Return of Experience (REX) on ESA Missions from a Dependability Perspective

TRISMAC

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TEC-QQD

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- Mission performance context and need
- Potential biases of current assessment
- I-O REX process
    - ➢ Outcomes
    - ➢ Mission Data selection criteria
    - ➢ Mission Data processing
    - ➢ Data aggregation and Digital Dashboard
- Challenges
- Future Work

Credits: Sacha Berna

Mission performance context and need

Mission performance requirements

Mission objectives not achieved in case of failures

Requirement: **Probability of mission success** under given conditions and **a given time interval**

Demonstration: Prediction based on the **probability of failure of all the elements constituting the system** that cannot be counteracted to restore the functional capability of the element to fulfil its functions (unrecoverable failures)

Mission objectives not achieved in case of insufficient system availability

Requirement: Percentage of time the system is able to perform its intended function given that the necessary conditions for this state are fulfilled and resources are available.

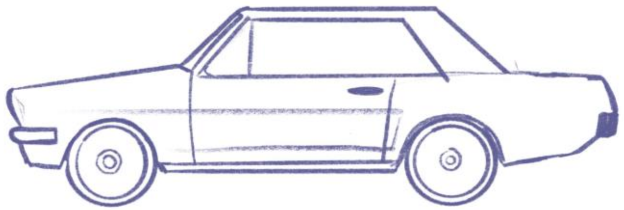
Demonstration: Duration of the system being in an operational state is derived from:

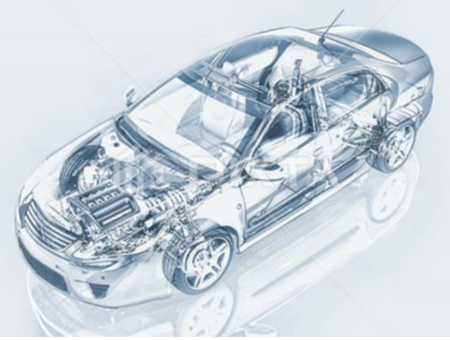
- Probability of interruption (*) of the mission
- Time needed to restore the system at its full operational capability

(*) Derived from unplanned interruptions represented by system intrinsic failure rate, possible radiation-induced events probabilities but planned interruptions such as orbital manoeuvers, calibration operations can also be considered)

Potential biases of existing assessment

- Model purpose: Reliability prediction models complexity are requirement driven: as soon as it is satisfied the effort of modelling can be stopped





As simple as possible, as complicated as necessary

- Data Sources:
  - Databases (NPRD, EPRD) are based on non-space environment field data
  - Standards for calculation can be outdated (e.g. MIL-HDBK-217F)
  - No or little test data
- Development assumptions on:
  - Operating conditions
  - Mission state following definitive failures

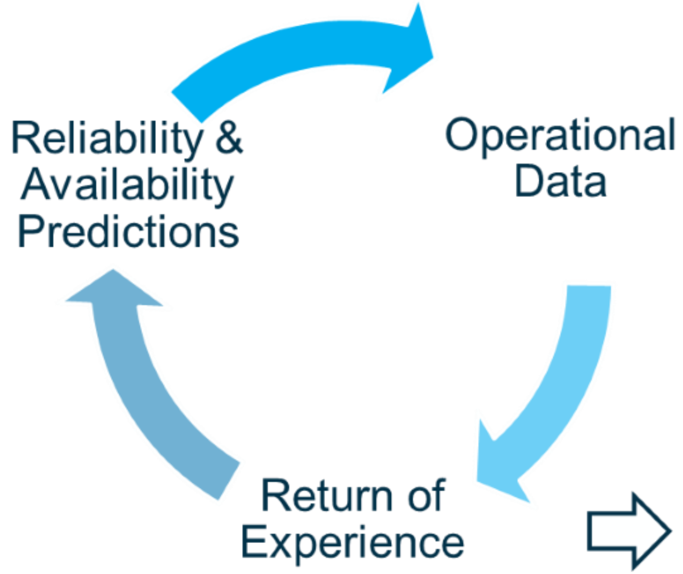
Input data can show conservativeness and are based on estimations rather than observations

One way to improve the prediction is to analyse the in-orbit data

In-Orbit Return of Experience
IO-REX

Predictions performed during the **design** phase

In-orbit Reliability and Availability **data observed**



In-orbit data applied to **increase accuracy** of **predictions** in future missions

Comparison between **Predictions** and **REX data**

Outcomes – **For the RAMS discipline**

Operations knowledge, data accuracy and representativeness

- Behaviour in contingency situations awareness: "*Situations and resolutions that are not considered in RAMS analysis*"
  - ➢ Gaining information of workarounds can help to better account for them in the analysis

Credits: *Sacha Berna*

- Support to CDF Risk Assessment: *"What happened during a similar mission ?"*
  - ➢ Analysing the collection of the anomalies database can help convincing the CDF team on the credibility and likelihood of certain risks and that mitigation measures have to be defined

- Failure rates refinement: "*As they are the building blocks for predictions, the predictions are just as good as these estimations are*"
  - ➢ Using the number of observed failures to infer the *a priori* estimation
  - ➢ Taking credit of number of installed unit/equipment (points of success, cumulated operating hours)
  - ➢ Knowing their operational conditions

- Failure mode identification
  - ➢ Support completeness and possibly complement existing failure mode catalogue (*ECSS-Q-ST-30-02C*)

Outcomes – **Other aspects**

New satellite design optimisation/Analysis improvement

- Consider the IO-REX distribution of randomic/systematic failures to:
  - Confirm the importance to introduce the systematic failures in the analysis
  - Know the type and when the systematic failures manifest
  - Confirm that the related failure source is handled appropriately in the new design
  - Introduce the appropriate countermeasures for future design and operation
- Include work arounds as mitigation actions during development analysis: take credit of effective mean for mission continuation

In-orbit monitoring

Credits: Sacha Berna

- Improvement of predictions for support to end-of-life/life extension decision supporting Space Debris Mitigation Policy
- Feedback on low-cost missions approach and relate to mission classification tailoring

Management Overview

- Synthesis of the performance of the satellite fleet with respect to availability and reliability metrics

In-orbit Return of Experience process – **Mission Data Selection and collection Criteria**

Mission selection

Mission design information

- Spacecraft configuration
- Design description and documents
- Orbit and mission planning
- Dependability analysis (*a priori*)
- …

Mission operation information

- With support of ESOC to narrow down Anomaly reports relevant for this process
- Definition of a sorting criteria, considering reports describing a:
  - Reliability prediction impact:
    - Anomalies in satellite platform representing permanent failures (with impact on mission lifetime), including those due to aging
    - Anomalies unexpectedly wasting consumables driving mission lifetime (e.g. fuel), occurred before the end of the nominal lifetime
    - Anomalies in payload instruments representing permanent failures (with impact on science useful lifetime), including those due to aging
  - Availability prediction impact:
    - On-board outages impacting the satellite nominal performance.

In-orbit Return of Experience – **Mission Data Processing**

Mission selection

Mission design information

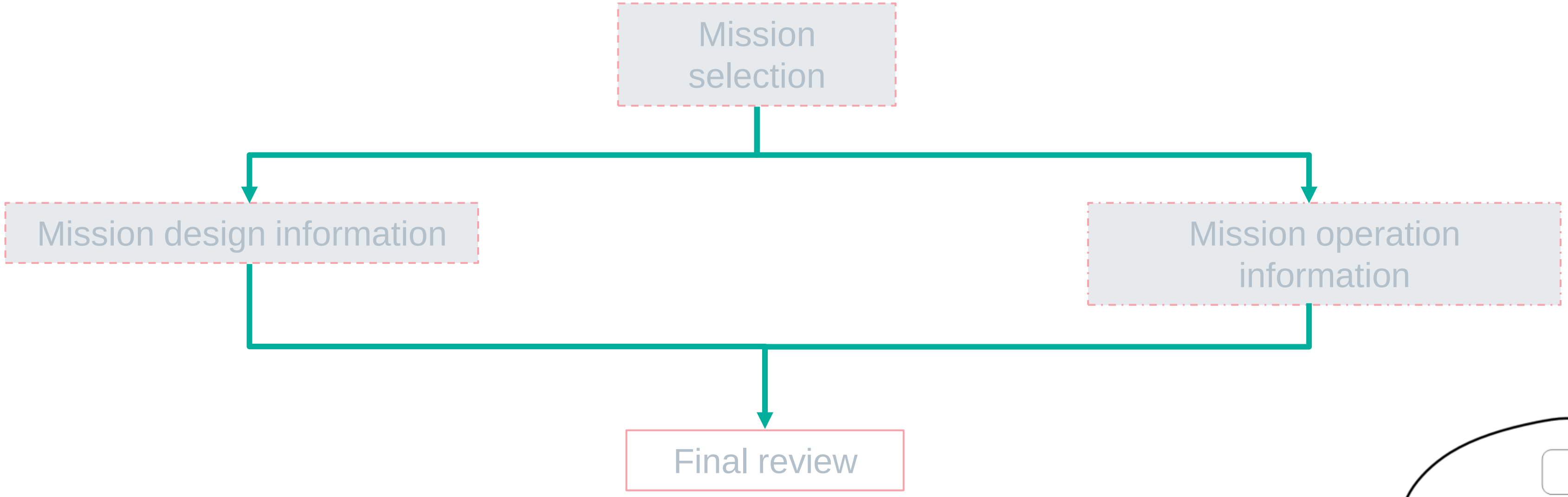
Mission operation information

- Mission information (*key design parameters, directorate, launcher, orbit, key dates, operating status,…)*
- Dependability metrics (*specified and predicted*)
- Spacecraft breakdown at unit level (*S/S, Unit, quantities and redundancy type*)
- Reliability prediction model (*RBDs*)

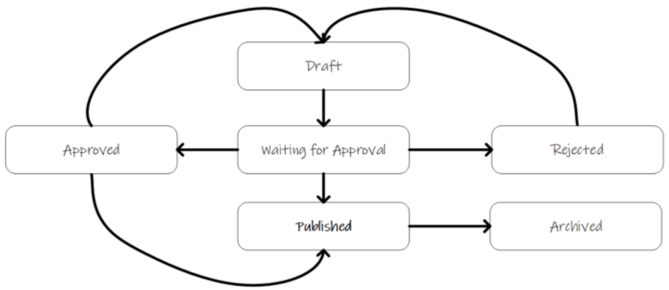
- For reliability:
  - Anomalies descriptions
  - Type of failure *(permanent, transient, degradation)*
  - Affected S/S and Unit *(when possible)*
  - Root cause *(when possible)*
  - Failure type
- For availability:
  - Outage descriptions
  - Type of outage *(planned or unplanned)*
  - Affected S/S and Unit *(when possible)*
  - Root cause *(when possible)*
  - Outage duration

Remark: Need for designation standardisation for read across the missions

In-orbit Return of Experience – **Mission Data Processing (Cont'nd)**



- Support of operation for sanity check and conclusion on a given REX
- Configuration management: Important to close and manage update of the REX



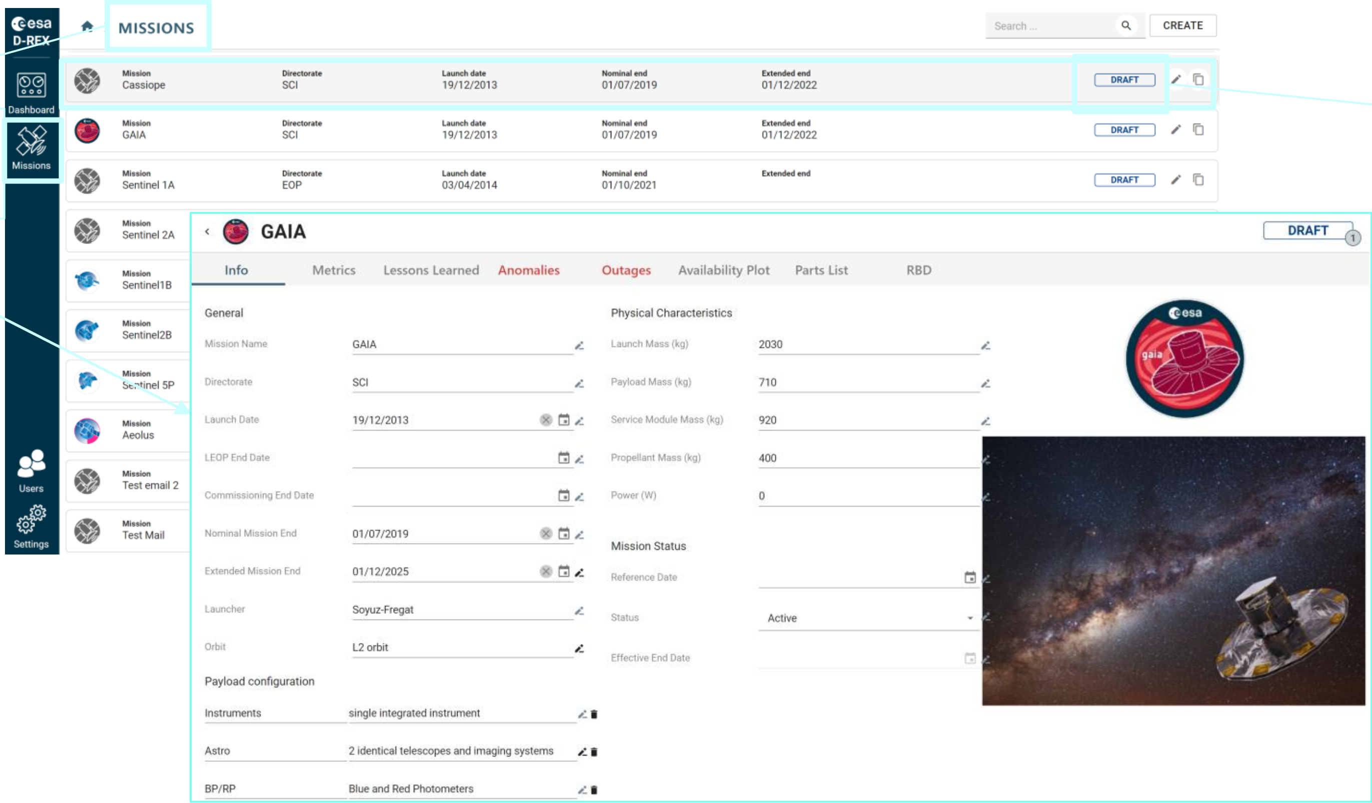
Publication workflow on the digital dashboard

Next step is to transfer this mission database through a digital dashboard

In-orbit Return of Experience – **Data Processing through the Digital Dashboard**

- An important milestone has been achieved in 2023 with the development of a REX Digital Dashboard by *FadeOut*

Missions data previously described



Current version status (w.r.t. the validation workflow)

Next step is the aggregation of data through the REX dashboard

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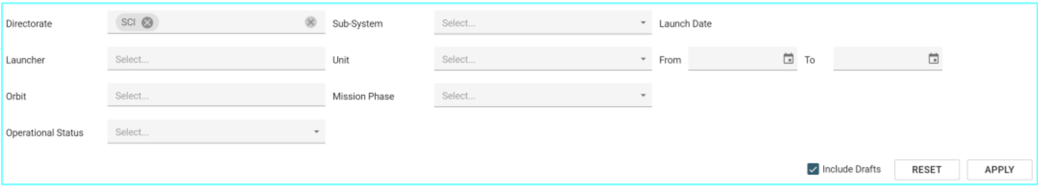
In-orbit Return of Experience – **Data Processing through the Digital Dashboard (Cont'nd)**

➢ Aggregation of data and missions overview



The current outcomes (visible and exportable) of the REX dashboard are:

- Satellite in-orbit vs. prediction reliability comparison (for reliability and availability)
- Distribution of failures per satellite sub-system
- Satellite outage distribution between subsystems or between planned/unplanned outages
- Number of safe modes
- Satellite availability evolution over the mission lifetime
- Lessons Learned from OPS

Overall → **16 satellites analysed** **2 satellites are on-going**

Challenges – **Samples size, monitoring and investigation level**

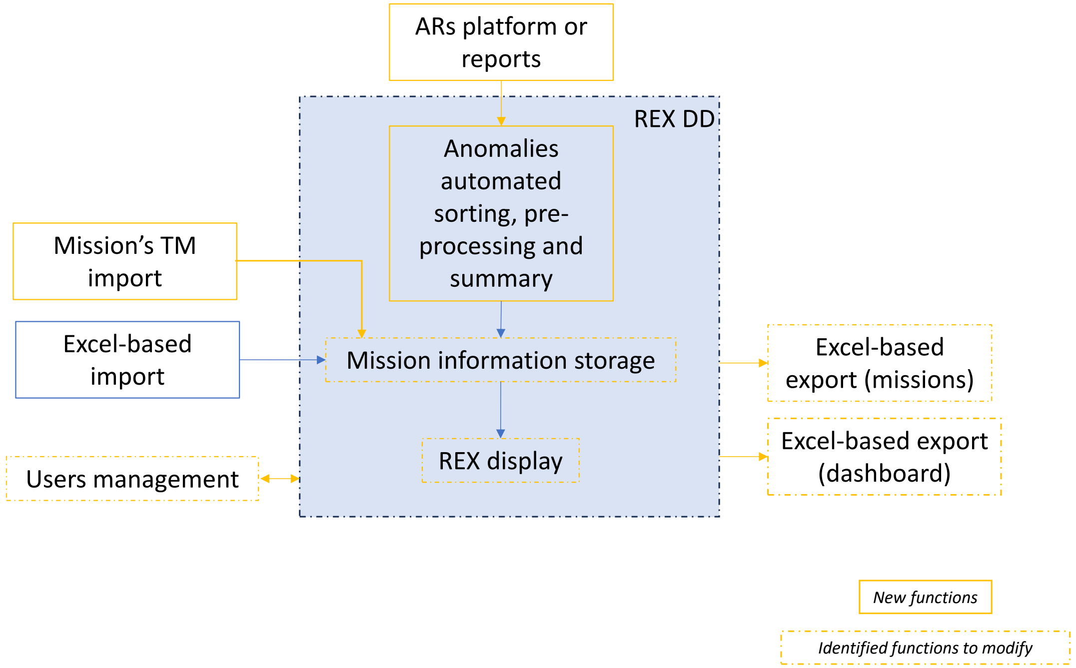
- Limited satellite fleet leading to poor statistics
- Availability is not **systematically** continuously monitored and depends on mission requirements
- **Root cause** not always determined
- Delay in the analysis of REX w.r.t. current technology

Future Work – **Automation and additional data**

- **Automation** of information extraction from the anomaly reports
  - Apply natural language processing and text-mining algorithms
  - **Direct interface** between the digital dashboard and OPS-ARTS*
  - Exploit attached **complementary analysis**
- Seek for inter-agencies or industrial partners **collaboration**
  - Data Cleanroom to merge, share and analyse sensitive data

Increase the number of missions studied

- **Integrate mission's information** from:
  - Observed temperatures and duty cycle of the units based on available telemetry files
  - Root cause analysis *(when available)*
- Improvement of the dashboard features
  - **Probability of successful disposal** calculation tool
  - Identification of failure modes that were not detected during the design phase



* *Anomaly Report Tracking System*

Thank you for your attention !

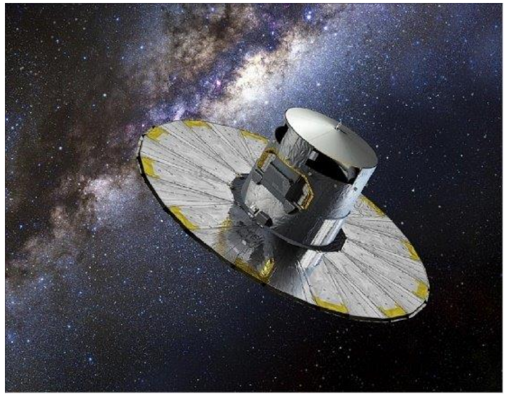
Any Questions (*or Return of EXperience*) ?

** Anomaly Report Tracking System*

Back-up slide – **Definitive failures not so definitive**

Operational workaround in degraded equipment

GAIA MPS



Artist's rendition of the deployed Gaia spacecraft. Copyright: ESA

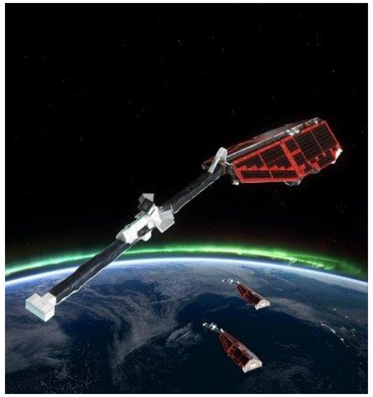
Operational workaround in degraded configuration

XMM antenna switch

Artist's rendition of the XMM-Newton spacecraft. Copyright: ESA

Operational workaround making use of other modules in the constellation

Loss of **SWARM** ASM-A & B



Artist's impression of the three Swarm satellite orbital configuration. Copyright: ESA/AOES Medialab