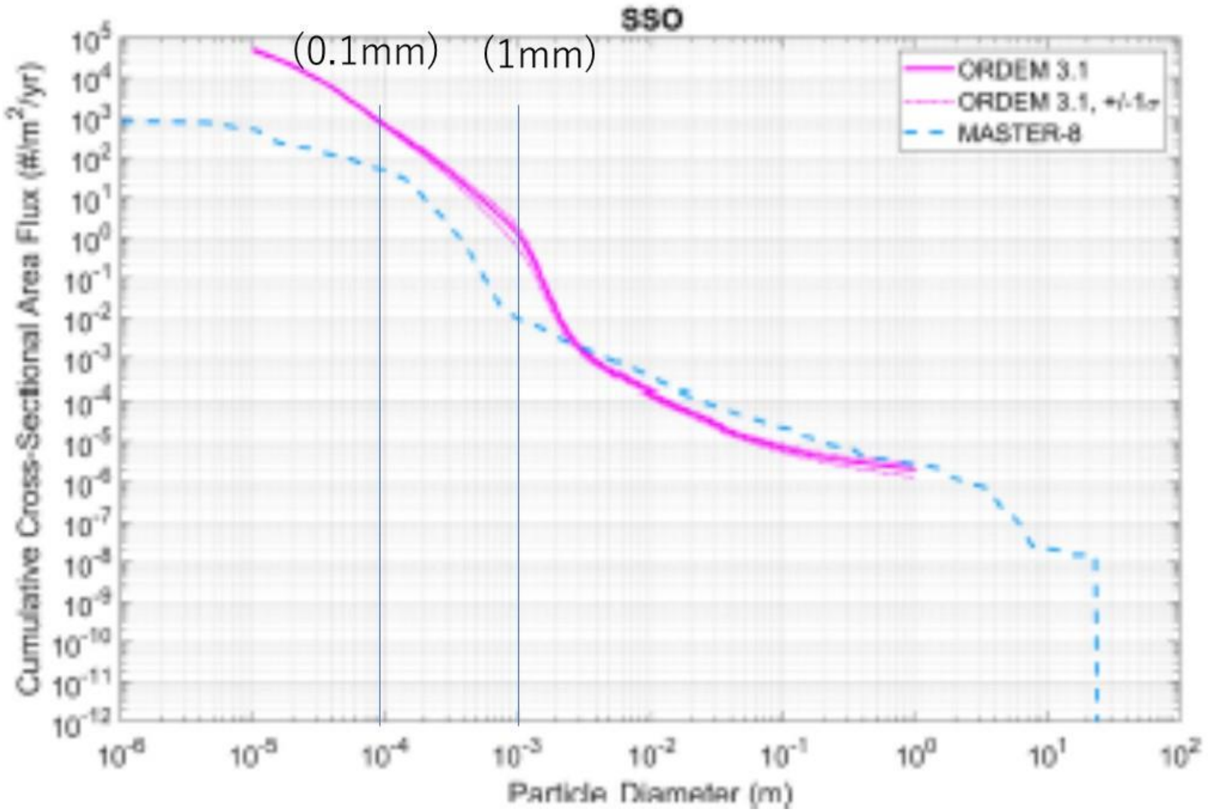
**B1 Debris Environment Models**

| Model specification | MASTER-8 | ORDEM 3.1(3.2) |
|---|---|---|
| Source | ESA | NASA |
| Modelling approach | Semi deterministic analysis | Measurement data |
| a) minimum size | 1 µm | 10 µm |
| b) orbital regime | 186 km (perigee altitude) to 500 000 km (apogee altitude) | 100 km to 40 000 km (> 10 µm) (LEO to GTO)<br>34 000 km to 40 000 km (> 10 cm) (GEO) |
| c) evolutionary period | 1957 to 2036 | 2015 to 2050 |
| Input parameter | <u>Target orbit scenario:</u><br>-Semi-major axis ,-Eccentricity, -Inclination, - Right ascension of ascending node,-Argument of perigee <u>Inertial volume scenario:</u><br>-Geocentric distance, ,-Right ascension, -Declination<br><u>Spatial density scenario:</u><br>-Lower/ upper altitude limit, -Lower/ upper decline Limit | -Apo/Peri<br>-Altitude<br>-Semi-major axis<br>-Eccentricity<br>-Inclination<br>-Argument of perigee |
| Output data | <u>Flux versus</u><br>-Size,-Mass,-Semi-major axis,-Eccentricity, -Inclination,-Altitude,-Latitude ,-Impact velocity, -Impact declination,-Time, etc.<br><u>Spatial density versus</u><br>-Size, -Mass, -Altitude , -Declination, -Time | <u>Flux versus</u><br>-Size, -Orbit position, -Altitude, -Latitude |
| TLE background | Yes | (Density discrimination)<br>(IN) Intacts<br>(LD) Low-density (1,4 g/cc) fragments<br>(MD) Medium-density (2,8 g/cc) fragments & microdebris<br>(HD) High-density (7,9 g/cc) fragments & microdebris<br>(NK) RORSAT NaK coolant droplets (0,9 g/cc) |
| Fragments | Yes | |
| SRM dust and slag | Yes | |
| NaK droplets | Yes | |
| Paint flakes | Yes | |
| West ford needles | Yes | |
| MLI fragments | Yes | |
| 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 |
| Web address | https://sdup.esoc.esa.int/ | https://orbitaldebris.jsc.nasa.gov/modeling/ordem.html |

# (Cont.) GAP between debris environment

**B1** | **Debris Environment Models** MASTER-8 and ORDEM 3.1 have been assessed when updated.

**Implementation of debris environment model to actual design.**




MANIS, et al.(2021) suggested there is a large difference in impact flux of small debris between MASTER-8 and ORDEM 3. 1

How to select a model for spacecraft design?
Cf. ISO 14200 describes;
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.


Reference

A. Horstmann, A. Manis, V. Braun, M. Matney, A. Vavrin, D. Gates, J. Seago, P. Anz-Meador, C. Wiedemann, S. Lemmens, FLUX COMPARISON OF MASTER-8 AND ORDEM 3.1 MODELLED SPACE DEBRIS POPULATION, Proc. 8th European Conference on Space Debris (virtual), Darmstadt, Germany, 20–23 April 2021, published by the ESA Space Debris Office Ed. T. Flohrer, S. Lemmens & F. Schmitz, (http://conference.sdo.esoc.esa.int, May 2021)

A. MANIS, M. MATNEY, A.VAVRIN, D. GATES, J. SEAGO, AND P. ANZ-MEADOR ,NASA Orbital Debris Quarterly News Vol. 25, Issue 3, September 2021

# Impact Risk Analysis Tools – Benchmark candidate

**B3** | **Impact Risk Analysis Tools** JAXA decided to assess using GCOM-C within this Fiscal Year.

JAXA proposes Benchmark Tests (as a sub-TF), focusing on the conditions where the most prominent differences are found among models, like SSO. (apart from IADC WG3)

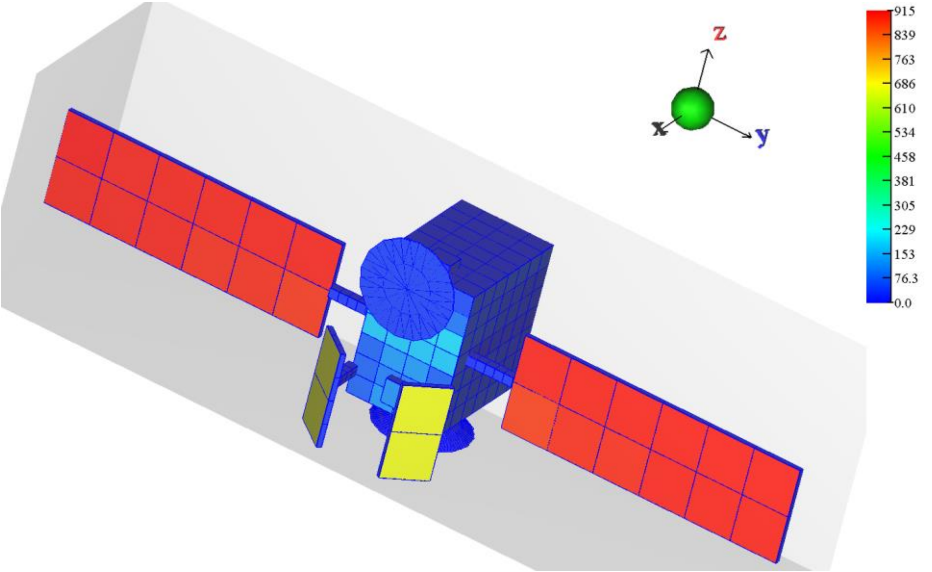
Operators surely want to understand the quantitative differences from design perspective.

## Candidate Condition & Analysis Image

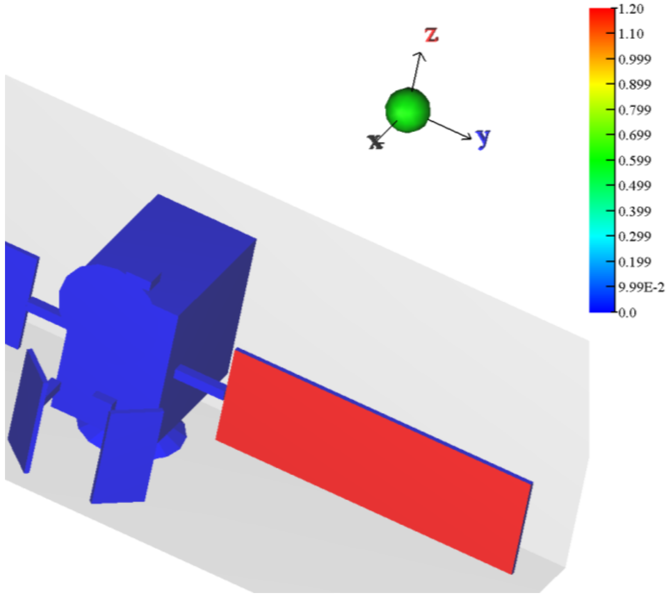
*Simulation for the risk assessments.*

| | SSO |
|---|---|
| **Semi-major axis (*a*)** | **7171km** |
| **Eccentricity (*e*)** | **0.0001** |
| **Inclination(*i*)** | **98°** |
| **Argument of perigee (ω)** | **0°** |
| **Right ascension of the ascending node (Ω)** | **0°** |

Debris (>10μm) **Collision Frequency** on Spacecraft surfaces [/year]




**Damage Frequency** on a surface with designated Damage Mode [/year]




(1-year from 2018/01/01 Orbit： SMA 7187km, ECC 1.0e-3, Inc 98deg Earth-pointing

# 7. Points of Contact in each Agency

Please contact POCs below for further Small Debris-related information.

| Agency | POC (section or persons) | Contact Address | Note |
|---|---|---|---|
| JAXA | S&MA Department<br>System and Orbit Safety Unit | Sustainability_SpaceDebris@ml.jaxa.jp | Space Debris HP is available at;<br>https://www.jaxa.jp/projects/debris/index_j.html<br>(in Japanese ONLY at this moment) |
| ESA | Independent Safety Office<br>(Product Assurance and Safety Department) | Paloma.villar@esa.int<br>Sergio.Ventura@esa.int | https://technology.esa.int/page/space-debris-mitigation |
| NASA | Office of Safety and Mission Assurance (OSMA)<br><br>Orbital Debris Program Office (ODPO) | Dr. Frank Groen, HQ 5F87, NASA Headquarters, 300 E ST SW, Washington,DC,20546-0001<br><br>Dr. Matt Forsbacka, HQ 5F87, NASA Headquarters, 300 E ST SW, Washington,DC,20546-0001<br><br>Dr. J.-C. Liou, XI-5, NASA Johnson Space Center, 2101 NASA Parkway, Houston, TX 77058 | https://sma.nasa.gov/ |