

ESA Clean Space Days 2026, ESTEC

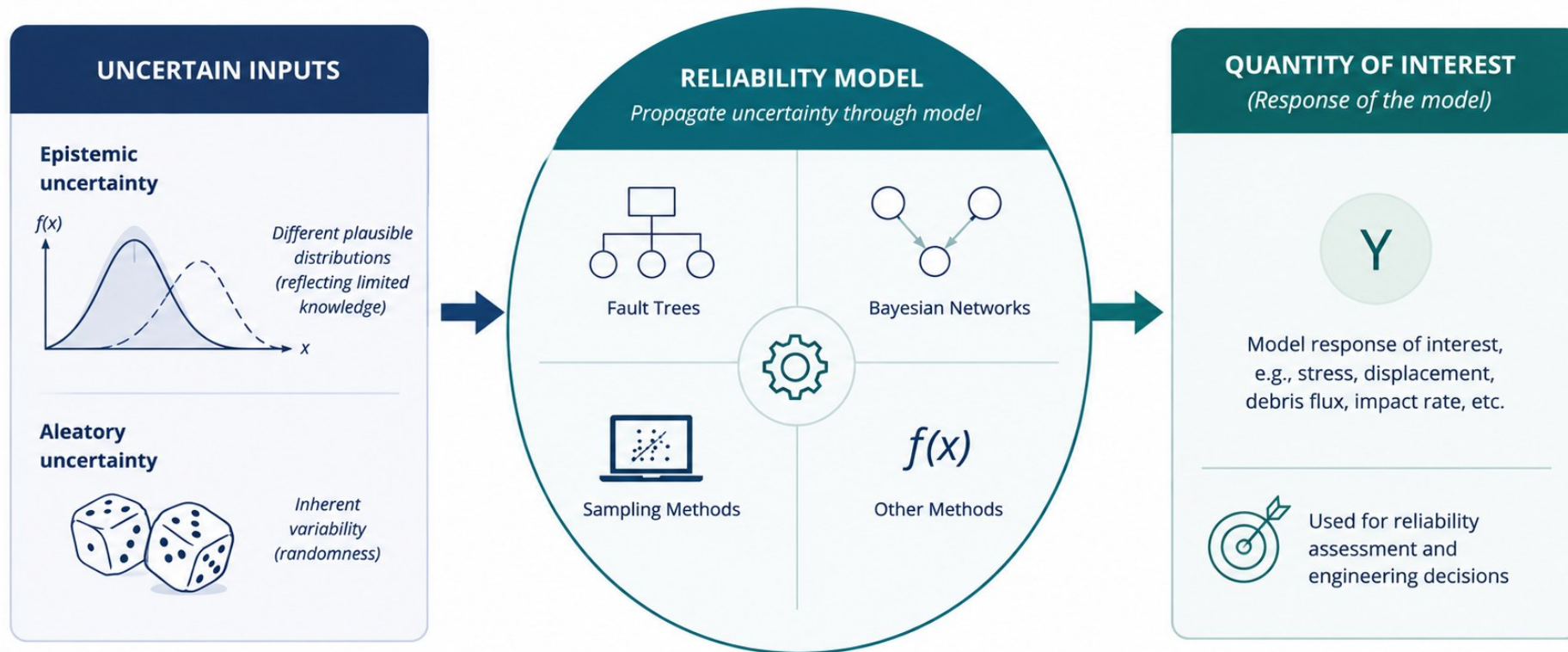
Operationalising PSD for Clean Space: Reliability Assumptions and Open Questions

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Uncertainty



Uncertainties are everywhere.

Probabilities of uncertain events

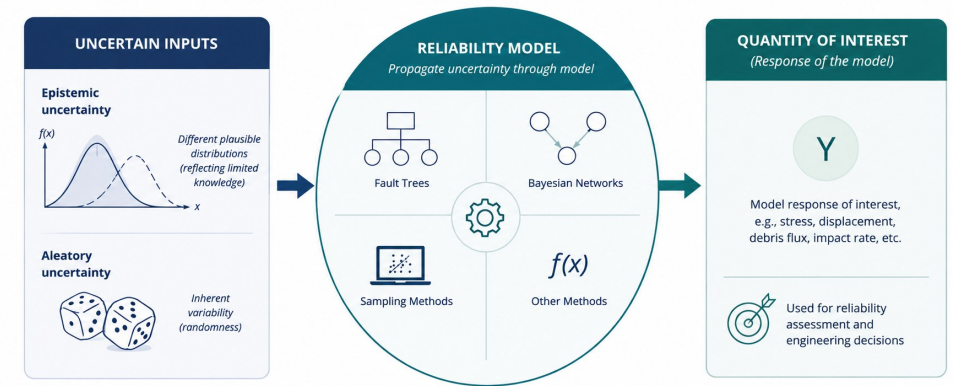
Probability

- In uncertain environment, the probability is likelihood that an event happens.

Probability of failure

- In uncertain environment, the probability of failure is likelihood that a **failure** happens.

$$P_f = P(g(X) \leq 0), \text{ } g - \text{limit state function, } g(X) \leq 0 - \text{failure domain, } X - \text{uncertain inputs}$$



Time-variant failure probability

- When focusing on time (when does failure happen) the following is more convenient:

$$F_T(t) = P(T \leq t) = \int_0^t f_T(\tau) d\tau = 1 - R_T(t), \text{ } T - \text{random time to failure, } f_T(t) - \text{failure density, } R_T(t) - \text{reliability}$$

Probability of successful disposal

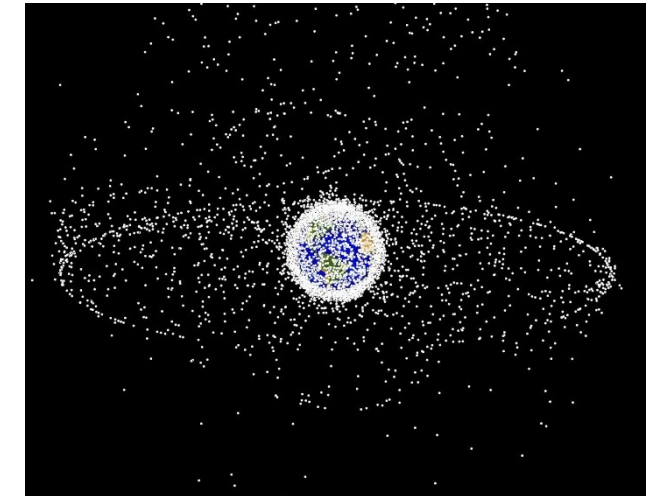
- PSD is likelihood that disposal succeeds.



Why PSD Matters in Clean Space / Zero Debris

LEO is becoming increasingly crowded as commercial and national mega-constellations scale from thousands to tens of thousands of satellites. This raises collision-risk, debris, and deorbiting challenges.

Constellation	Status	Target satellites	Country/Region
Starlink	Active / expanding	9,600 now → 42,000 planned	USA
Guowang	Planned	13,000	China
Qianfan	Planned	14,000	China
Honghu-3	Planned / proposed	10,000	China
Amazon Leo	Planned	3,236	USA
Eutelsat OneWeb Gen2	Planned	6,118	UK / Europe



We have the responsibility to contribute to the solution.



Why PSD Matters in Clean Space / Zero Debris

Debris growth problem

- Space debris is increasing; uncontrolled accumulation can trigger cascading collision risk (Kessler syndrome)

PSD requirement

- ESSB-ST-U-007 introduces $\text{PSD} \geq 0.9$

Engineering question

- Everyone agrees with the goal, but PSD calculation raises interpretation issues:
 - What counts as “successful disposal”?
 - Which failures and/or any failure events (e.g. degradation ...) are included?
 - Over what time horizon?

PSD \geq 90% turns a sustainability objective into a reliability modelling challenge.

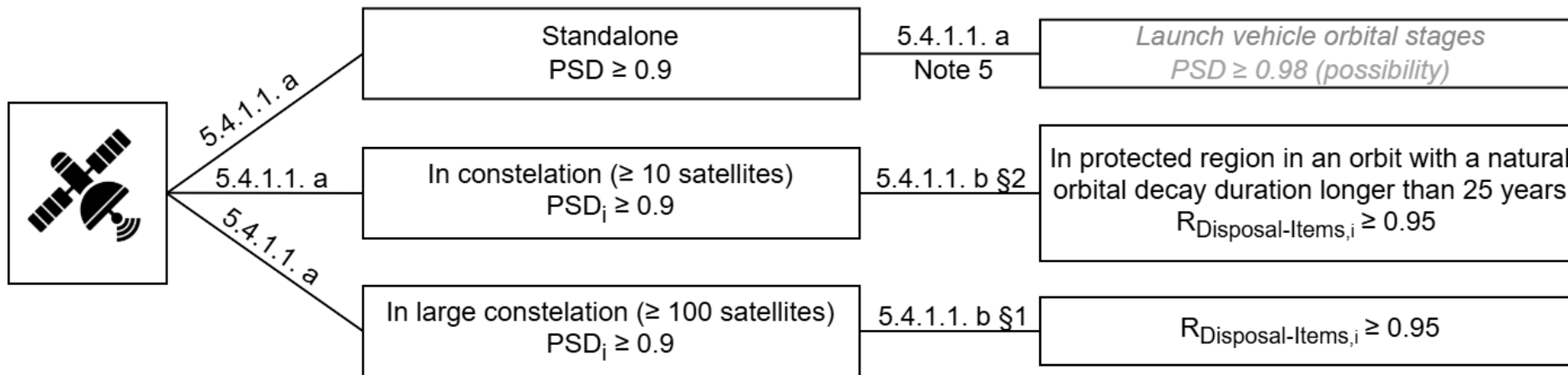
Probability of successful disposal requirement

“The overall probability of successful disposal of a spacecraft or launch vehicle orbital stage in Earth orbit shall be kept above 0.9 through to end of life, including the contributions from system reliability and from collisions with space debris or meteoroids preventing the successful disposal.”

ESSB-ST-U-007 5.4.1.1a requirement

- The **reliability** calculation considers subsystems, units and functions **used for the disposal only**. (5.4.1.1.a Note 1)
- Collisions on appendages are considered unless demonstrated that they do not affect the disposal functions. (5.4.1.1. a Note 4)

$$PSD = R_{\text{Disposal-Items}} \cdot P_{\text{Impact-Avoid}}$$



For which time horizon do we compute the PSD?

„Through to end of life“: define the PSD time horizon

Which contributors must be considered when assessing whether disposal will still succeed at EOL?

- **Disposal phase only** Too narrow?



Considers **only failures during the disposal maneuver**. This misses earlier events that remove disposal capability, e.g., ageing or loss of redundancy.

- **Operational lifetime → EOL** Common practice?



Considers **all contributors that can prevent future disposal**, while focusing on functions needed for disposal (excluding payload).

- **From launchpad** Unclear boundary?



Includes **launch/early-life events if they affect later disposal capability**. Otherwise PSD becomes general mission success, not disposal capability.

PSD is a capability-to-dispose-at-EOL metric, not just a disposal-burn reliability number.



Document basis for the PSD time horizon

ESSB-ST-U-007

- PSD ≥ 0.9 “through to EOL”
- Includes system reliability and MMOD / collision contribution
- Focuses on functions needed for disposal

NASA STD 8719.14b and French LOS

- NASA uses the same ≥ 0.9 disposal-success threshold
- French LOS combines reliability, passivation and ageing
- Both support assessment at the disposal epoch

Time-horizon implication

Launch → operations → EOO → EOL

- Failures, degradation and loss of redundancy before EOL can remove disposal capability
- Wear-out, Limited life items and consumables should feed into EOL reliability
- Disposal must remain achievable until EOL

Combine impact-avoidance probability over the entire time horizon, disposal-relevant reliability from launch to EOO, and disposal success probability.



PSD as a living metric

ESSB-ST-U-007 5.4.1.2 f: PSD shall be **reassessed** in the following occurrences:

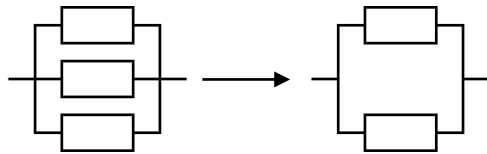
1. **Mission lifetime extension**
2. **Detected anomaly**
3. **Recorded failures** from the same product family
4. **Change in the radiation environment**, when recommended by the radiation experts
5. **Change in the space debris environment** affecting the operational orbit or disposal approach when recommended by the space surveillance segment supporting the mission
6. **As a minimum at 50% of the nominal mission lifetime**, in case none of the occurrences above are triggered, unless agreed to be unnecessary between the approving agent and the spacecraft operator

PSD reassessment

When the PSD is reassessed, two boundary conditions change:

In-orbit data:

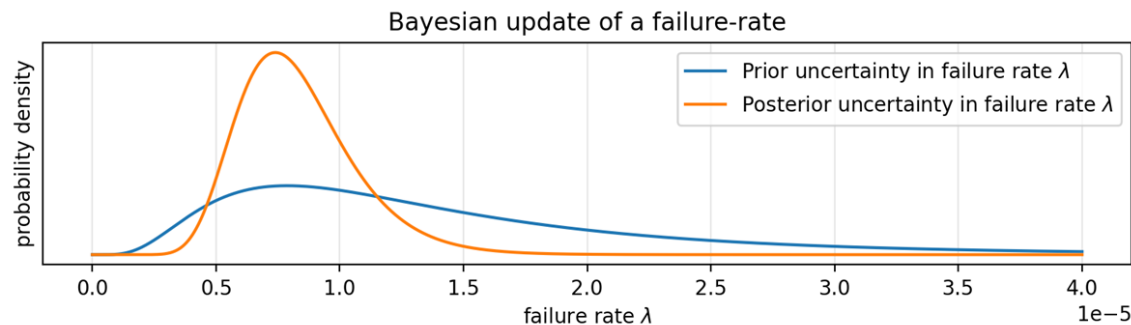
- **Model structure** (e.g., RBD or fault tree)



- **Parameter values**

- replace nominal assumptions with current in-orbit estimates (e.g., remaining propellant, failure rates)

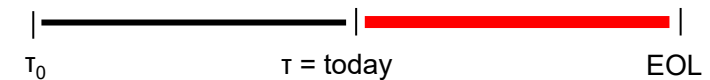
- **Parameter uncertainty**



Assessment time:

- We know that the spacecraft has survived until today.
- Are we interested in how likely a successful completion of the mission until EOL is

$$PSD = P(T > t_{EOL})$$



- Or are we interested in when disposal should be finished to comply?

$$t_{EOL} \text{ such that } P(T > t_{EOL}) \geq 0.9$$





How to calculate PSD?

“The calculation of the probability of successful disposal can be based on reliability analyses performed according to ECSS-Q-ST-30, and ECSS-Q-HB-30 or any other methods set by the approving agent.”

ESSB-ST-U-007 5.4.1.1a NOTE 3

The standard does not prescribe one PSD formula. It points to reliability analyses that must be selected, justified, and accepted for the mission.

ECSS-Q-ST-30

Dependency / reliability analysis framework

- reliability prediction / RBD
- FMEA / FMECA
- fault tree analysis
- common-cause analysis
- FDIR and contingency analysis

Role: identify disposal-critical failures and quantify the system reliability contribution.

ECSS-Q-HB-30 series

Product assurance handbooks supporting reliability analysis

- reliability data sources and their use
- worst-case analysis
- human dependability analysis
- reliability prediction guidance / draft developments

Role: provide handbook-level guidance supporting the implementation of reliability analyses.

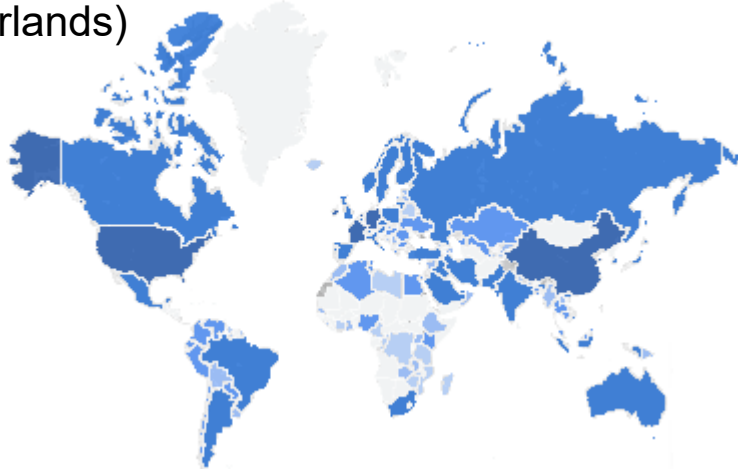


reliability.space interactive handbook (ECSS-Q-HB-30-02A **draft**)

Web-hosted handbook with interactive components and an active user basis: handbook.reliability.space

Nov 2023 – June 2026:

- >14,000 unique users
- ~35 daily users
- >125 different countries (1. USA, 2. China, 3. Netherlands)



Interactive reliability tools directly in the handbook covering EEE, mechanical, miscellaneous, and system-level models

The screenshot shows the user interface of the ECSS-Q-HB-30-02A digital reliability handbook draft. At the top, it says "ECSS-Q-HB-30-02 Digital Handbook Draft". Below this is a search bar with the text "Search" and a keyboard shortcut "Ctrl + K". A blue link reads "Welcome to the draft of the ECSS-Q-HB-30-02A digital reliability handbook".

On the left side, there is a vertical table of contents with expandable sections:

- Part 1 - Methodologies
 - 1. Handbook
- Part 2 - Methods
 - 2. Handbook
- Part 3 - EEE
 - 3. Handbook
 - 4. Models
- Part 4 - Mechanical
 - 5. Handbook
 - 6. Models
- Part 5 - Miscellaneous
 - 7. Handbook
 - 8. Models
- Part 6 - System
 - 9. Handbook
 - 10. Models
- Part 7 - Glossary
 - 11. Handbook

The main content area on the right has a title "Welcome to the draft of the ECSS-Q-HB-30-02A digital reliability handbook". Below the title, it states: "This is a draft of the digital version of the ECSS-Q-HB-30-02A reliability handbook, which is currently under preparation by the ECSS. This handbook offers:"

- **Technical content** in the [Handbook](#) sections,
- **Interactive content** in the [Models](#) sections.

Below this is a section titled "Objective". The text reads: "The ECSS-Q-HB-30-02A reliability handbook was developed to provide a reliability methodology that can be used for space applications, without the limitations and shortcomings of existing [reliability prediction](#) methodologies. The present digital handbook is a digitalized version of the ECSS-Q-HB-30-02A reliability handbook that offers easier access, interactive content, and a contemporary design."

Further down, it says: "This digital handbook contains 7 parts. These parts can be accessed by clicking on the icons below or browsing the table of contents on the left side of this page."

At the bottom of the main content area, there are two cards:

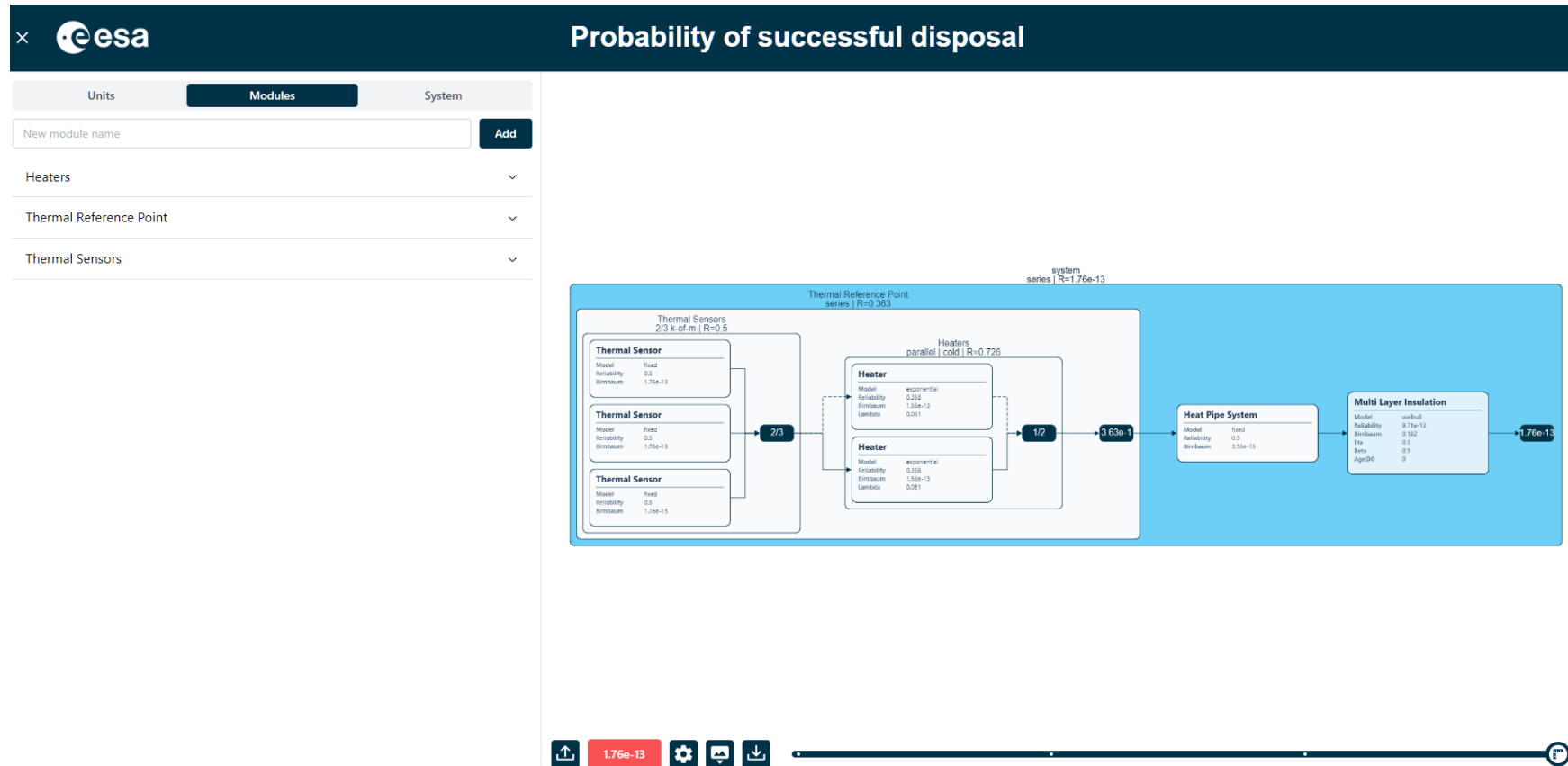
- Methodologies**: Accompanied by an icon of a network diagram. The text says: "Gives a brief introduction to the project life cycle and to the different phases describing an item's reliability over time. These concepts are needed to understand the taxonomy and for the reliability prediction process discussed in this handbook."
- Methods**: Accompanied by an icon of a lightbulb, a bar chart, and puzzle pieces. The text says: "Provides information on different reliability prediction and methods inputs, allowing to understand the background of the models defined in the following parts."





From method to implementation: PSD tool prototype

Work in progress - developed to support the calculation of PSD.





Conclusions

PSD ≥ 0.9 is easy to state, but non-trivial to model.

Disposal capability

PSD is not just the reliability of the disposal maneuver.

Modelling boundary

Disposal phase, operational lifetime and broader mission contributors lead to different PSD interpretations.

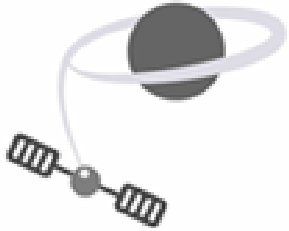
Living metric

In-orbit evidence can update the model structure, parameter values or parameter uncertainty during operations.

Traceable method

ECSS-Q-ST-30 and ECSS-Q-HB-30 series provide the basis, but assumptions need justification and approval.

Standardized method is necessary to calculate PSD in order to be consistent with the target and the compliance demonstration.



Thank you for your attention!



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