"Joint Design, Verification, and Operations Expertise to Improve Spacecraft Reliability and Performance"

FADAT 3rd Edition

14 June 2016

ESA-ESTEC

Noordwijk, The Netherlands

www.congrexprojects.com/2016-events/16m02

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Conference Committee

The FADAT workshop chairpersons are:

- Luigi Bianchi – ESA
- Otto Brunner – ESA
- Alessandro Donati – ESA
- Benoit Laine – ESA

Workshop Organisers:

- Antonio Harrison Sánchez – ESA
- Stephanie Di Blasio – ESA Conference Bureau

What is the Scope of the Workshop?

FADAT is the “Failure, Test and Operations Data” Workshop. The FADAT initiative aims at the enhancement of space systems dependability and safety by making use of life cycle failure and performance data during design, verification, and operations in an iterative and integrated way.

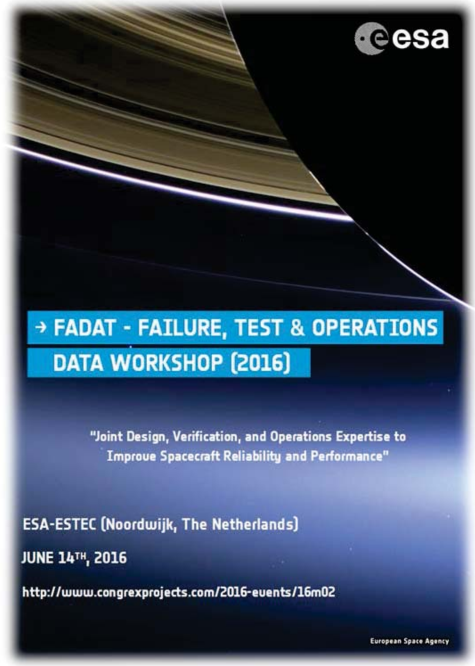
In this edition, we will focus on the process of information feedback from space operations to design and development with the purpose to build knowledge for the benefit of all on-going and future projects.
In addition, we will explore data analysis applications in-use or in-development for design, verification, and operations of space missions. We will address their current status, identify future needs or necessary improvements, and discuss their potential for integration.

Overall, the FADAT initiative continues to strive for a more effective data feedback process for the benefit of all ESA projects, fostering new cooperation between design, production and verification, and in-orbit operations.

Workshop Agenda

ESA- Failure, Test & Operations Data (FADAT) Initiative Introduction

A. Harrison Sánchez
ESTEC
14/06/2016



Outline

1. ESA FADAT Initiative Introduction
    a. Goal and Approach
    b. Objectives FADAT 3
    c. Benefits
    d. Implementation
2. Workshop Committee
3. Workshop Agenda

Introduction
Goal & Approach

- We can learn a lot from all our **testing and flight experience**, but we do not do it enough. Why?
  - Typical space project **lifecycle is linear**
  - **Different groups** in charge
- How can we improve our risk informed decision making throughout the project lifecycle?

BETTER INTEGRATION AND CLOSED LOOP UTILIZATION OF FAILURE AND EXPERIENCE DATA

- How are we attempting to achieve this?
  - **Fostering cooperation** among design, testing, and operations
    - FADAT **Workshops**
  - Devising new processes to harvest the available experience data supported by analysis tools
  - Starting new initiatives to **fill gaps in the processes and supporting tools**

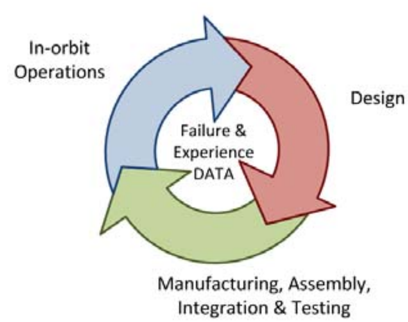
Typical project lifecycle
© ESA, ECSS

Introduction
FADAT 3 Objectives

"Joint Design, Verification, and Operations Expertise to Improve Spacecraft Reliability and Performance"

1. The FADAT Initiative aims at the enhancement of system dependability & safety by exploiting life cycle failure and experience data of space systems during design, verification, and operations in an iterative and integrated way

2. The **FADAT 3rd Edition Workshop objectives** are to:
   a. focus on the process of information feedback from space operations to design and development with the purpose to build knowledge for the benefit of all on-going and future projects.
   b. explore data analysis applications in-use or in-development for design, testing, and operations of space missions. We will address their current status, identify future needs or necessary improvements, and discuss their potential for integration.



FADAT exploits the potential for improvement of risk informed decision making through integration and closed loop utilization of data

Benefits in Design

- Improve **risk assessments** (e.g. during feasibility studies at CDF)
- Identify **technologies / designs** having caused problems across ESA's missions
- Assess **equipment reuse** risk
- Support **trade-offs** for selecting the most reliable equipment for the intended application
- Provide **operational reliability** parameters
- Address **human-in-the-loop** of space system design and in risk analysis & mitigation

Concurrent Design Facility (CDF) in session credit ©ESA

Benefits in Verification and Operations

- **Verification** of space systems
  - Data collection on test and flight failures to evaluate **effectiveness of different type of tests** in capturing in-flight failures
  - Improve **cost-benefit correlations** for more effective test planning
- **Operation** of space systems
  - Identify **operations prone to failures** and errors across different missions
  - Support trade-offs for selecting the **anomaly recovery strategy** yielding the highest chance of success

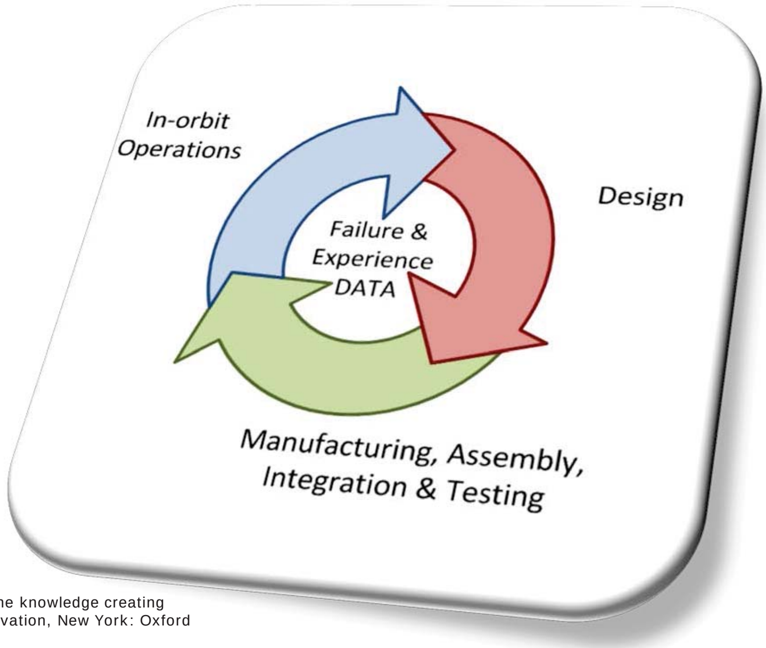
GOCE ready for testing at ESTEC, credit ©ESA

Deep space radio antenna in *Cebreros, Spain Credit ©ESA*

Implementation

A feedback process is needed

To transform "tacit" knowledge acquired **through in-orbit experience and during testing** into explicit knowledge for more successful future missions and technologies *



From the groundbreaking work of : I., Nonaka, and Takeuchi, The knowledge creating company: how Japanese companies create the dynamics of innovation, New York: Oxford University Press, pp. 284, ISBN 978-0-19-509269-1, 1995.

Workshop Agenda: Morning

Time	Title	Presenter(s)	Agency/Company
09:00-09:15	Welcome & Opening	Wolfgang Veith	European Space Agency (ESTEC)
09:15-09:30	FADAT Initiative Introduction	Antonio Harrison-Sánchez	European Space Agency (ESTEC)
09:30-10:15	Further Development and Application of the Catalogue of Failure Data (CFDA)	Paul Pearson, Jean-Paul Blanquart	Airbus Defence and Space (GB, FR)
10:15-11:00	RAMS Exploitation of In-Orbit Data: RIDE Demonstrator	Fabian Rother	Telespazio-VEGA (DE)
11:00-11:15	Coffee Break		
11:15-11:45	ASSET and ASSET+ Methodologies and Associated Lessons Learned	Piero Messidoro, Francois Vergès	Thales Alenia Space (IT), Airbus Defence and Space (FR)
11:45-12:15	Model and Test Effectiveness Database (MATED) Evolution	Otto Brunner	European Space Agency (ESTEC)
12:15-12:45	Second Closure of Anomalies	Karsten Baumann	Airbus Defence and Space (DE)
12:45-13:45	Lunch Break		

Workshop Agenda: Afternoon

Time	Title	Presenter(s)	Agency/Company
12:45-13:45	Lunch Break		
13:45-14:15	CNES Feedback from Flight Experience Process	Fabienne Guimbard	Centre national d'études spatiales CNES (FR)
14:15-14:45	Feedback from In Orbit Performances	Grégory Personne	Airbus Defence and Space (FR)
14:45-15:15	Survey of Novel Methods and Plug-in Tools to Support Diagnostics	Alessandro Donati, José Martínez	European Space Agency (ESOC)
15:15-15:45	TEC/Web MUST Evolution: Access to Flight Data for Discipline Engineers	Alessandro Donati, Benoit Laine	European Space Agency (ESOC/ESTEC)
15:45-16:00	Coffee Break		
16:00-17:00	Panel Discussion (Chairpersons)		
17:00+	Conclusions (Organiser)		

Workshop Committee

1. The workshop committee chairpersons are:
   a. Luigi Bianchi (TEC-QQD)
   b. Otto Brunner (TEC-MXC)
   c. Alessandro Donati (OPS-OSA)
   d. Benoit Laine (TEC-MTV)
2. The workshop organisers are:
   a. Antonio Harrison-Sánchez, D/TEC-QQD
   b. ESA Conference Bureau

3rd FADAT Workshop
ESTEC, Noordwijk, June 14th 2016

Catalogue of Failure Data for safety and dependability Analysis (CFDA)

P Pearson, J-P Blanquart

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CFDA: Catalogue of Failure Data to Support Space Safety and Dependability Analyses

ESTEC Contract (n°4000110072/13/NL/PA)

OBJECTIVES:

- to provide the framework for an effective support to safety & dependability analysis through the development of a catalogue of failure event input data
- To suggest improvements of the associated safety & dependability analysis elements.

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CFDA Motivations

- D&S analyses support information is fragmented and contained in many documents (ECSSs, in-house documents etc). There is a need to collect the important information together to aid the analyst.
- Perceived problems when reviewing supplied analyses – having a common database source to check analysis content will provide consistency of review and, if Suppliers use the Catalogue, a common content to review.
- Analyses are performed for different phases of a programme, but there is little documentary guidance for the analysts of what needs to be considered for each of these phases. Catalogue provides support for all phases of a programme.

CFDA in a few words

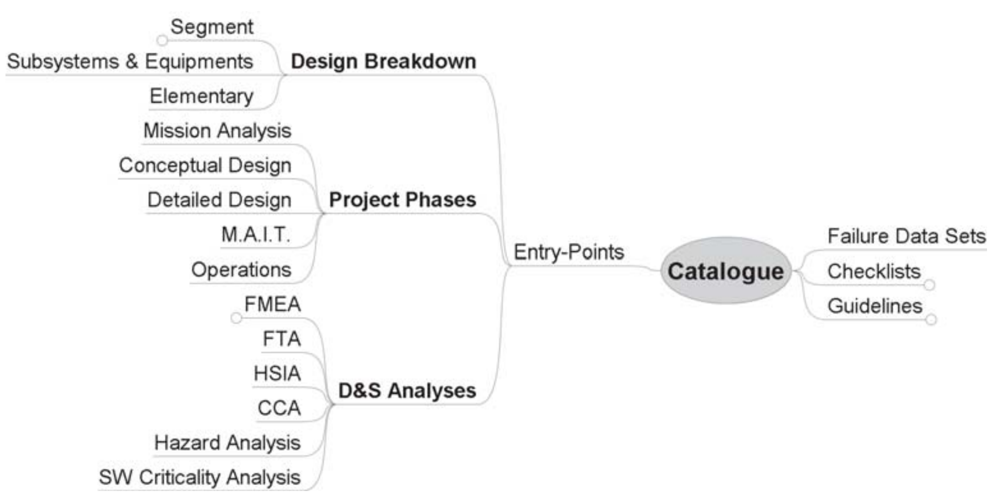
- The catalogue of failure event input data comprises data sets for:
  - Functional failures and associated failure events and scenarios at the various levels
  - Physical failures of hardware and associated failure modes, hazards, events and scenarios at the various levels
  - Software errors and associated functional failure modes, events and scenarios,
  - Human operator failures and associated error modes, events and scenarios,
  - Failures during operations
  - Common cause failures and associated phenomena, events and scenarios.
- Catalogue is not intended to provide quantitative data, only qualitative.

Project logic

- **User requirements**
  - Questionnaire, analysis, Airbus DS Experience
- **Failure data sets development**
  - Structure, organization, contents
- **Catalogue development, user interface**
  - Excel based, “The Cube”
- **Validation pilot application**
- **Extension**
  - Complementary failure data sets (project and organization,
  - Complementary analyses (Human Dependability Analysis, IFA)
  - An improved catalogue application, web-based

Failure data sets
Structure and organization

- Structured set of [component; failure cause; failure mode]



DEMONSTRATION

Summary and perspectives

- ## Benefits
  - CFDA is part of an overall initiative from ESA which is endeavouring to improve the effective D&S support to Projects.
  - The Catalogue will benefit the analyst in the following way:
    - Help to improve the consistency and creation of commonly produced Dependability and Safety analyses and their documentation (data from a common source, common terminology)
    - Speed up the production of Dependability & Safety analyses
    - Support the review of Dependability & Safety Analyses
    - Support the investigation and diagnosis of Anomalies
- ## Utilisation, dissemination
  - CFDA incorporated in Airbus Defence and Space processes
  - CFDA is made available to the Space community
- ## Future
  - Organization still to be defined.
  - Support from external Users will be more than useful
    - Feedback and contributions to the contents (failure data sets), features…

RAMS Exploitation of In-Orbit Data: RIDE Demonstrator

FADAT-3 Workshop, ESTEC, 14/06/2016

Telespazio
A Finmeccanica/Thales Company

14/06/2016 Telespazio VEGA Deutschland GmbH

Telespazio
A Finmeccanica/Thales Company

Agenda

- Introduction
- Brief summary of RIDE1 Study
- RIDE2 Study
  - Consolidation
  - Challenges for the Demonstrator Software
- Presentation of RIDE2 Demonstrator
- Outlook

Introduction

Why RAMS Exploitation of In-Orbit Data?

- RAMS and risk assessments rely on the availability of realistic input data.
- This input data is coming mainly from three different sources:
  - MIL-HDBK-217F, Notice 2 for EEE components
  - Manufacturer supplied information
  - Expert judgement based on experience and on the adaptation of data from space and non-space applications
- The input data are rather conservative and are based on estimations rather than on observations.
- One way to address the problem is to analyse AIV and in-orbit data.

Brief Summary of RIDE1 Study

Objectives

- Identification of interesting RAMS characteristics and which input data need to be collected
- Assessment of ESOC's and ESTEC's data sources
  - Where the identified input data are available and
  - Which additional capabilities/features are needed
- Definition of the user requirements for a system performing the RAMS exploitation of the collected data

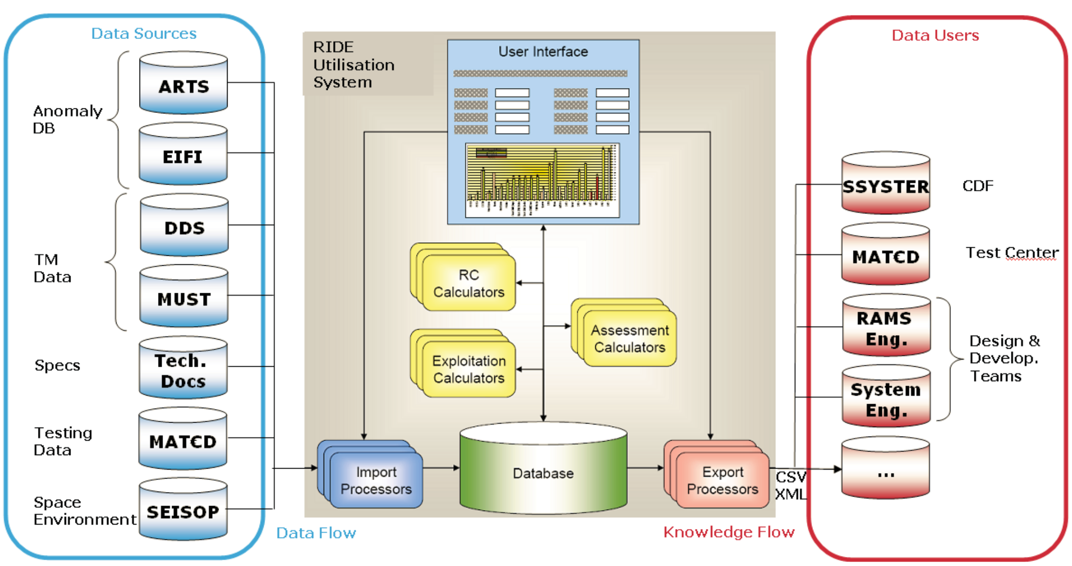
Brief Summary of RIDE1 Study

Results

- A list of 26 relevant RAMS characteristics and the corresponding algorithms
- A list of more than 100 input data items to be collected for each anomaly in order to calculate the RAMS characteristics
- Analysis of ESA databases in the light of the required data items
- Availability status for each data item in the potential sources
- Use cases and user requirements for a system which collects the data items and calculate the RAMS characteristics: the RIDE system

Brief Summary of RIDE1 Study

Results



RIDE2 Study

Objectives

- Consolidation of the information collected in the previous study in the light of the main stakeholders and the existing infrastructure, processes and tools.
- Development of a proof-of-concept demonstrator of the RIDE system.

- Example use case: Which gyros shall we take for the next mission?
  - Check laser gyros across missions for anomalies
  - Check missions that used the same gyros
  - Compare with anomalies on mechanical gyros
  - Check for NCRs and test philosophy during AIV
  - Check circumstances of certain anomalies: TM of gyro, space weather, etc.

RIDE2 Study

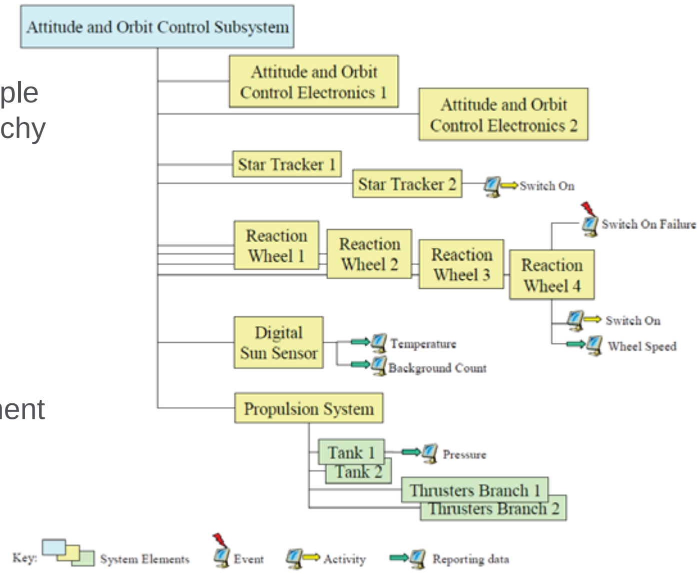
Consolidation

- Interviewed potential ESA internal and external stakeholders of the RIDE system with the help of a questionnaire about their requirements and expectations
- Existing RAMS characteristics confirmed and few new ones suggested
- Analysis of existing data sources performed
- No significant changes with respect to the results of the RIDE1 study

RIDE2 Study

Challenges for the Demonstrator Software – Spacecraft Model

- See snapshot from ECSS-E-ST-70-31C, Figure 4-1: Example product delivery system element hierarchy
- Equivalent to product tree delivered by industry and stored in MATED
- Problems:
  - Different hierarchy for different spacecrafts
  - Different names for same component on different spacecrafts
- Simplified spacecraft model used by Demonstrator



RIDE2 Study

Challenges for the Demonstrator Software – Input Data from ARTS

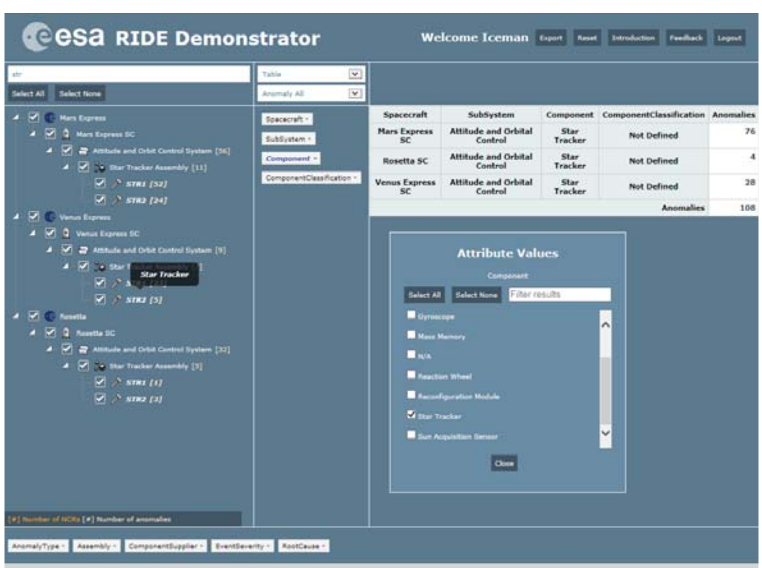
- In-flight anomalies recorded and processed at ESOC
- Level of detail as required by ESOC
  - Root causes different to industry classification and no simple mapping
  - Root cause not mandatory
  - Affected subsystem/component not always specified: "platform"
  - Different names for same component on different spacecrafts
  - Multiple occurrences of the same anomaly recorded in a single ARTS entry
- Detailed pre-processing of anomalies required which requires good knowledge of the spacecraft
- Platform anomalies from MEX, VEX and Rosetta harmonised for Demonstrator
- Similar issues exist for other input data sources => no direct automation

RIDE2 Study

Challenges for the Demonstrator Software – User Interface

- RIDE shall act like a dashboard to solve access problems to the input sources of RIDE, e.g. ARTS, MUST, SEISOP, MATED…
- RIDE shall only provide a subset of information originating from other sources, minimise the duplication of data
- If further investigations are required on external data, the external tools have to be used
- Information linking and an intuitive GUI

Presentation of RIDE2 Demonstrator



Outlook

What are the potential next steps

- Define and design common spacecraft model based on product tree
  - Partly used in MATED
  - Can be integrated into ARTS, WebMUST, NCTS, MATED, etc.
- Define collaboration process between ESTEC and ESOC for ARTS data
- Decide on post-processing of ARTS & NCTS data of current missions
- Develop RIDE system based on experience from RIDE1 & RIDE2
- Integrate RIDE into ESA system lifecycle

THANK **YOU** FOR YOUR ATTENTION

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WE LOOK AFTER THE EARTH BEAT

ASSET and ASSET+ methodologies and associated lessons learned

Piero Messidoro – Thales Alenia Space
Francois Vergès – Airbus Defence and Space

83230350-DOC-TAS-EN-001

2016 June 14th

FADAT 2016

ThalesAlenia Space

THALES ALENIA SPACE INTERNAL

Overview

2

- ASSET = Analysis of Spacecraft qualification Sequence and Environmental Testing

- ESA TRP study

(https:\exchange.esa.int\asset)

- Objective: investigate the factors that influence the effectiveness of environmental testing on the basis of lessons learned from the past and in view of future project needs
- An extension focused on Thermal testing, was completed in the first half of 2016 – final presentation 15 June @ ESTEC

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ThalesAlenia Space

Team

- *European Space Agency*: Benoit Laine
- *Thales Alenia Space Italia*: Piero Messidoro (*Study manager*), Mauro Pasquinelli (*Deputy study manager*), Pietro Giordano, Andrea Ferrero, Lorenzo Pace
- *Thales Alenia Space France*: Jerôme Buffe, Patrick Hugonnot, Jerôme D'Add
- *Airbus DS France*: Francois Vergès (*Airbus DS study manager*)
- *Airbus DS Germany*: Reiner Werner

ASSET: Methodology

- The process has been:
  - Individuate and detail relevant issues in environmental testing and possible improvements
  - Select, inside each company's databases, non-conformances and flight anomalies that could give useful information for the purpose of the study
  - Perform a detail assessment of those anomaly cases (root cause, understanding)
  - Analyze test programs and test conditions to assess trends, test effectiveness, relevance of ECSS standard w.r.t. practice.

- The guidelines have been defined as general questions:
  - Which problems that occurred in previous programs could have been avoided through a different test campaign (limited to environmental tests)?
  - Which type of methodologies and database(s) should be developed/improved to follow-up the test effectiveness topics?

- Important point: the analysis considers only the perspective of detecting flaws, i.e. screening objective. Tests also have other objectives, and impact on planning and cost are not directly considered, e.g. added value of a STM/QM for early identification if design issues – is not addressed here.

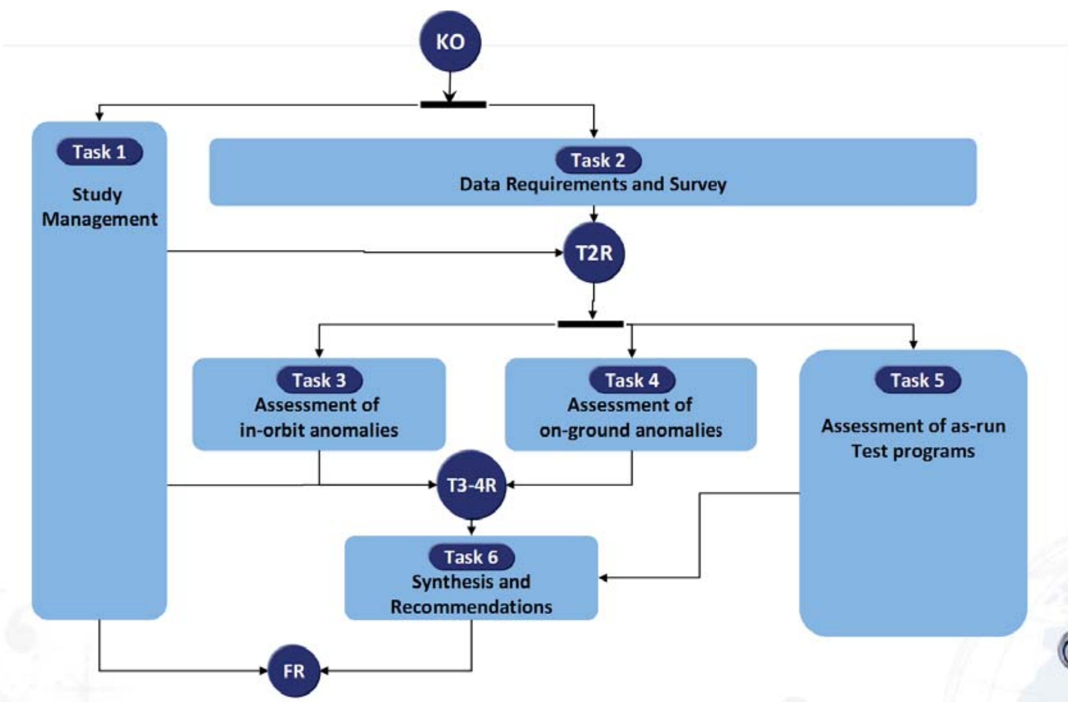
Considered space programs

- **Science**: INTEGRAL, XMM-Newton, Cluster 2, Mars Express, Rosetta, Venus Express, Herschel, Plank
- **Human-rated**: ATV, Node 2, Node 3, Cupola
- **Telecommunications**: Artemis
- **Earth observation**: ERS 2, MetOP, GOCE, CryoSAT, MSG

- Additional programs, covering all the four above mentioned categories, have been considered out of the ESA perimeter, with results and relevant cases provided in anonymous form

- 35843 NCRs and 199 FLAs have been screened
- **108 NCRs** and **35 FLAs** have been considered to give relevant information to the purpose of the study and further analyzed
- Each test program has been analyzed in terms of plan and test conditions

ASSET workflow and study logic



ASSET study results

- The outcomes of the different analyses have been consolidated into a set of recommendations
  - Discussed with the engineering and AIV/AIT experts of participating companies for refinement
  - Presented to ESA/ESTEC, ECSS, AIV and AIT teams, and disseminated
- The study concluded that environmental testing, as performed on the considered programs, is effective in screening for flaws so that anomalies do not occur in flight. Nevertheless, some aspects to be improved have been proposed.
- An important objective was also to propose recommendation on the type of database that could be developed or improved to ensure efficient follow-on work on this topic, and this is the focus of this presentation, as it fits with the FADAT scope.

ASSET+: Overview and objectives

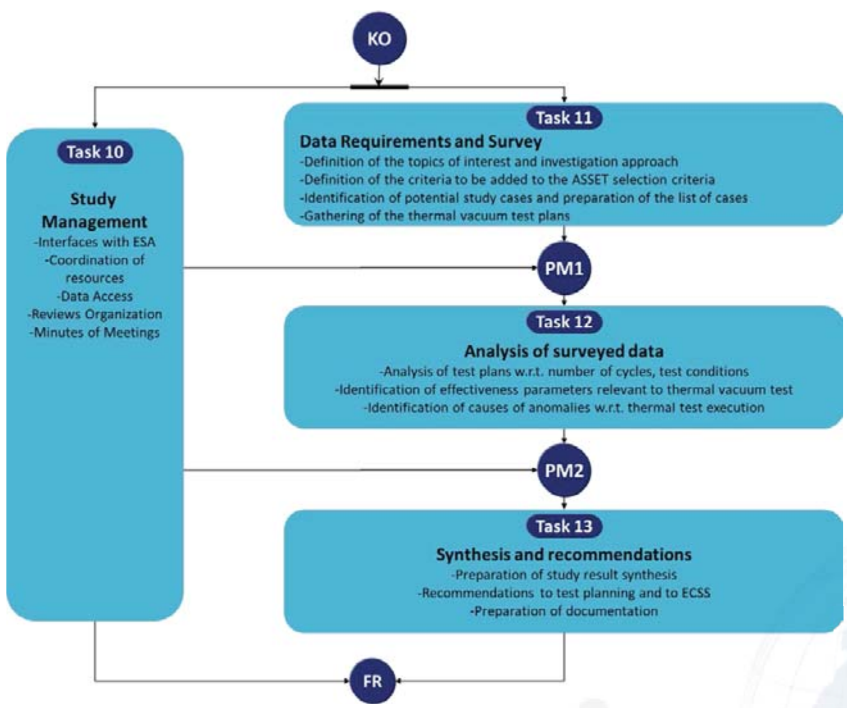
- ***ASSET+*** (*ASSET-plus*) started from a subset of the outcomes and considerations originating from the analysis and synthesis activity of ASSET
- Objectives:
  - Better understand the parameters that influence thermal vacuum test effectiveness
- Typical questions:
  - Are the anomalies found in TVT really precipitated by the vacuum, the temperature conditions, the cycling, or could some of the anomalies be detected by a different test (e.g. functional test in clean room)?
  - Why the anomaly are precipitated in TV test, even on already qualified+accepted hardware?
- Focus on Thermal Vacuum test at spacecraft level

ASSET+: Considered programs

- The following ESA space programs have been considered:
  - **Science**: Herschel (ADS-D), Planck (TAS-F), GAIA (ADS-F), Bepi Colombo (ADS-D/TAS-I)
  - **Earth observation**: MetOP (ADS-F), GOCE (TAS-I), CryoSAT (ADS-D), MSG (TAS-F), Sentinel 1 (TAS-I) –Sentinel 2 (ADS-D), SMOS (TAS-F), Swarm(ADS-D)
  - additional programs (commercial and national) can be used to provide cases in anonymous form, from the Science and Earth Observation categories, but also for Telecommunications

- 52 NCR and 12 FLA have been considered to give relevant information to the purpose of the study and further analyzed

ASSET+ worlflow and study logic



ASSET+: main results – work under consolidation…

- The first outcome is that **current practice and approach in TVT is good**: the findings confirm the importance **to perform the TV test in realistic flight conditions, in vacuum,** and to perform the functional tests both at hot and cold conditions.
- Findings on temperature levels
- Findings on number of cycles
- At the time this presentation is sent for the proceedings, work is ongoing to consolidate the conclusions

Methodology

- Same methodology as ASSET
- Survey of NCRs and FAs from ESA space programs (plus relevant cases from commercial programs in anonymous form)
  - Definition of selection criteria
- Analysis of the selected cases to improve understanding and address the topics of interest (significant effort).
  - Individuation of parameters of interest
  - Definition of study questions
- Assessment of as-run tests
  - Questionnaires aimed at understanding of
    - Test programs
    - key test parameters

Study questions – ASSET+

1. How critical is the vacuum condition to precipitate flaws? Are the anomalies specifically related to the vacuum condition, or could they be anticipated by tests on the spacecraft before TV without losing in test effectiveness?
2. Does TV cycling at S/C level precipitate flaws (i.e. anomaly appears because of the temperature cycling)? If yes, what is the impact on test effectiveness of each TV cycle?
3. Are there anomalies that would have been found earlier if sun simulation had been used during TVT? Are there anomalies found thanks to sun/infrared simulation? Are there anomalies which are linked to the use or lack of infrared flux?
4. How critical is the temperature level to precipitate flaws? Are the anomalies related to the extreme temperature level?
5. Is there a relation between failure of functional test and test phase (hot phase/cold phase)?
6. Do ground and flight anomalies occur also at not extreme temperatures? What type of anomalies appear during transitions? Which type of tests performed during thermal transients would have helped to detect a flight anomaly on ground? Which type/level of test actually found such non conformances on ground?
7. Are there anomalies that are not related to a spacecraft flaw, but are due to operations/facility?

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ASSET+ test program questionnaire

	Question
1	Was the objective to reach qualification or acceptance temperature or another?
	Was the target temperature reached?
2	What was the temperature margin?
3	How was the heating performed?
4	Has sun simulation been used?
	Watts per square meter
5	Has infrared flux been simulated?
	Watts per square meter
6	Have Functional tests been performed during transitions?
7	Have Functional tests been performed only at last plateaus (hot+cold)?
8	Has burn-in test been performed?
9	What was the total number of cycles?
10	How many anomalies have occurred per cycle and (hot/cold) phase?

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Lessons learned

The study highlighted a number of difficulties:
- Accessing the data
- Understanding the data
- Capturing the knowledge and making it available
- Elaborating lessons learned

It also showed different ways to working with such data:
- Working with repositories as MATED
- Searching the reports in free text

It proposes ways forward:
- Double closure of anomalies

The difficulties: Accessing and understanding NCRs and FAs

- The data collection performed during the ASSET study highlighted that the effort to get relevant pieces of information from ended programs is very high and often prohibitive
- At least 1 FLA out of 35 (and many ground NCRs) revealed that same problems occur again in later programs because the past experience is difficult to access while handling very specific domains. This seems to be a symptom of the lack of proper feedback from operations to engineering
- Anomaly reports are written to support the process of their resolution for the project, and not to provide feedback to people external to the projects.
- The reports capture the process of the investigation, as followed, by and for people involved in the project (use of acronyms and reliance on background knowledge).
- There is no wrap-up or executive summary, often no clear conclusion on anomaly root cause.
- The reports are not meant to be used by people lacking the inside knowledge

The difficulties: Accessing and capturing test programs and conditions

- The data about tests is spread over a larger number of documents:
  - Test plan : high level and in preparation of the tests – it is an intention
  - Test spec : for each test, it is a request, i.e. an intention
  - Test procedure : for each test, it may deviate from the test spec
  - As run procedure : for each test, captures deviations – Usually not easy to read and understand : written to capture a process. Uses acronyms and background knowledge. Sometimes hand written, in a hurry.
  - Waivers and NCRs
  - The "applied levels" are sometimes captured in different documents, e.g. temperature targets for each unit in TVAC
  - The severity (wrt expected flight levels) is difficult to assess, as it relates to discipline analysis data. E.g. difficult to assess overtest
  - People often have a simplistic approach to the verification level (qualification/acceptance) and reality is often in a grey area (e.g. temperature reached during TVAC different for each equipment)
- It is very important and difficult to capture what the test program and conditions were exactly, and people tend to remember incorrectly.
- It is difficult to wrap-up the data and build knowledge, usable by others

The difficulties: Capturing the knowledge and make it available

- There is no systematic way of capturing the knowledge and making it available.
- The exercise to go through anomalies is very enriching, as there is a lot to learn from the mistakes made in the past. Unfortunately, there is no systematic lesson learned, hence the risk that mistakes are repeated.

Different tools to look for data

Two methods were used when looking for data:

- MATED (link to the MATED presentation):
  - Data are pre-processed, i.e. categorised. Someone has made the data analysis and classified the anomalies and captured the test program
  - Advantage: processed and classified data already available
  - Potential problem: initial analysis may be incorrect, database bias by mistakes
- Free search in the repository of anomalies (NCTS, Pandora, Fisheyes):
  - Raw data from the complete repository
  - Advantage: no risk to miss an anomaly that was incorrectly analysed
  - Difficulty: analysis is to be performed systematically
- Both approaches were used, showing complementarity.

Proposed way forward

Considering the difficulties encountered, and the amount of effort spent to capture the data, it is proposed:

- To adopt a system of double closure of anomalies, i.e. anomaly is closed in the frame of the project, and reconsidered from a knowledge management/process improvement perspective, by dedicated people sensitive to the terminology/taxonomy, performing or formalizing the root cause analysis if necessary, formatting the data in a clear and useable way, and disseminating it to the interested parties (industry, discipline experts)
- When using tools as MATED, to trace the analysis performed (justification of the classification), source of information, and to add a validation step of the data. Add some level of detail in the definition of the levels applied (QM, STM, FM, PFM is not sufficient to derive the severity of tests, also depending on the environment)
- In the longer term, Model Based System Engineering approaches should allow a better access to the data (ref to ongoing TRP study on Model based requirement verification lifecycle)

Conclusions

- ASSET (+) led to interesting results
- One important outcome is that currently we have achieved a good level of test effectiveness
- The study showed the willingness and the capability of large system integrators to collaborate on such research topics, despite being competitors
- Important Lessons Learned emerged relevant in particular to processing of NCR/FLA and Databases which can be considered for further improvements of our processes
- In particular, it is important to have a process to capture the knowledge and disseminate lessons learned to all parties including engineering disciplines

Model and Test Effectiveness Database (MATED) Evolution

Otto Brunner
ESTEC
14/06/2016

Presentation Overview

- Introduction
- Database status
- Data types and typical sources
- Analysis capabilities
- Improvements
- Examples
- Conclusions

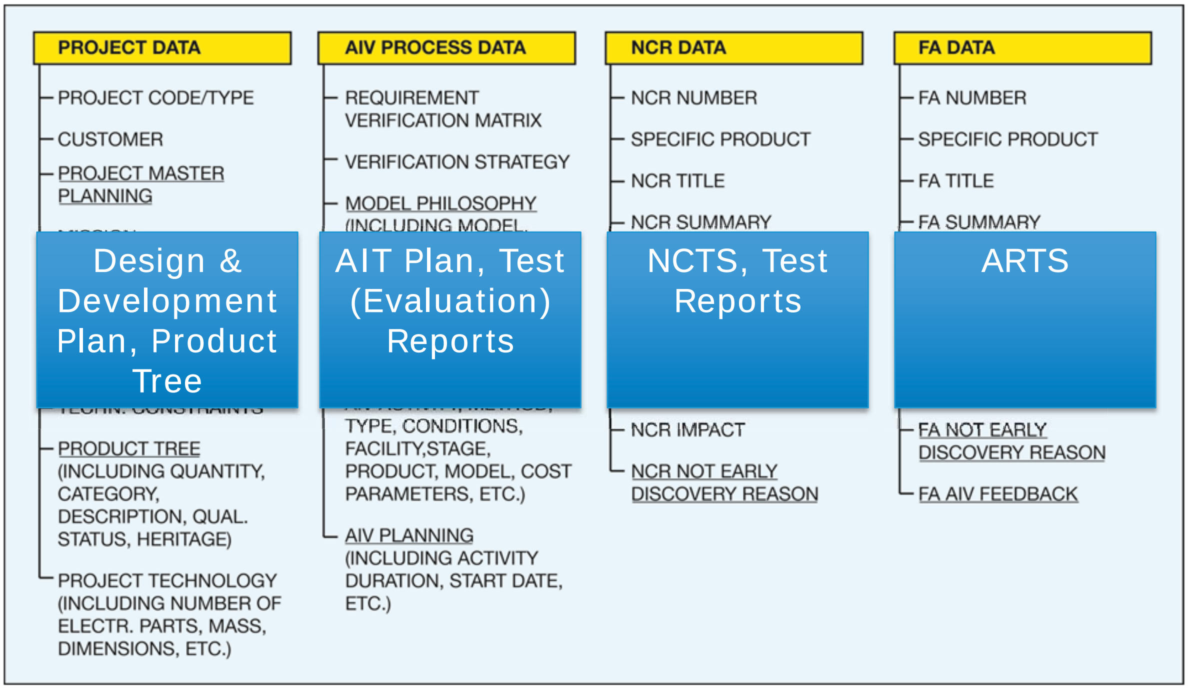
Introduction

- The Model- And Test Effectiveness Database MATED has been setup to facilitate investigations on past project planning and implementation of AIV activities, and relate these to NCRs experienced during the AIV campaign and to flight anomalies encountered during operation.
- Objective is to improve the effectiveness of the selected model-, assembly-, integration and test- (AIT) approach for new projects!
- Lessons Learned can be derived from the data stored and used for improving the s/c model philosophy, AIV approach and related standards.
- The tool includes advanced analysis capabilities which allow to perform detailed statistical evaluation of the stored spacecraft project data, or of any subset based on user selected criteria.

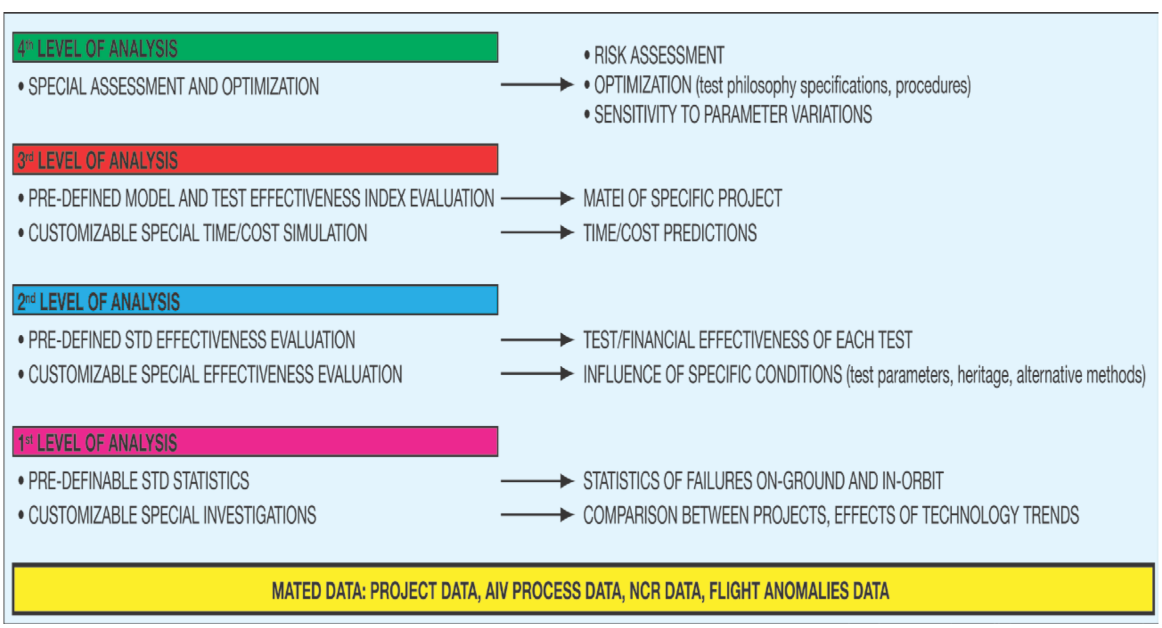
Status

- MATED is located on a server in ESTEC;
- Data from 27 Projects (13 scientific, 4 telecommunication, 7 earth observation and 3 pressurised modules) have been collected, with more than 100 Flight models and more than 4300 AIV related NCRs and 329 related Flight Anomalies;
- Data are provided by ESA and European industries and Space Agencies;
- ESA projects included are, among others: INTEGRAL, CLUSTER, XMM, MARS EXPRESS, VENUS EXPRESS, ROSETTA, HERSCHEL, PLANCK, ARTEMIS, ERS-2, MSG-2;
- MATED is maintained by ESA and accessible by MATED partners via internet browser;
- A high level of data security is maintained by keeping the underlying software on the newest standard.

Data types and typical sources



Analysis levels



Improvements

- Version 3.1 – released 23-02-2009

- Version 4.0 – released 12-05-2015
    - Update of hardware and operating system (MS server 2012 R1);
    - Update underlying software to up-to-date versions for security reasons Oracle database 12c, Java JDK 1.7, Tomcat container 7.0.50, Apache 2.4.10;
    - Regain compliance with up-to-date browsers Internet Explorer, Firefox, Chrome;
    - Update underlying software for analysis results visualisation from Oracle OLAP to FusionCharts XT;
    - Upgraded analysis: GUI, navigation tree, filter section;
    - Drill down on data in analysis charts;
    - Update of documentation SRS, SDD, ICD, SUM.

Improvements

- Version 4.1 – released 26-02-2016
    - Batch file pre-loading for partner users (under test);
    - Batch loading templates can be downloaded from file server (to be provided by MATED Application Manager);
    - Enhanced security features for access control (password age, length, complexity, account locking after to many invalid login attempts.

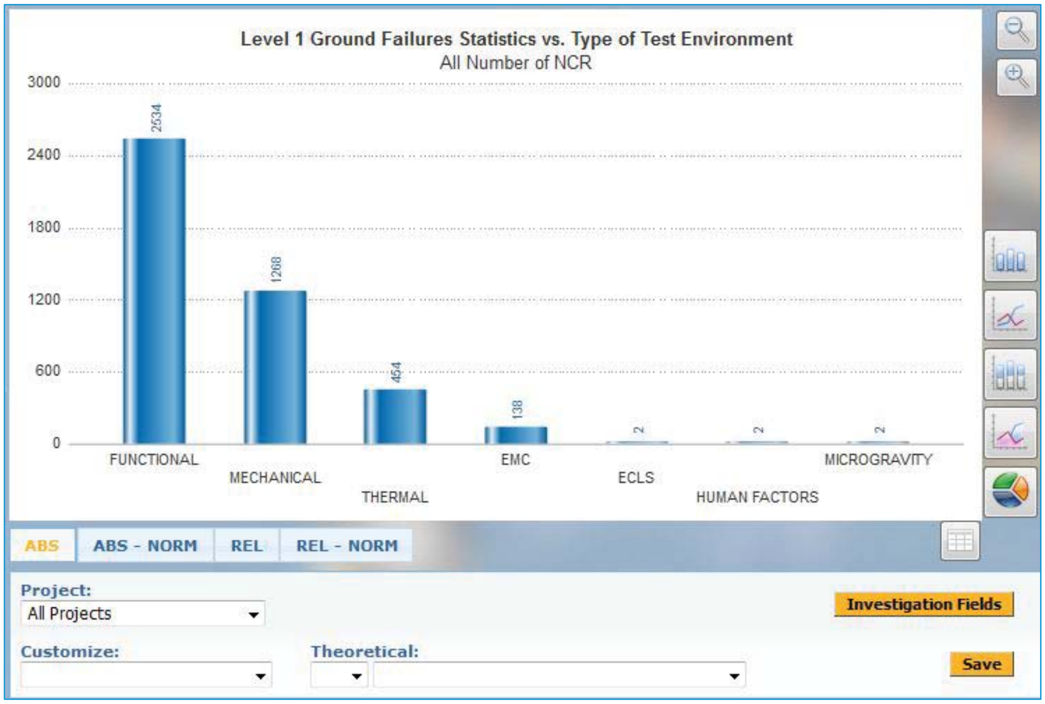
- Version 4.2 – release planned August 2016
    - Improvement of database maintenance: verification and release of pre-loaded batch files, consolidation of key words, statistical analysis of database content for multiple projects and supplier related;
    - Visualisation of metadata: originator, insertion date, revision date;
    - Key word use information;
    - Improved table navigation by adding line numbers;
    - Improved handling of incomplete data.

Future improvements

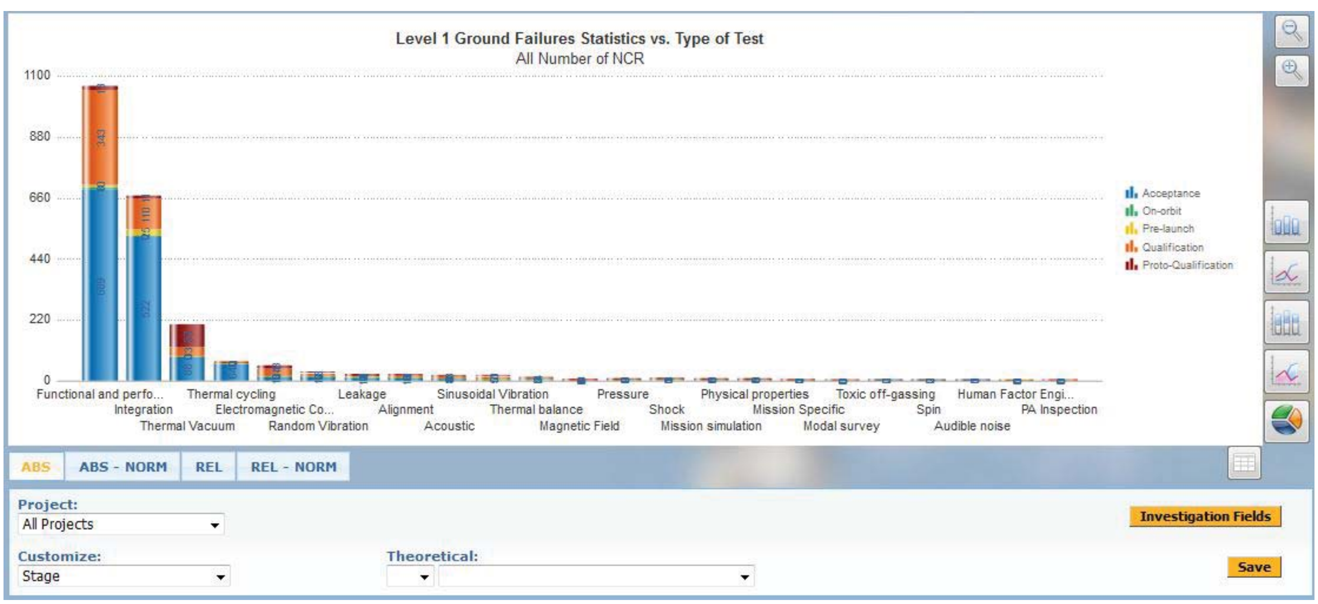
- Points under discussion (funding to be identified)
  - Table enhancements:
    - increase of field size to be more in line with NCTS and ARTS;
    - adding columns for additional information;
    - adding new tables;
  - Data review function – introduction of mandatory data verification step;
  - Project reports;
  - Additional reference data set;
  - Improved user management;
  - Exchange facilities for statistical data;
  - Improved information on AIV activities e.g. number of thermal cycles, levels;
  - Advanced query possibilities.

NCR versus type of subsystem

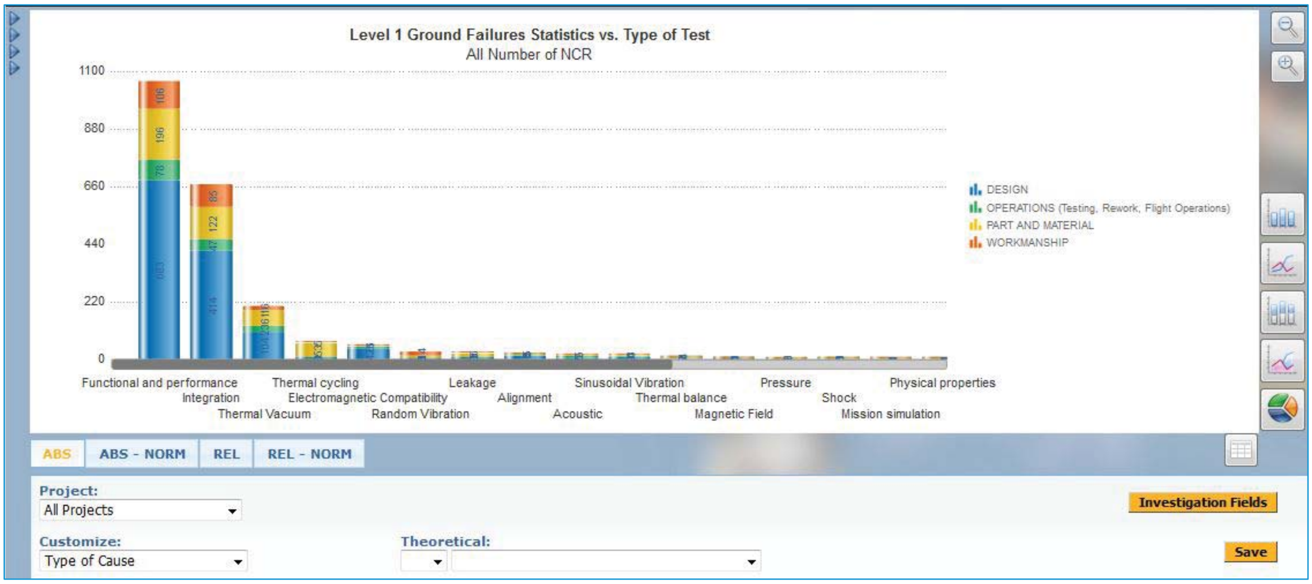
NCR versus test environment



NCR versus type of test & verification stage



NCR versus type of test and type of cause



MATED Evolution | Otto Brunner | ESTEC | 14/06/2016 | FADAT 3 Workshop | Slide 13

European Space Agency

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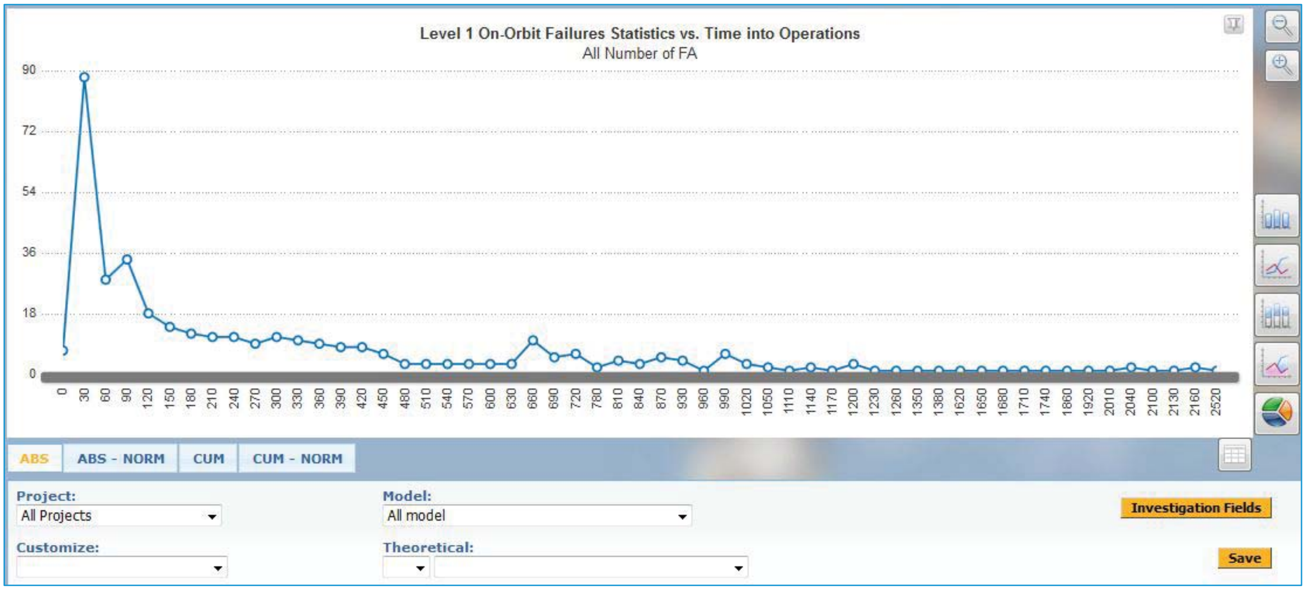
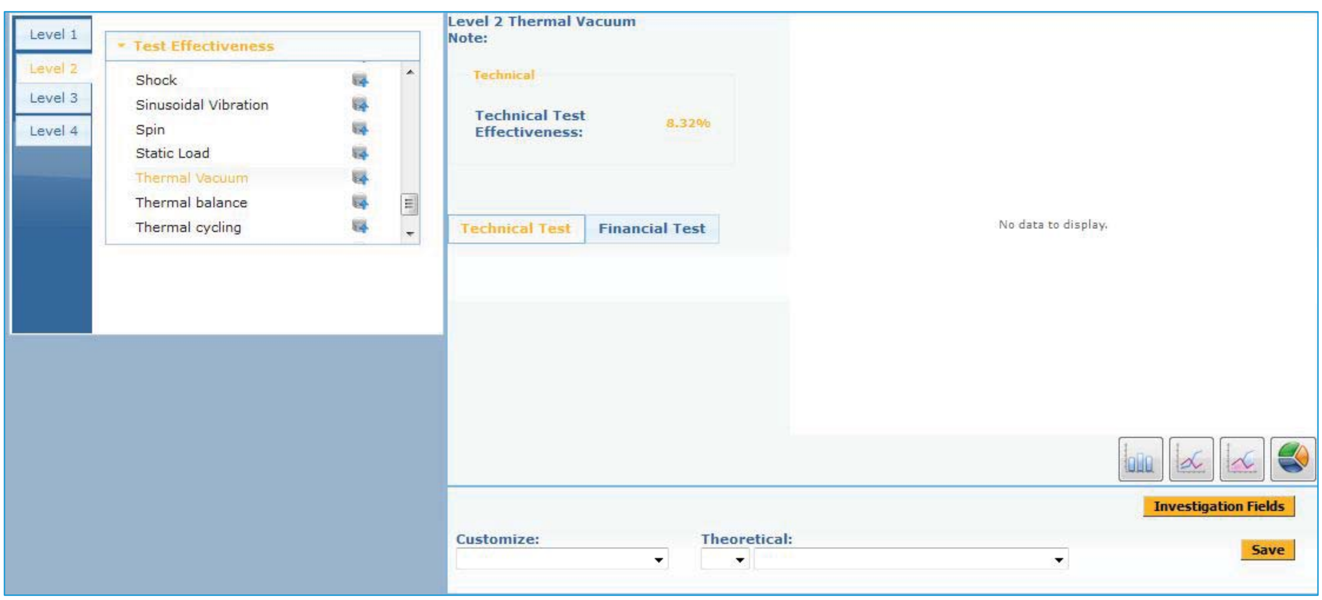
Flight anomaly versus severity

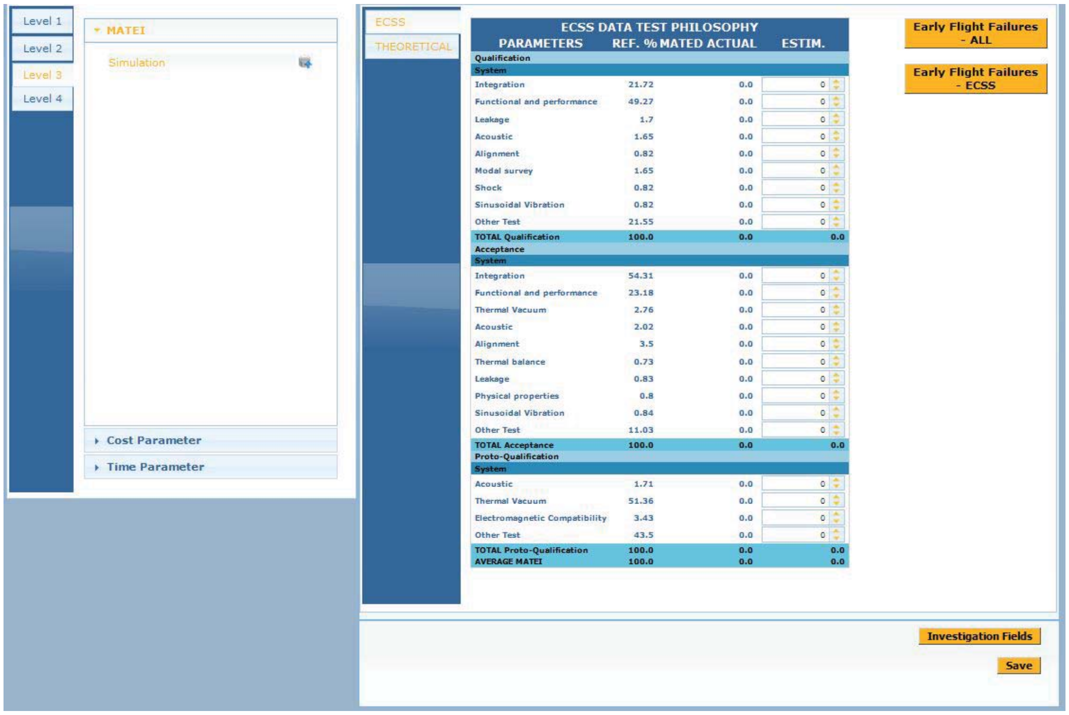
Infant Mortality



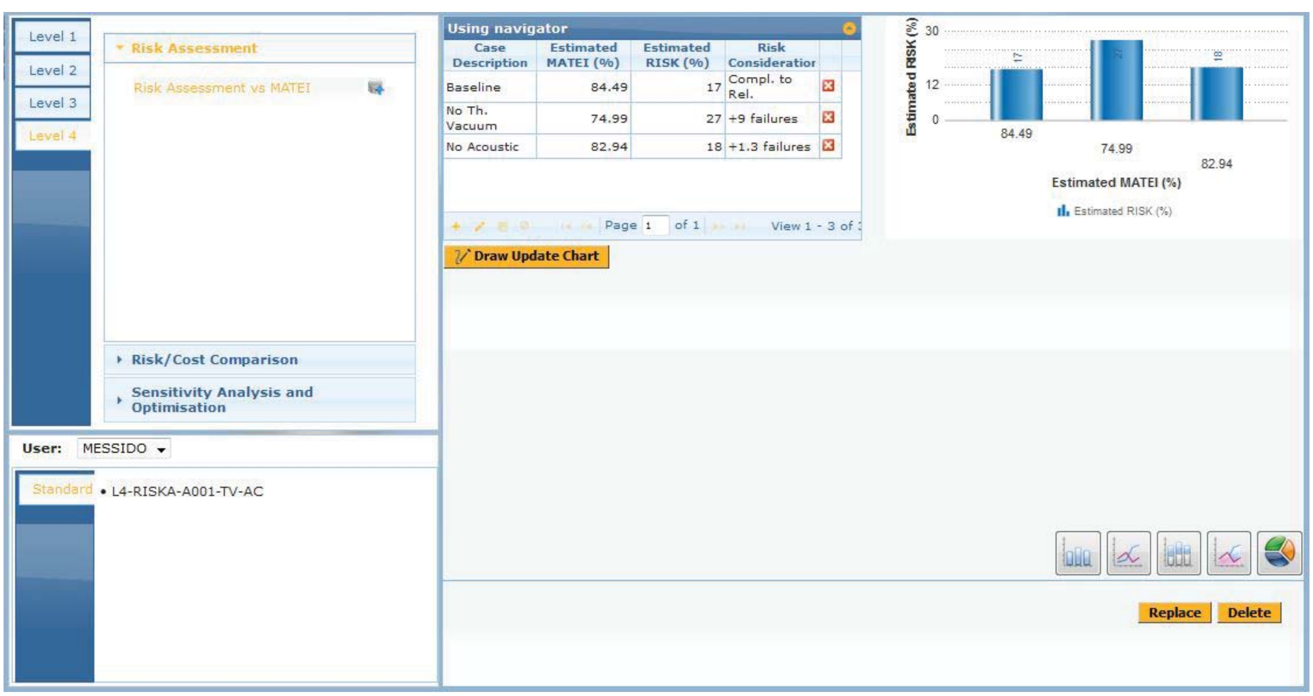
Level 2 analysis: Test Effectiveness



Level 3 analysis: MATEI



Level 4: Risk assessment vs. MATEI



Conclusions

- MATED is a comprehensive European repository of Project AIV information, related NCRs and flight anomalies.
- MATED provides functionalities to generate statistical evaluations, optimize verification planning, and to improve cost estimations based on real data.
- Relations between test activities, ground failures and flight anomalies are identified enabling the formulation of lessons learned for AIT planning, in particular on thermal vacuum , acoustic and SVT tests.
- MATED enables an assessment of the own AIT approach compared to reference data, e.g. standards.
- The most important improvements identified at the previous workshop in Turin have been implemented or implementation is under way.
- Future additional improvements are proposed.
- Data collection has been slow recently and needs to be strengthened with additional attention to legal aspects of data exchange.

Second Closure of Anomalies

Karsten Baumann, Airbus DS

Failure, Test & Operation Data Workshop - FADAT 3rd Edition
14th June 2016, ESTEC

AIRBUS DEFENCE & SPACE

Introduction

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This presentation

- Introduces the topic of second closure of anomalies in satellite MAIT
- And the major lessons learned on the process as applied in Airbus DS Space Systems in MAIT

Why this topic?

- Anomalies impact the flow of MAIT and create schedule delays, additional cost and variation
- Reducing the number of anomalies reduces variation
- Reduced variation improves quality as well as cost and schedule credibility

We distinguish two categories of anomalies

- Anomalies caused by MAIT
- Anomalies found by MAIT and either caused by design or detected post equipment acceptance

Anomalies impact the flow of MAIT and create schedule delays, additional cost and variation

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A short excursion into the theory of anomaly management - definitions used in this presentation

Important references for us

- ECSS-Q-ST10-09C chapter 5.3 Corrective and preventive actions
- ISO 9000:2015 Quality Management Systems – Fundamentals and vocabulary

Anomaly (ECSS)

Any deviation from the expected situation

Correction (ISO 9000)

Action to eliminate a detected nonconformity

Corrective Action (ISO 9000)

Action to eliminate the cause of a nonconformity and to prevent recurrence

Preventive Action (ISO 9000)

Action to eliminate the cause of a potential nonconformity or other potential undesirable situation

In Airbus DS anomaly management, correction is often referred to as closure 1, corrective as closure 2 and preventive as closure 3

Source: ISO 9000:2015

Standard NCR management process in Airbus DS ADS.E.101

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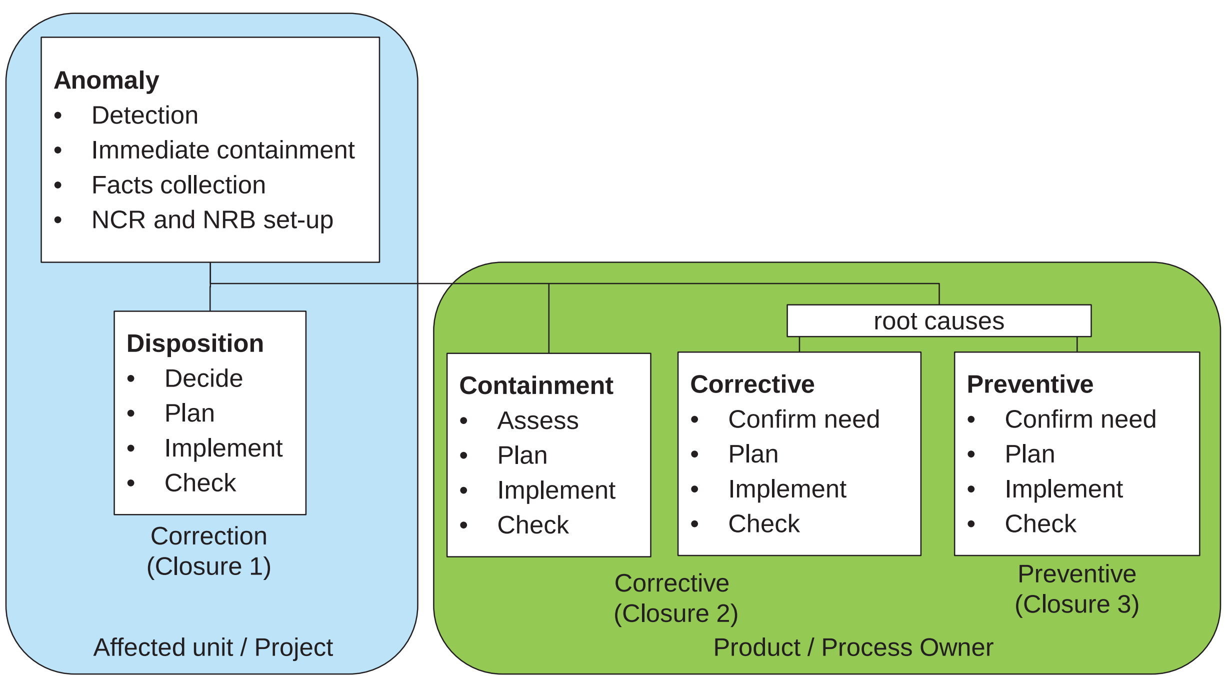


Anomaly management following the Correction, Corrective and Preventive methodology is widely applied in Airbus DS

Source: Airbus DS ADS.E.101, latest version by Eric D'Andrimont

Transfer process from Closure 1 to Closure 2

What we have after closure 1

- A detailed description of the initial finding with technical details, e.g. part number, material, drawings,…
- An analysis of effects and cause
- Impacts analysis, e.g. stress
- A repair and verification procedure
- The final check stating ‚ok‘

What we need for closure 2 and 3

- A short and conclusive description of the facts
- A root cause analysis
- Identified the root process and the process owner
- Identification of affected units outside the project scope

Transfer process

The information we typically get out of closure 1 is different from what is needed for closure 2.
The step from Correction to Corrective and Preventive requires consolidation of information and handover of NC ownership.

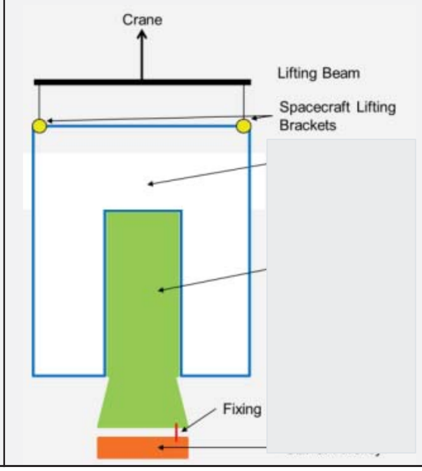
Closure 2 Standard Reporting Sheet

Issue	Description		Root Cause
What happened? What happened Where During which process step Sequence of events Do not put any names of people	***When:*** ***Ref:*** ***Impact:***	Date NCR Reference Hardware impact.	***Why did it happen?*** 1) Process and Materials 2) People 3) Tools & Environment 4) Engineering 5) ….
Correction Action	**2nd Closure**		**Schematic / Picture**
1st Closure: Disposition (+ immediate containment if needed within project)	***2nd Closure answering the Root Cause analysis:*** Identify actions in answer to the root cause (+ wider containment if needed outside of project)		

The Closure 2 Standard Reporting Sheet has been introduced in 2014 in Airbus DS to further improve systematic communication and management of second closure of anomalies in MAIT.

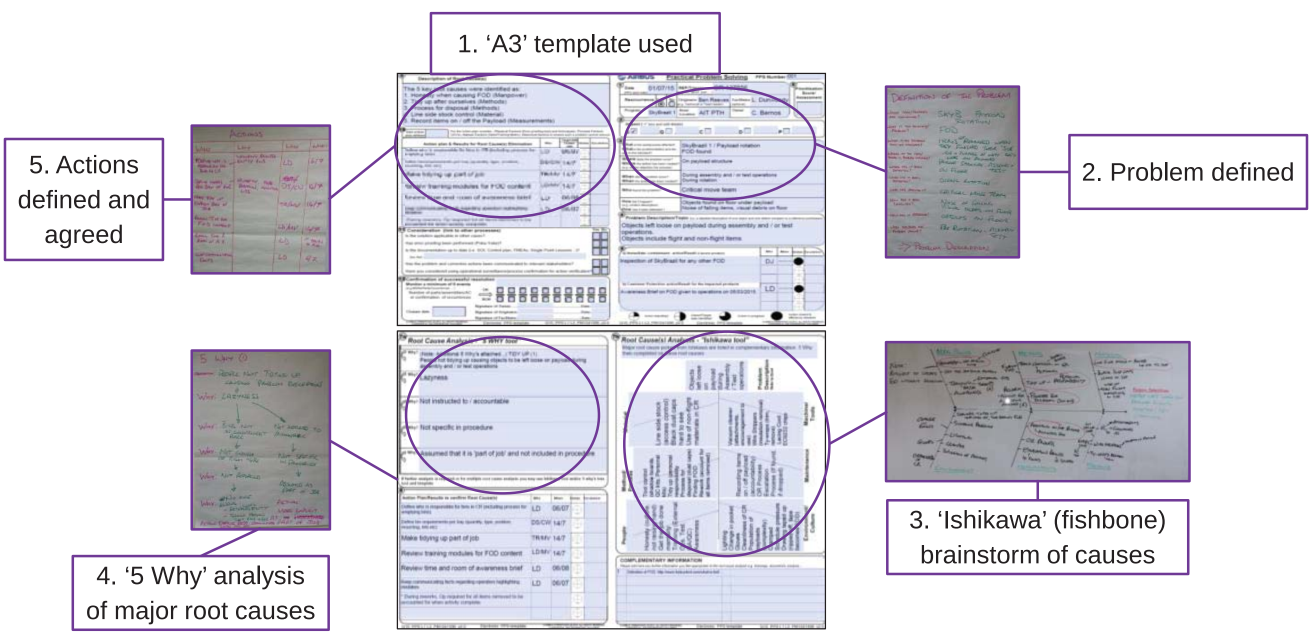
Example: A lifting issue in MAIT

Issue	Description	Root Cause
What happened? One of the 38 fixings securing the GSE to the satellite was not removed prior to lifting.. During the lift it was observed that the load cell displayed 1,500kg (1,200kg was expected mass). Lift was stopped, H/W made safe for investigation.	***When:*** 01 April 2016 ***Ref:*** REF.NCR.00057 ***Impact:*** Potential stress to satellite. Lifting held until agreement with customer at NRB.	***Why did it happen?*** Critical move procedure requires operator, QC and QA to confirm that all fixings are removed, however fixing was missed and remained engaged. Root causes determined as: • Quantity of fixings to remove undefined • Fixing missed by 3 people (human error) • Poor visibility of fixings • MGSE fixing control

Correction Action	2nd Closure	Schematic / Picture
1st Closure: Fixing was remove, no signs of deformation. All lifting points were inspected and showed no damage. NRB held with Stress Team to determine whether lifting could commence	***2nd Closure answering the Root Cause analysis:*** • Procedures to be fully reviewed to define quantities of MGSE fixings • Shadow board for fixings to be implemented → update MAIT best practise • Update standard MGSE spec requiring yellow fixing → update GSE standard spec • Investigation and analysis to be communicated across AIT to ensure risks are mitigated on all sites.	

Root cause analysis

- Airbus is implementing systematically root cause analysis as part of its group wide QUEST quality improvement initiative
- Root Cause analysis is performed by a Multifunctional Team



Root cause analysis is the first and most important step in closure 2.

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Conclusion and Questions

Conclusion

- Anomalies impact the flow of MAIT and create schedule delays, additional cost and variation
- Anomaly management following the Correction, Corrective and Preventive methodology is widely applied in Airbus DS
- The step from Correction to Corrective and Preventive requires consolidation of information and handover of NC ownership
- The Closure 2 Standard Reporting Sheet has been introduced in 2014 in Airbus DS to further improve systematic communication and management of second closure of anomalies in MAIT
- A proper root cause analysis is the first and most important step in Corrective and Preventive Management

→ The second closure of anomalies has helped us to substantially reduce the number of anomalies caused by MAIT

→ The Space Systems Quality Board has adopted the Closure 2 Standard Reporting Sheet to rigorously track corrective and preventive closure.

Questions

- Should our NCR tools support the consolidation of information and handover of NC ownership
- Do we see a benefit to wider apply the presented method between ESA and industry?

CNES FEEDBACK FROM FLIGHT EXPERIENCE PROCESS

Fabienne GUIMBARD

14/06/2016

1

SOMMAIRE

- NOMINAL AND ANOMALIES MONITORING
  - Bi-annual Performance Review Meeting (PRM) and annual exploitation Review (REVEX)
  - Anomalies management
  - Routine exchanges with experts and project
- IN-ORBIT SUPPORT (MCO) : CONTRACTS WITH SUPPLIERS
- LESSONS LEARNT (REX) TOWARDS THE FUTURE
- LESSONS LEARNT (REX) BETWEEN OPERATORS

2

SOMMAIRE

- **NOMINAL AND ANOMALIES MONITORING**
  - Reviews
  - Anomalies management
  - Routine exchanges with experts and project
- IN-ORBIT SUPPORT (MCO) : CONTRACTS WITH SUPPLIERS
- LESSONS LEARNT (REX) TOWARDS THE FUTURE
- LESSONS LEARNT (REX) BETWEEN OPERATORS

NOMINAL AND ANOMALIES MONITORING

Reviews

- Bi-annual PRM (Performance Review Meeting)
  - Status of all subsystems (power, AOCS, DHS…)
    - Long term monitoring
    - Anomalies
- Annual exploitation review (REVEX)
  - Status of all subsystems
  - Mission
  - Quality
  - …
- Extension mission review (REDEM)
  - Status of all subsystems to confirm mission can be extended for the coming year

NOMINAL AND ANOMALIES MONITORING

Anomalies management

- In case of anomaly, creation of a working group for investigation and resolution
  - Experts from CNES
  - Experts from industry
  - Operations engineers

- Regular meetings for investigations

- Report writing when finished
  - Recommendations for operations and safety
  - Feedback for other missions (REX)

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NOMINAL AND ANOMALIES MONITORING

Routine exchanges with experts and project

- Monthly reports
  - Status of all subsystems (power, AOCS, DHS…)
    - Long term monitoring
    - Anomalies

- CNES and satellite prime contractors (ADS, TAS, …)
  - OIA (Operational Interface Agreement) with CNES experts for their support in case of anomalies (working groups or specific questions)
  - In-Orbit Support (MCO) with satellite prime contractors and equipment suppliers for long term monitoring and anomaly investigation (working groups, specific questions, reviews)

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NOMINAL AND ANOMALIES MONITORING

To conclude :

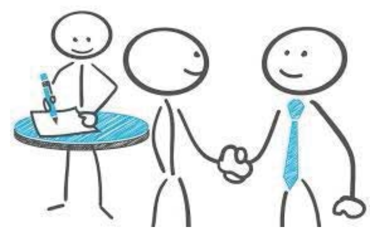
- All is analysed
- All is understood (in 99% of the cases)
- But it requires money and people
- Specific to our missions (strategic and/or scientific)

SOMMAIRE

IN-ORBIT SUPPORT CONTRACTS

In-Orbit Support with industrial satellite prime contractors

- Expert support during the system lifetime. The contracts usually last 6 years maximum
- Nominal and exceptional contexts
- A pre-defined amount of anomaly investigation is included within the contract
- Contract auto terminates if the satellite is lost



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IN-ORBIT SUPPORT CONTRACTS

Activities included in the contract

- « ROUTINE » activities :
  - Long term monitoring of satellite's performance
  - Database and software management
  - Benches and simulators maintenance
- « NON ROUTINE » activities : (pre-negociated standard hours)
  - Anomalies investigations (limited to a certain volume of hours)
  - Contribution to working groups in case of anomalies
  - Contribution to exceptional operations (in case of de-orbitation or anomaly)
  - Simulator's models evolutions
- « EXCEPTIONAL » activities : (with additional costs)
  - Same as « non routine » when it is an important (long) activity.

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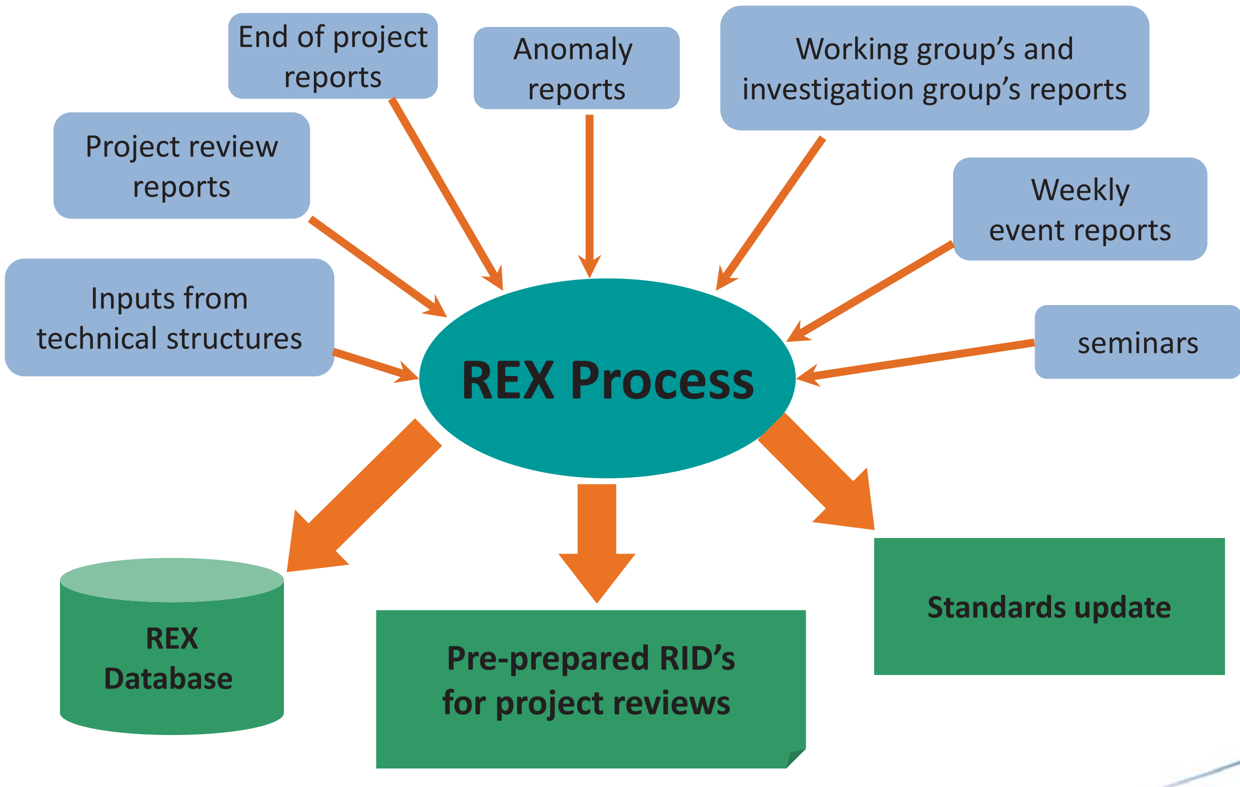
IN-ORBIT SUPPORT CONTRACTS

To conclude :

- It is expensive but necessary for our strategic missions
- Comfortable and efficient
- Difficulty is mantaining the skills in long term, especially for the projects where everything is OK

SOMMAIRE

LESSONS LEARNT TOWARDS FUTURE MISSIONS



LESSONS LEARNT TOWARDS FUTURE MISSIONS

What ?	Who ?
Suggest	*Anyone at CNES*
Select/Analyse	*Contact points in every structure (senior experts)*
Analyse/ Finalise	*REX Entity (2 people)*
Approve	REX Board (COREX) contact points : 17 people
Manage	*REX Entity*

LESSONS LEARNT TOWARDS FUTURE MISSIONS

Example of uploading a wrong parameter in operation (1/2)

2006 What was seen

After an update of Earth sensors parameters, the satellite switched to coarse pointing mode

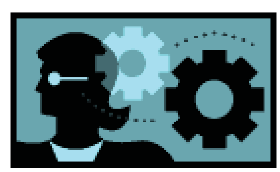
What had happened

The list of values was provided by the prime via a document (paper), indicating *at the bottom of the table* that the figures needed to be divided by 100 before typing them for upload.
The operator forgot to make the division...

LESSONS LEARNT TOWARDS FUTURE MISSIONS

Example of uploading a wrong parameter in operation (2/2)

REX Process



REX Database

Chart n°142
Recommendation

To set up actions to secure input data and manual typing :

- standard formats and units
- identification of risks in cas of errors
- cross-verification, coherence control
- test on simulator when possible

RNC (CNES requirements) C&C handbook

R117: On-board test of critical TCs, before execution
R248: Identify critical TCs, and make their use secure
R249: Show to the operator all TC data in physical values
R257: Test all OBSW modification on simulator with the actual OBSW, before upload
R288: Harmonise physical units

2008

LESSONS LEARNT TOWARDS FUTURE MISSIONS

To conclude :

- Design authority & operations co-located
- Efficient process even if it is difficult to address projects that are in advanced development
- Time to spend but finally useful
- Not easy to correlate with satellite prime constructors internal lessons learnt process

SOMMAIRE

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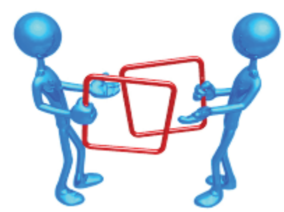
- **LESSONS LEARNT (REX) BETWEEN OPERATORS**

LESSONS LEARNT BETWEEN OPERATORS

Due to same satellite prime contractor, sharing of information

Eumetsat : ERS, ENVISAT, METOP / Spot2, 4, 5 => same platforms

- Sharing bi-annual PRM => sharing experience, anomalies and atypical behavior
  - Examples of METOP -> Spot5 :
    - A blocked SEU counter led to a reconfiguration => new procedure created to avoid this problem
    - Wheels management in deorbitation
    - Monitoring of 50V regulator not done on Spot5
  - Example of Spot5 -> METOP :
    - Operations on deorbitation
    - Problem on an on-board event table linked to local hour drift



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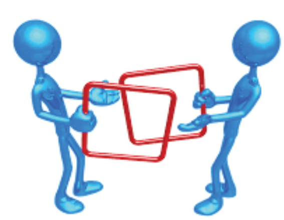
LESSONS LEARNT BETWEEN OPERATORS

Due to same satellite prime contractor, sharing of information

ADS : Spot6, 7 / Pleiades 1A, 1B

- Sharing bi-annual PRM => sharing experience, anomalies and atypical behavior
  - Examples of PHR -> Spot6/7 :
    - Friction torque on gyroscopic actuators : methodology for lifetime estimation
    - Problem on MAN/CAP that led to safe mode => SW patch for correction
    - LNTHD desynchronisation => SW patch for correction
  - Examples of Spot6/7 -> PHR
    - Radiation resistance REX (for lifetime extension)



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CONCLUSION

- Even if in the past it was not easy to motivate operational teams for REX, it has now became a reflex.

- Now this process works well, thanks to :

  - Reactivity and proximity of CNES experts
  - IOS contracts to maintain close ties with industrial partners
  - Efficient lessons learnt process

FEEDBACK FROM IN ORBIT PERFORMANCES

Grégory Personne, Airbus DS

Failure, Test & Operation Data Workshop - FADAT 3rd Edition
14th June 2016, ESTEC

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Feedback From In Orbit Performances – Airbus DS ENS fleet

Airbus DS in-orbit fleet for Earth Observation, Navigation & Science - Key facts

- ✓ **66 satellites launched since 1983**
- ✓ **Over 521 years accumulated in orbit**
- ✓ **42 operating satellites currently**
- ✓ **More than 7 years lifetime in average**
- ✓ **Record lifetime for Soho >20 years in operations… still running!**

⇒ **Available telemetry provides substantial data for performance analyses**

… and in-orbit unexpected events to investigate and resolve across the fleet

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Airbus DS is organised to maximize the benefits from in-orbit experience

Global vision:

- In-flight experience is a key asset and shall **influence future designs**
- "test as you fly, fly as you test"… I**n orbit conditions are unique** vs fidelity of ground testing: space environment, mission duration vs ageing, actual mission profiles, etc.
- In-orbit support cover both anomalies investigation/resolution and in-orbit experience return
  => **Deserves dedicated effort / organisation to 'mine this gold'**

Transnational network in place Airbus DS

- To improve and structure the in-orbit experience sharing and capitalisation
- To organize access to /sharing of this information (dedicated portal)
- Information sorted out per technical domains (MSC)
- Addressing anomalies / unforeseen events and actual in-orbit performances
- Transnational coordinated network with one focal point per ENS satellite
- Synergies with Telecom Satellites In Flight Support

Dedicated powerful & efficient tool

- Telemetry management tool TELMA for regular mass-data archiving & processing

Strong willingness to improve Spacecraft design using in-orbit feedback

Objective

To use the In-orbit performances to influence and optimize future designs at Airbus DS:
- master the right level of margins (while securing missions)
- simplify process or design
- master achievable performances on key topics

Methodology

Selection of key topics each year with strong expectations on concrete results and achievements and in coordination with ENS programs.

Collect in-orbit data to analyse and challenge the current sizing hypothesis.

Analysis carried out with lean methods: ease the sharing and dissemination of this information.

Status

A few analyses already completed covering various domains (solar array sizing, image post-processing, orbit prediction/propagation, sloshing dynamics, GPS performances,….)

More studies planned for 2016 and beyond: thermo-elastics, radiations, battery ageing, etc.

Results: some concrete applications and results in the area of
- satellite design enhancement
- margin management consolidation
- designers mindset evolution

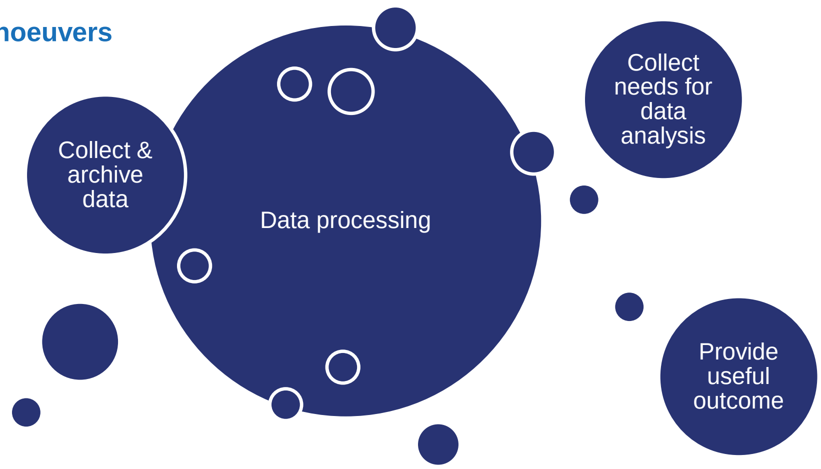
Feedback From In Orbit Performances – how?

Collect & archive data from satellites in orbit
- ✓ **Raw telemetry**
- ✓ **Ground Control data (FDS, TC)**
- ✓ **Flight Events e.g. anomalies, manoeuvers**

Collect the needs for data analysis from
- ✓ **Spaceraft Designers**
- ✓ **Customers/Operators**

Process the data
- ✓ **Mass-data analysis**
- ✓ **Focused investigations**

Provide readily useful outcome
- ✓ **Knowledge briefs**
- ✓ **Performance files**
- ✓ **Event statistics**
- ✓ **Requirements for design enhancement for**
  - ➢ **improved in-orbit support**
  - ➢ **Performances & availability optimization**



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Example of in-orbit feedback: Optimization of power sizing

Facts:
- recent LEO missions often exhibit large in-orbit energy margin.
- Battery ageing usually better than anticipated after a few years in orbit
- After a thorough analysis, 2 main causes of SA over-design put forward
  - Power sizing assumptions too conservative (at S/C PDR level) : margin+ summation rules, failure cases, mission scenario, thermal analyses.
  - Solar array performance better than predicted.

Results:
- issue of recommendations for the different stakeholders implied in the SA sizing (System Engineer, Power & Thermal MSC, SA supplier).
- Application to program e.g. co-engineering with SA subcontractor
  - Consolidation of the design drivers and maturity of requirement at system level.
  - Assessment of the technology maturity with supplier.
  - Agreement with the supplier of the sizing rules and margin policy.
- Additional benefit: optimisation of Thermal Control sizing method to avoid overdesign.
- Consolidated assumptions on Platform Product Line to avoid over-sized battery.

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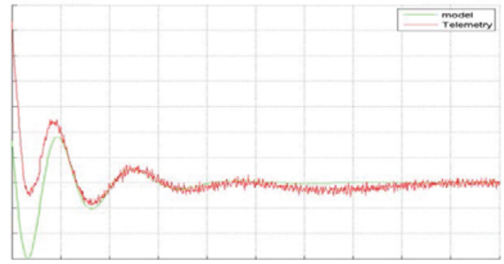
Example of in-orbit feedback: Dynamic Impact of Fuel Sloshing

Fuel sloshing dynamic impact on agile satellite

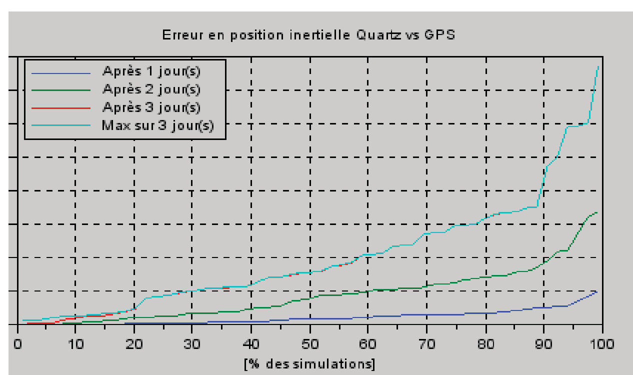
- In orbit performance: analysis of the dynamic impact of fuel sloshing on agile satellite during manoeuvres, in term of frequency&damping and impact on satellite pointing.
- Achievement: characterization of damping (higher than prediction) and frequency ; comparison with actual on-ground modelling and update of parametrization to get a best fit ; sensitivity to remaining fuel mass
- Applications: consolidated hypothesis for S/C with high-demanding pointing requirements and/or large on-board sloshing mass.



AIRBUS DEFENCE & SPACE

Example of in-orbit feedback: Orbit Propagation on-ground

- In-orbit performance: analysis of orbit propagation performances with current Airbus DS in-house tool (Quartz) and process.
- Achievement:
  * assessment of actual performances for orbit predictions over 3 days
  * identification and test of improvements: upgraded model, management of solar activity prediction
  * assessment of mission analysis performances (orbit maintenance).
- Applications:
  enhanced processing for orbit propagation



AIRBUS DEFENCE & SPACE

Example of in-orbit feedback: Propellant Gauging

Thermal propellant gauging technics (TPGT)

- This technic can be used in complement to usual gauging technics like PVT and dead reckoning .
- It is an independent and absolute method that **allows improving overall gauging accuracy especially when remaining mass is low**.
- It consists in heating the tank in orbit , analysing the tank thermal evolution and measuring the thermal tank inertia then deriving the propellant mass in the tank.
- Extensive in-orbit experience has been gained in Telecom on Eurostar tanks including propellant passivation with experience return on near EOL gauging measurements.

<u>- Achievements:</u>

* application to Alphasat with specific tank thermal H/W and ground thermal calibration of tank ,
* adaptation to MEX and VEX with Eurostar tank design but no calibration on ground and no specific thermal H/W

=> Operational difficulties on MEX as the heaters were not powerful enough, several consecutive tests were proposed to achieve accuracy with a statistic approach.

<u>- Applications:</u>

* Embedded case-by-case on upcoming satellites from product line

<u>-limitations:</u>

-not well suited for cases with large propellant mass e.g. controlled reentry

What’s next?

Standardised TM data collection & archiving, with support from our customers

Continuation of focused data analysis

- Achieved performances
- Events statistics

Closing the loop with satellite designers

- Collecting the needs
- Supporting on-demand requests
- Fostering the benefits of in-orbit Return of Experience

Airbus DS are exploring new avenues in the field of data mining for

- Early detection of anomalies
- Machine learning & behaviour forecast

Thanks for your attention

Survey of Novel Methods and Plug-ins Tools to support Diagnostics

Jose Martinez, Alessandro Donati
Data Analytics Team for Operations
OPS-OSA

FADAT 14/06/2016

Issue/Revision: 1.0
Reference:
Status:

Outline

1. Quick overview of
   a. MUST
   b. WebMUST
   c. DrMUST
   d. Novelty Detection

2. Introduction on current developments
   a. Dependency Finder
   b. Scripting Engine
   c. Generic API

3. Conclusions

European Space Agency

MUST

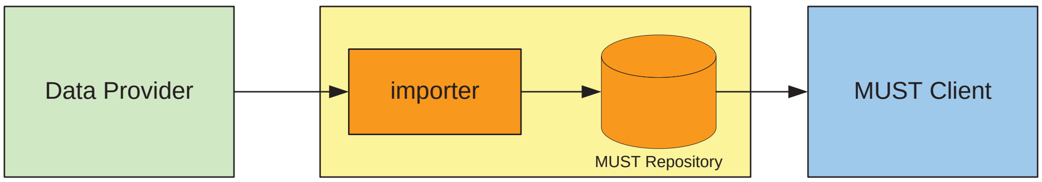
1. **Parameter Archive** with data directly available in engineering form

2. No further processing required for basic tasks (e.g. plotting, export)

3. So far used by: Smart-1, Integral, XMM, Rosetta, Venus Express, Envisat, Cluster, ERS-2, Cryosat, Goce, Giove, Proba-1, Proba-2, Galileo, Herschel, Plank, Lisa Path Finder, SMOS, Sentinel-1A/B, Sentinel-2A, Sentinel-3A, Swarm

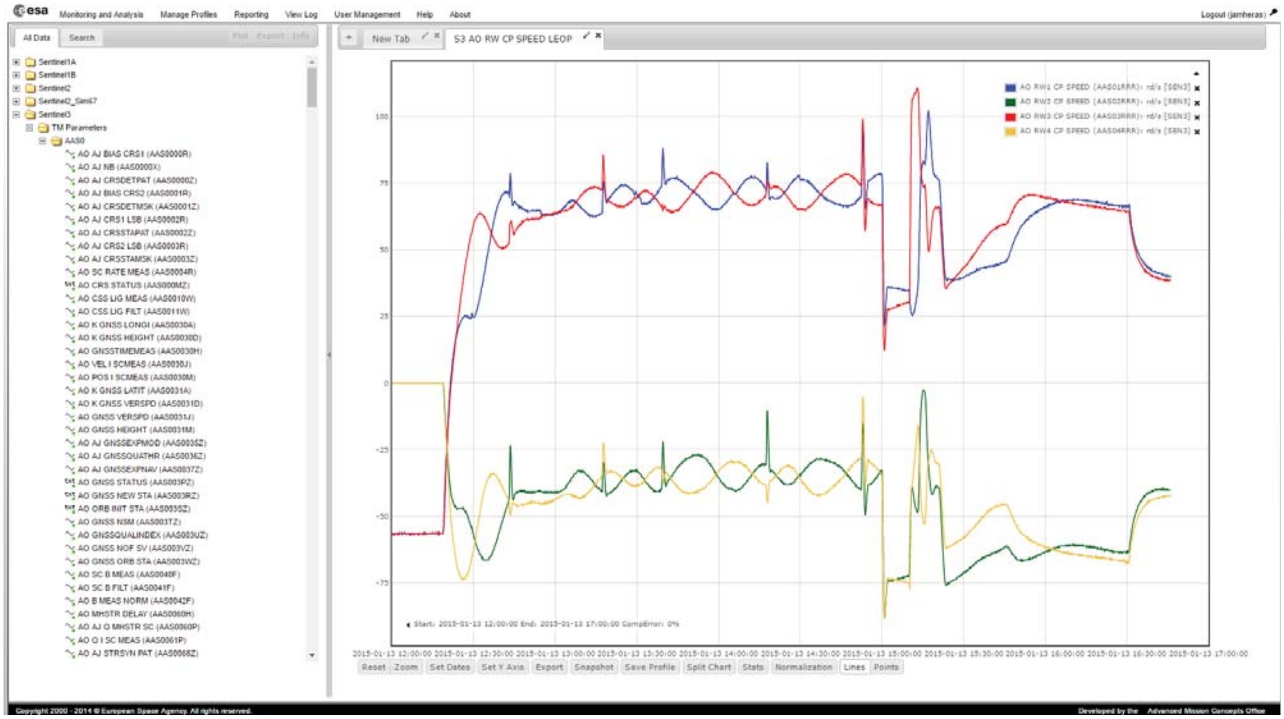
4. **TEC-MUST**: MUST for TEC (bringing flight data to discipline experts)

MUST

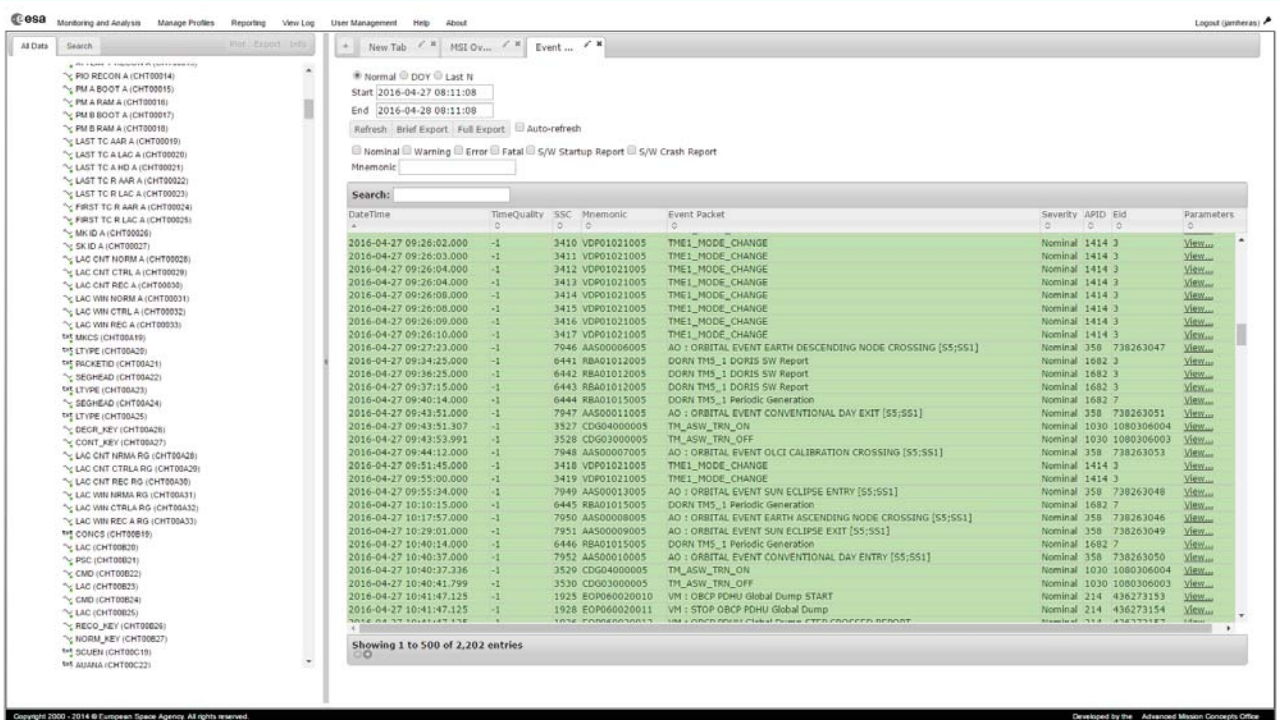


1. MUST uses a client / server architecture:
   a. Server:
      – Imports data in the MUST Repository (decommutated and calibrated)
      – Makes this data available
   b. Client:
      – Makes use of the data in the MUST Server

WebMUST
Web Client to visualize data



WebMUST
Web Client to visualize data



DrMUST

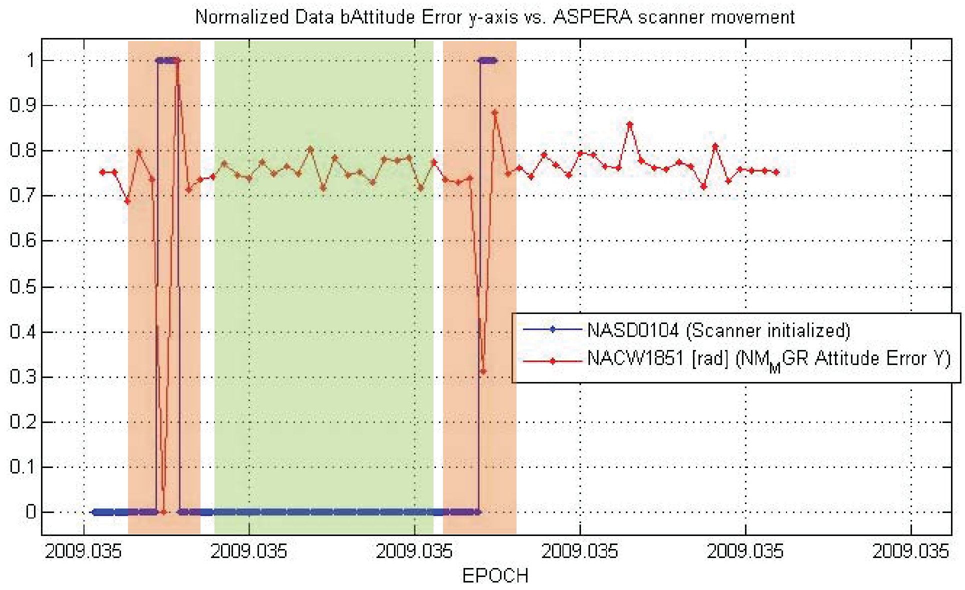
1. MUST Client to support **Anomaly Investigation**

2. Preconditions
   a. Engineers know there is an anomaly
   b. Engineers know when the anomaly happened
   c. Engineers know when there was no anomaly

3. Inputs
   a. Time periods when the anomaly happened
   b. Time periods when it was nominal

4. Output
   a. List of parameters involved in the anomaly

DrMUST



DrMUST

1. DrMUST finds all parameters that
   a. Have a different behaviour between anomaly and nominal period
   b. In case there are several anomaly periods, behaviour in anomaly periods should be similar

2. Not only anomaly investigation – Also Characterization
   a. Examples: solar flares, eclipses, South Atlantic anomaly, etc.

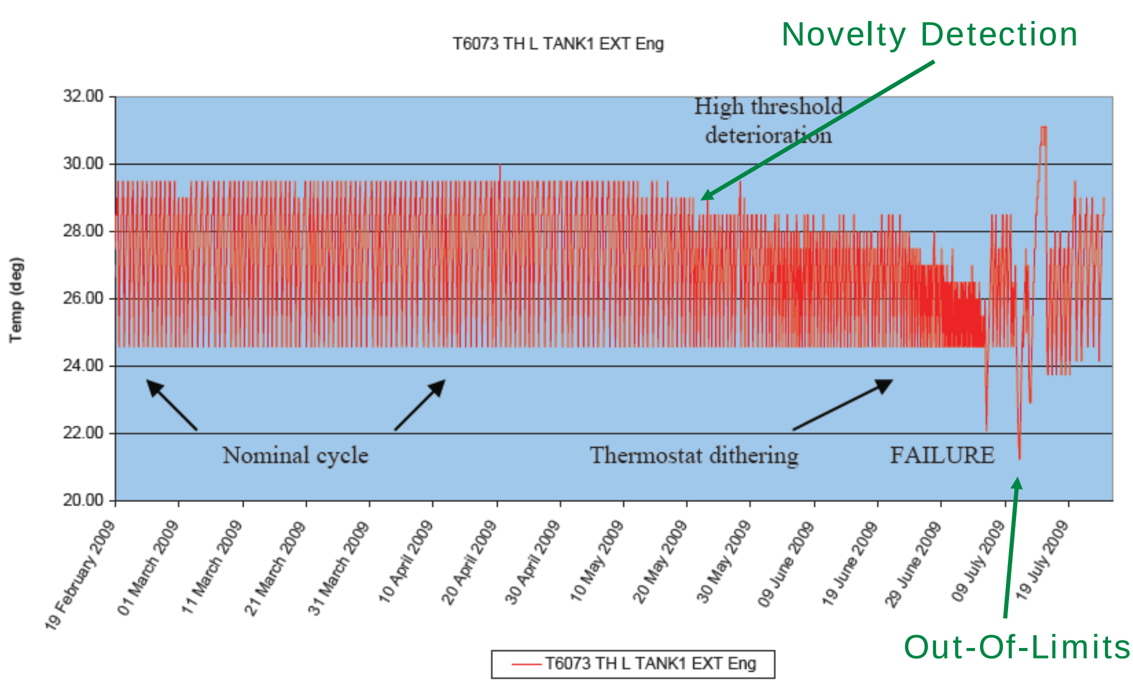
Novelty Detection

Novelty Detection

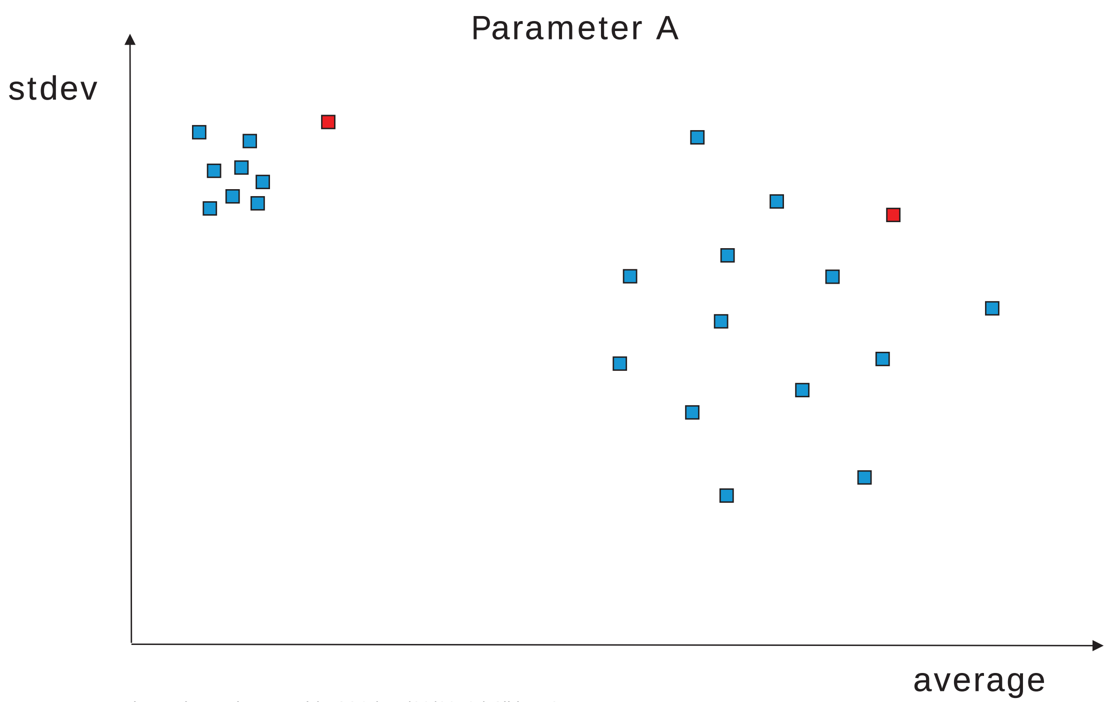
Novelty Detection

1. MUST Client to support **Early Anomaly Detection**
2. Preconditions
   a. Engineers know when there was no anomaly
3. Inputs
   a. Time periods with nominal behaviour
4. Output
   a. List of parameters with an unusual behaviour
   (the assumption is that an unusual behaviour signals often an anomaly in the way to happen)

Novelty Detection



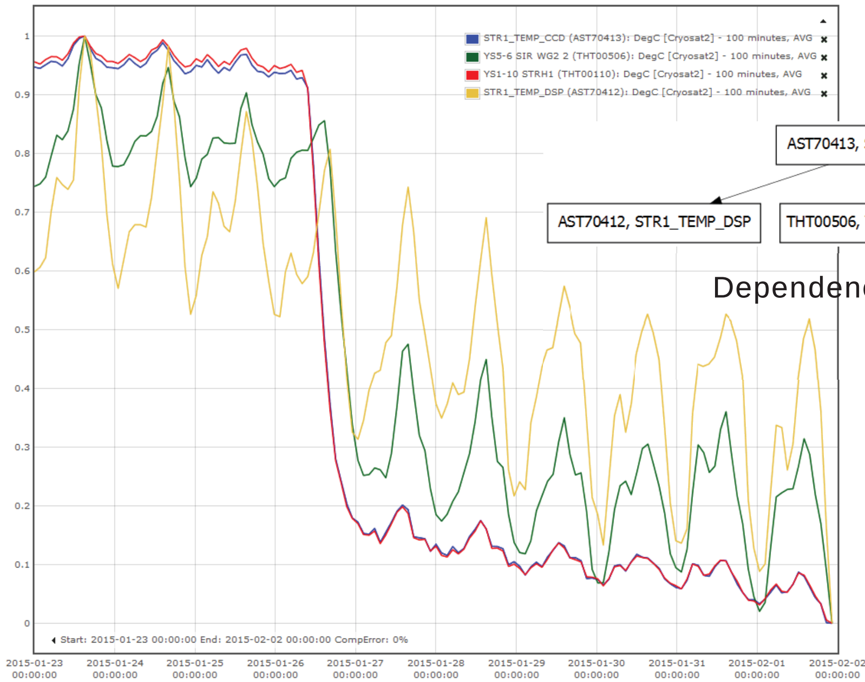
Novelty Detection

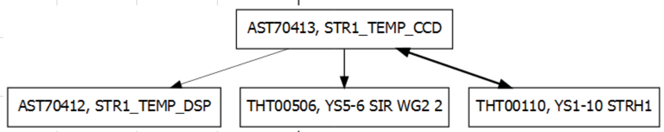


Dependency Finder

1. MUST Client to support **Better understand parameter dependencies**
2. Preconditions
   a. There is data available (e.g. in MUST)
3. Inputs
   a. Time periods to analyze
4. Output
   a. Dependency Graph
   b. Dependency Matrix

Dependency Finder

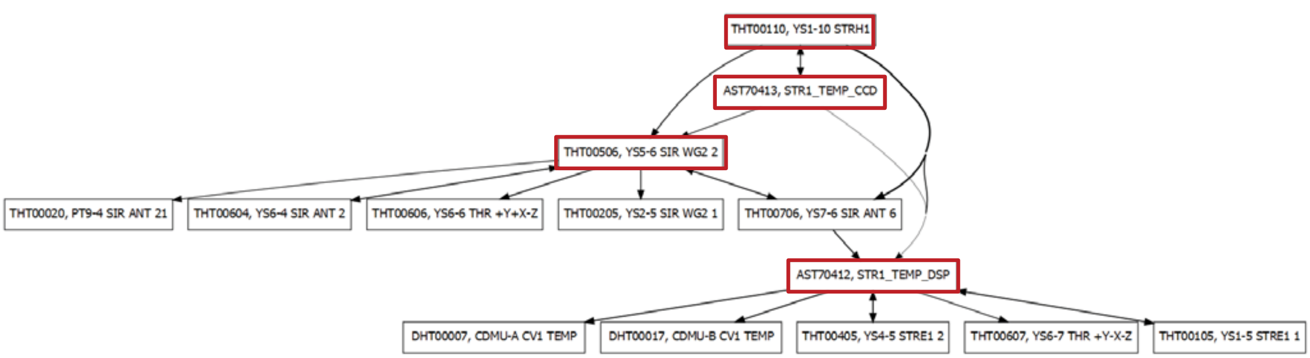




Dependencies graph

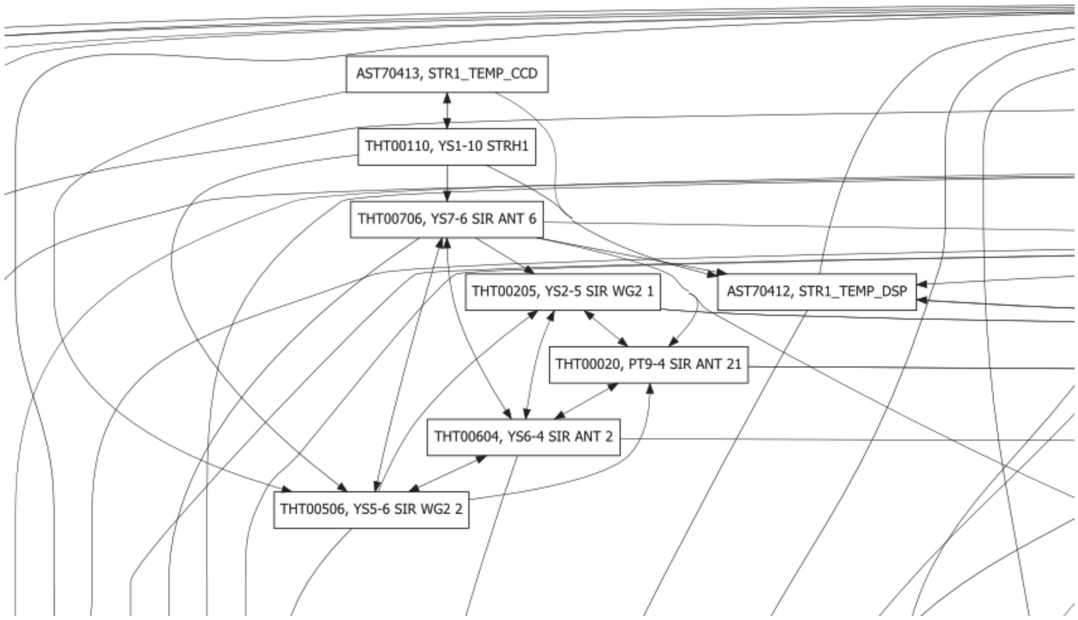
Plot of the parameters in the graph

Dependency Finder



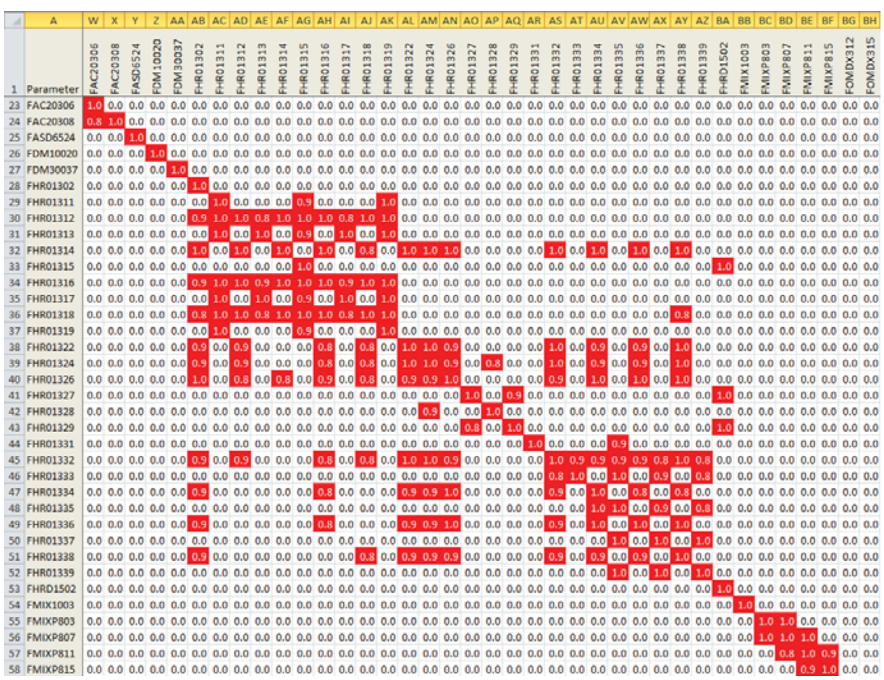
Previous dependencies graph included in a larger dependencies graph

Dependency Finder



Partial view of the whole dependencies graph

Dependency Finder



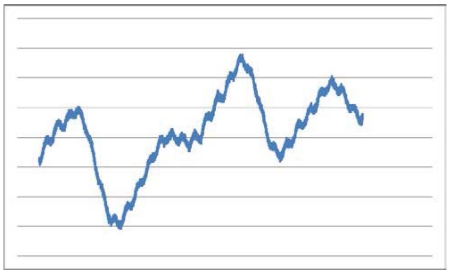
	A	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN
1	Parameter	FAC20306	FAC20308	FASD6524	FDM10020	FDM30037	FHR01302	FHR01311	FHR01312	FHR01313	FHR01314	FHR01315	FHR01316	FHR01317	FHR01318	FHR01319	FHR01322	FHR01324	FHR01326
23	FAC20306	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	FAC20308	0.8	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	FASD6524	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	FDM10020	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	FDM30037	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	FHR01302	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	FHR01311	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	1.0	0.0	0.0	0.0
30	FHR01312	0.0	0.0	0.0	0.0	0.0	0.9	1.0	1.0	0.8	1.0	1.0	1.0	0.8	1.0	1.0	0.0	0.0	0.0
31	FHR01313	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0	0.9	0.0	1.0	0.0	1.0	0.0	0.0	0.0
32	FHR01314	0.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	0.8	0.0	1.0	1.0	1.0
33	FHR01315	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	FHR01316	0.0	0.0	0.0	0.0	0.0	0.9	1.0	1.0	0.9	1.0	1.0	1.0	0.9	1.0	1.0	0.0	0.0	0.0
35	FHR01317	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0	0.9	0.0	1.0	0.0	1.0	0.0	0.0	0.0
36	FHR01318	0.0	0.0	0.0	0.0	0.0	0.8	1.0	1.0	0.8	1.0	1.0	1.0	0.8	1.0	1.0	0.0	0.0	0.0
37	FHR01319	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	1.0	0.0	0.0	0.0
38	FHR01322	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.9	0.0	0.0	0.0	0.8	0.0	0.8	0.0	1.0	1.0	0.9
39	FHR01324	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.9	0.0	0.0	0.0	0.8	0.0	0.8	0.0	1.0	1.0	0.9
40	FHR01326	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.8	0.0	0.8	0.0	0.9	0.0	0.8	0.0	0.9	0.9	1.0
41	FHR01327	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42	FHR01328	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0
43	FHR01329	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
44	FHR01331	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
45	FHR01332	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.9	0.0	0.0	0.0	0.8	0.0	0.8	0.0	1.0	1.0	0.9
46	FHR01333	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
47	FHR01334	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.9	0.9	1.0
48	FHR01335	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
49	FHR01336	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.9	0.9	1.0
50	FHR01337	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
51	FHR01338	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.9	0.9	0.9
52	FHR01339	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
53	FHRD1502	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
54	FMIX1003	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
55	FMIXP803	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
56	FMIXP807	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
57	FMIXP811	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
58	FMIXP815	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

	A	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG	BH
1	Parameter	FHR01327	FHR01328	FHR01329	FHR01331	FHR01332	FHR01333	FHR01334	FHR01335	FHR01336	FHR01337	FHR01338	FHR01339	FHRD1502	FMIX1003	FMIXP803	FMIXP807	FMIXP811	FMIXP815	FOMDX312	FOMDX315
23	FAC20306	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24	FAC20308	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	FASD6524	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	FDM10020	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	FDM30037	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28	FHR01302	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	FHR01311	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	FHR01312	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	FHR01313	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
32	FHR01314	0.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
33	FHR01315	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
34	FHR01316	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	FHR01317	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
36	FHR01318	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
37	FHR01319	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38	FHR01322	0.0	0.0	0.0	0.0	1.0	0.0	0.9	0.0	0.9	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
39	FHR01324	0.0	0.8	0.0	0.0	1.0	0.0	0.9	0.0	0.9	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	FHR01326	0.0	0.0	0.0	0.0	0.9	0.0	1.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41	FHR01327	1.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
42	FHR01328	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
43	FHR01329	0.8	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
44	FHR01331	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
45	FHR01332	0.0	0.0	0.0	0.0	1.0	0.9	0.9	0.9	0.9	0.8	1.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
46	FHR01333	0.0	0.0	0.0	0.0	0.8	1.0	0.0	1.0	0.0	0.9	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
47	FHR01334	0.0	0.0	0.0	0.0	0.9	0.0	1.0	0.0	0.8	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
48	FHR01335	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.9	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
49	FHR01336	0.0	0.0	0.0	0.0	0.9	0.0	1.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	FHR01337	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
51	FHR01338	0.0	0.0	0.0	0.0	0.9	0.0	0.9	0.0	0.9	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
52	FHR01339	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
53	FHRD1502	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
54	FMIX1003	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0
55	FMIXP803	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	0.0	0.0	0.0
56	FMIXP807	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	1.0	1.0	0.0	0.0	0.0
57	FMIXP811	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	1.0	0.9	0.0	0.0
58	FMIXP815	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	1.0	0.0	0.0

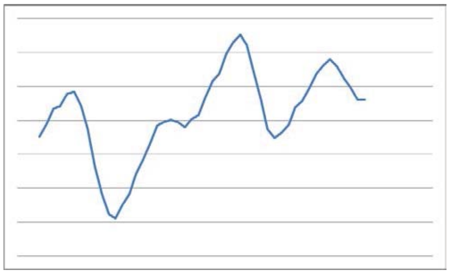
Dependencies shown as a matrix (partial view)

Dependency Finder

- TM Time Series are heterogeneous: have different distributions, different sampling rates, etc.
- We homogenize them:
    - Take averages in orbit length periods
    - Discretize them



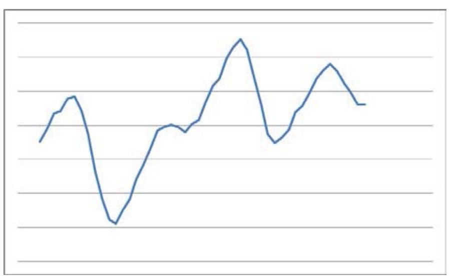
Original time series



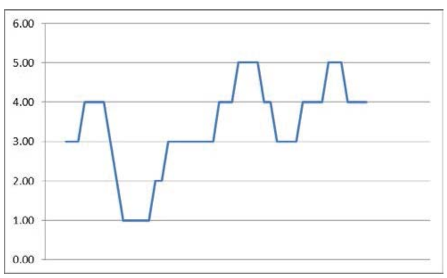
Time series averaged per orbit

Dependency Finder

- Discretization
    - Due to the Central Limit Theorem, we now that the distribution of the averaged data is approximately Gaussian
    - To compute the number of we use the Scott's normal reference rule, which is optimal for normally distributed data



Time series averaged per orbit



Discretized averaged time series

Now, $P(A=a_1)$ can be easily computed

Dependency Finder

- Probabilistic Independence
  - $P(A{=}a \cap B{=}b) = P(A{=}a) \cdot P(B{=}b)$
  - $P(B{=}b \mid A{=}a) = P(B{=}b)$

- Probabilistic **Dependence**
  - $P(A{=}a \cap B{=}b) \neq P(A{=}a) \cdot P(B{=}b)$
  - $P(B{=}b \mid A{=}a) \neq P(B{=}b)$

Dependency Finder

- **Lift:** Degree of Dependence

$$lift = \frac{P(A = a \ \cap B = b)}{P(A = a) \cdot P(B = b)}$$

- Find all dependencies with
  - a high lift
  - a high **conditional probability**

$$P(B = b \mid A = a) = \frac{P(B = b \cap A = a)}{P(A = a)}$$

Scripting Engine

1. WebMUST plugin to **support the creation of new synthetic parameters**

2. Preconditions
   a. There is data available (e.g. in MUST)
   b. WebMUST Scripting Engine package is available

3. Inputs
   a. Synthetic Parameter(s) in Operational Language (OL) or JavaScript

4. Output
   a. Parameter Graphical Representation
   b. New MUST Parameter(s)

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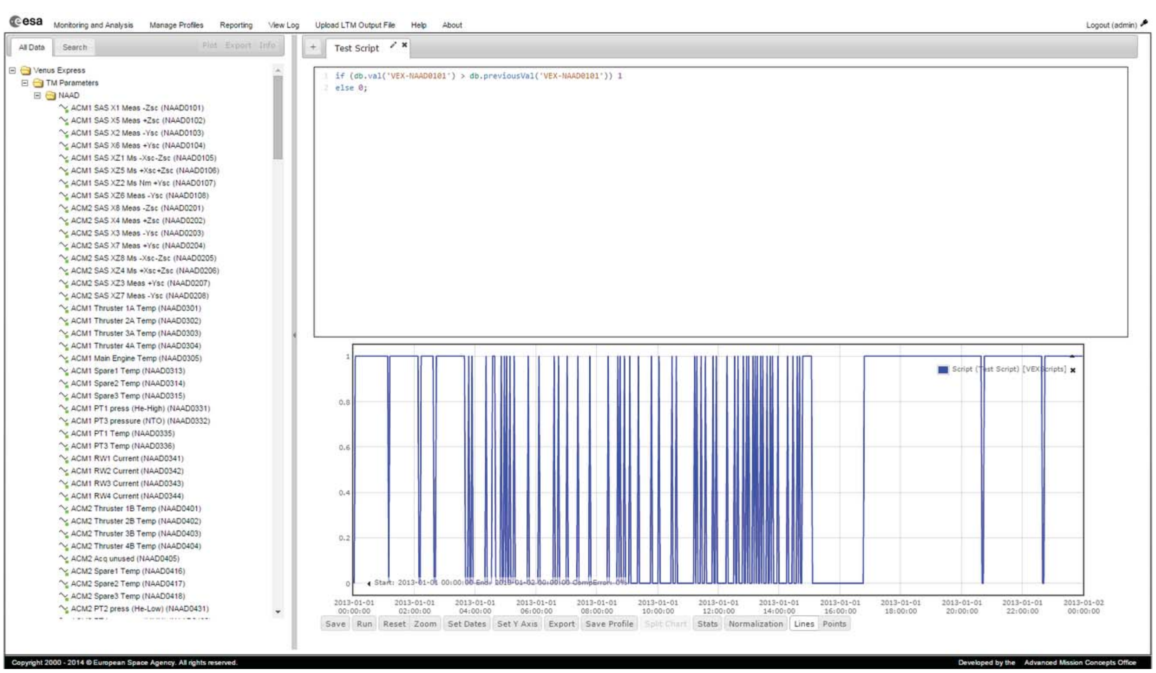
European Space Agency

Scripting Engine



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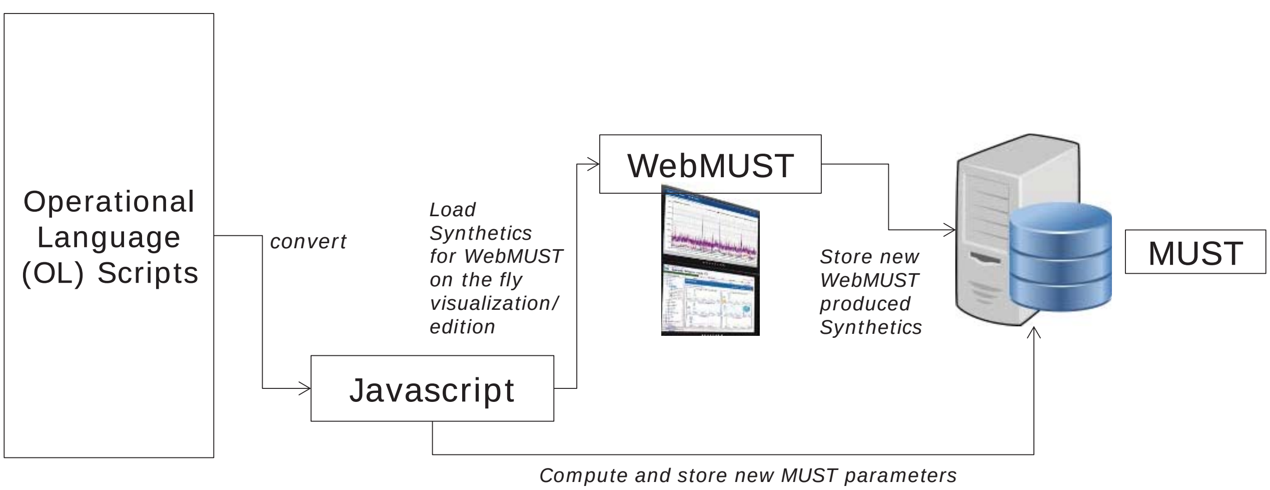
European Space Agency

Scripting Engine

1. Wide known scripting Language: JavaScript
2. Support for Operational Language (OL) synthetics
3. Secure Repository Access
4. Instant Visualization of the created synthetics
5. Manage all the synthetics lifecycle inside one single tool
6. Combine Parameters from different domains

Scripting Engine



Generic API (MUST Link)

esa

1. Interface to retrieve data and use available services

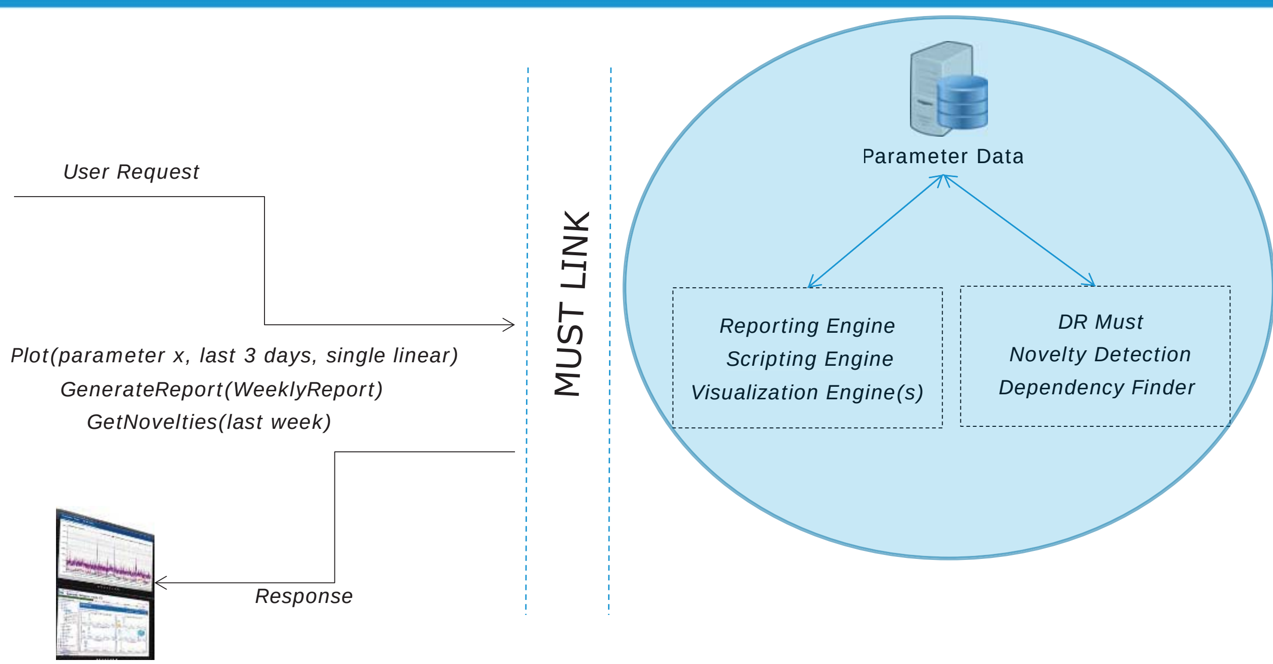
1. Preconditions
   a. There is a parameter archive available (e.g. MUST)
   b. The user is properly authenticated in the system

2. Inputs
   a. Data or Service Requests matching the systems distributed interface

3. Output
   a. Requested Data and Services

Generic API (MUST Link)

esa



User Request

Generic API (MUST Link)

1. High Personalized Solution and User Tailored Applications
2. Implement Particular Functionalities on the Fly
3. Any Programming Language
4. Instant Data Access
5. Building Blocks for easier integrate Data mining, Planning and Visualization Frameworks

Conclusions

1. The Data Analytics Team for Operations (DATO) works on
    a. Making flight data available and accessible
    b. Performing Advanced Data Analysis
    c. Data visualization
    d. Providing Data Analytics services
2. Common areas of interest with the FADAT community
    a. Integrate flight data with discipline expertise data
    b. Perform advanced data analysis with data contributed by the FADAT community
3. DATO is open to pursue further collaboration within FADAT community.

Feedback

1. Are there other data analytics functionalities or services that could be of interest for the FADAT community?

2. Point of Contact:
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TEC WebMUST Evolution: Access to Flight Data for Discipline Engineers

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Outline

TEC WebMUST Evolution:
Access to Flight Data for Discipline Engineers
and Way forward

1. Needs & Motivation
2. Development of TEC WebMUST
3. Different simulation models
4. The Gap
5. How to bridge it
6. Conclusions

NEEDS & MOTIVATION

M1 – Engineers involved in development of spacecraft have (in general) very little information about the behaviour of the Spacecraft in flight, while the spacecraft operations phase represents a wealth of information.

In particular, models are built during the design phase, they are used for the verification, correlated with ground test data. Feedback from flight would allow to consolidate or challenge the hypotheses used for design (e.g. aging), refine the modelling, reduce margins where possible…

Up to now, there was very little link between design/verification and operations, except for LEOP phase and in case of major anomalies.

-> Motivation is to provide access to flight data to discipline engineers.

Development of TEC WebMUST

The **idea** to create a **direct access for TEC engineers from their desktops at ESTEC to the ESOC server containing telemetries** of (selected) ESA missions in flight, was **initiated in 2008** by a meeting between E. Tremolizzo (TEC-ECC) and A. Donati (ESOC).

The concept took quickly shape and when required at TEC level (in 2011) it was extended to all TEC and soon translated into a direct access to a dedicated PC in ESOC with a service called **TEC-MUST**.

Periodic presentations and surveys were put in place to assure a smooth yet **highly customized evolution** of the TEC-MUST along the years, to the point that is today a well proven tool, not only for TEC engineers who want to access inflight data, but also increasingly for those working in the testing area.

Development of TEC WebMUST

TEC WebMUST was developed to provide TEC discipline specialists with access to (raw) flight data.

First feedback from specialists:

- Excellent
- But flight data are in a format that requires a significant effort to understand "what is what", and map the telemetries to engineering data.

NEI00022	TM	OBCD	PCDU Temperature 2P

Needs to be mapped to the thermal model corresponding node number

-> Need to provide more than data. To make it an interpretable piece of information

Development of TEC WebMUST

esa

TEC WebMUST was upgraded to provide TEC discipline specialists with access to flight data, organised by discipline and with more description. Technical documents are added as reference.

This makes the flight data much more accessible.

There is still quite some work to map the telemetry to the engineering data and model parameters.

There is also risk for confusion.

Next step is ideally to have a fully and automatic data mapping between flight telemetry and engineering/model data

It would open the use of models developed during development for operations.

Different simulation Models

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TEC - Models are elaborated during the spacecraft development phase, to support the design and verification activities. For example, CAD, Finite Elements model, thermal model, power, AOCS, …

Those are representations of the spacecraft, based on the physics of each discipline (e.g. stiffness for FEM, conductance and radiative exchanges for thermal…)

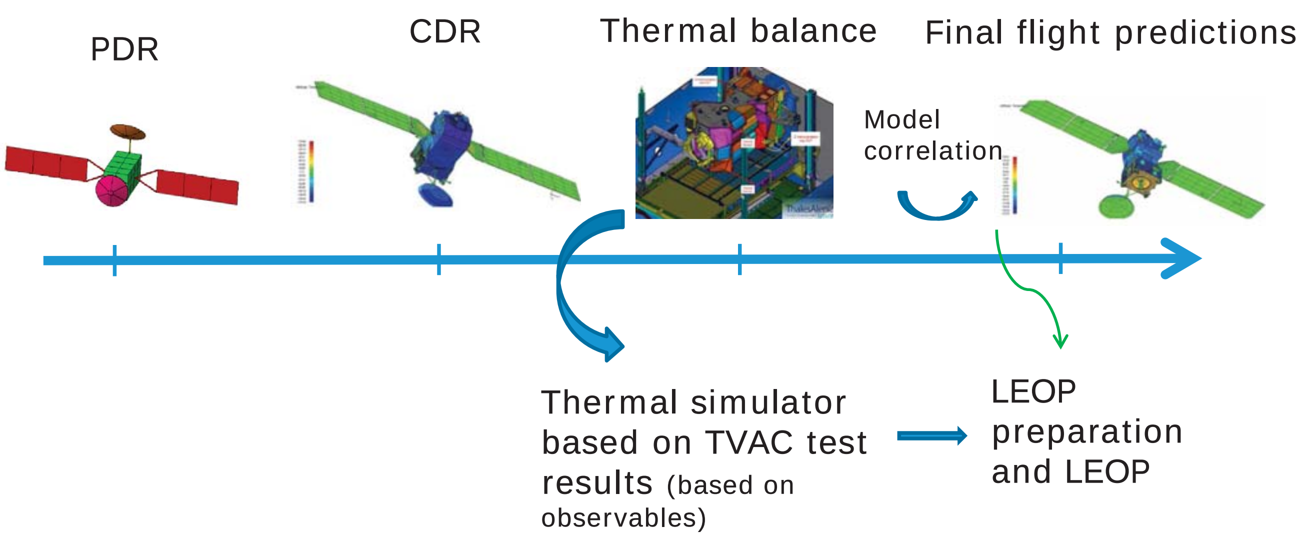
The models are used for sizing (i.e. using worst cases). Their predictive capability is checked/refined through correlation with ground tests (e.g. sine test, thermal balance test), to allow final flight predictions.

Those models are in most cases not used during operations.

OPS - Spacecraft operation simulators are based on simplified behavioural models (i.e. based on observables), sometimes they are not realistic (the physics is not represented) and are not compatible with the model based approach done by the spacecraft engineers

Simulation models – 2 separate worlds

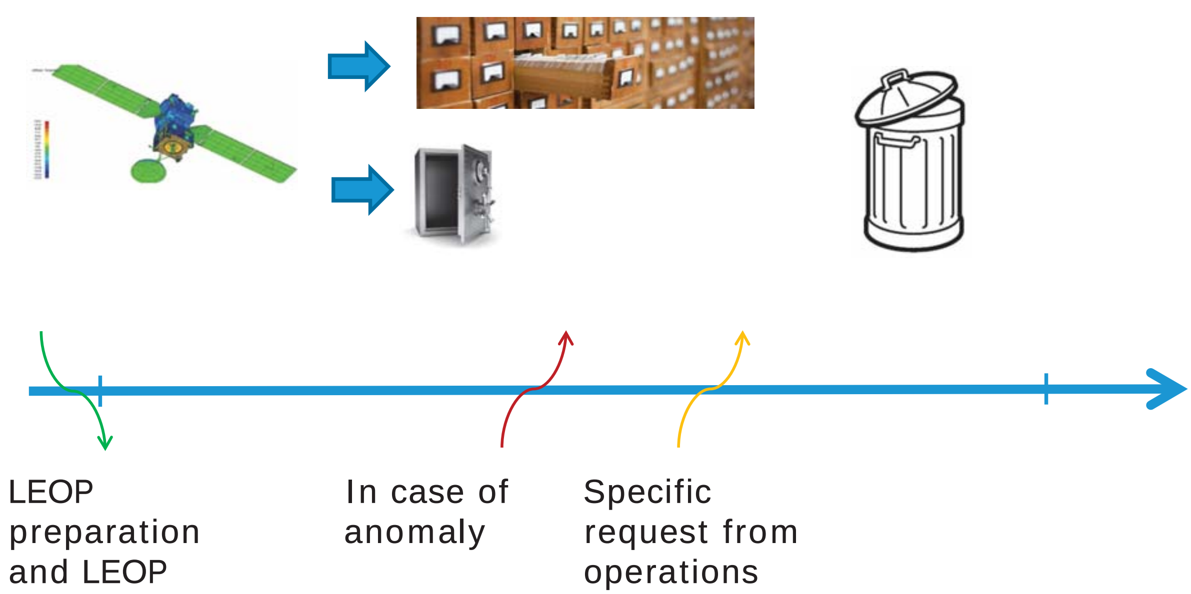
S/C development – discipline models (e.g. thermal)



S/C simulator and operations

Simulation models – 2 separate worlds

S/C development – discipline models (e.g. thermal)



S/C simulator and operations

Next steps - Motivation & Needs

N1 – Improve the predictive capability of the simulation models used for development exploiting available spacecraft telemetry data

–> Allow easy use of telemetry data with models

N2 – Increase reuse of engineering models for operations and compatibility between models used in the design and operational simulators (https://exchange.esa.int//thermal-workshop/attachments/workshop2015/parts/TSsim.pdf)

- Increase overall the predictive capability of models, reduce margins

N3 – provide feedback concerning technologies tested in space, to optimize/as input for future R&D development specifications

The GAP

How to Bridge the Gap

How to bridge the Gap

Re-use of simulation models built during development phase

1. What to do
   a. Identify ways that will allow to re-use the models used in the development phase in the operations simulator
   b. Identify way of (formal) mapping between in-flight measurements (telemetry) and the corresponding model parametric definitions -> allow systematic feedback from flight to design and verification teams through correlation of models with flight data
   c. Generalise Model Based System Engineering approach across both sides (design & operations) with handover

2. Benefits
   - Increase predictive capability of operation simulators
   - Improvement of model predictive capability for S/C development
   - Enable compatibility between simulators – foster co-simulation

How to bridge the Gap

Framework & Contributing studies

1. WebMUST for TM data exchange
   a. Use of interface/APIs to automatise the process of model's tuning with available telemetry

2. Future study on Analysis of Flight Data using Model based driven diagnostics
   a. Use model-based planning for diagnostic and refinement of spacecraft discipline models.
   b. Better identifying anomaly root causes
   c. Support the definition and/or refinement of the discipline models of spacecraft subsystems
   d. Increasing the capability of flight data analysis
   e. Support the prediction of Spacecraft behaviour

Conclusions

Conclusions

Conclusions

1. Discipline Models and Flight Operation Data, so far, have been two separated areas with limited exchange
2. Bridging the gap among them enriches both
   a. Better discipline Models
   b. Better Operations
3. Collaboration has already started:
   a. TEC-WebMUST
   b. Joint TRP study
4. New areas to bridge the gap have been identified
   a. Re-use of design simulator's models
   b. Increase fidelity of design simulator's models

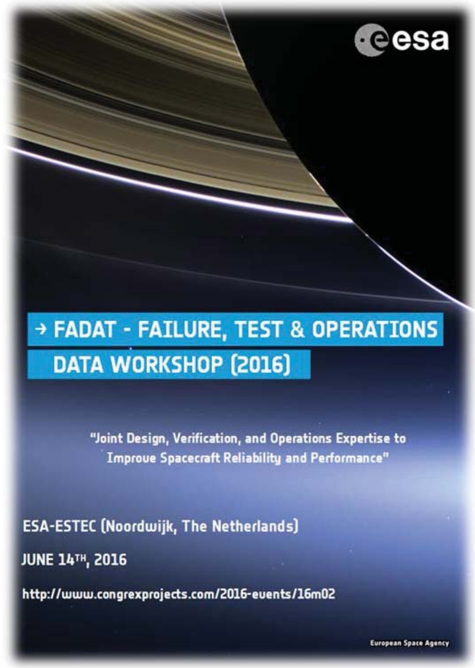
Contacts

- ESOC point of contact for all activities of TEC-WebMUST and MUST:
  Alessandro.Donati@esa.int
- ESTEC/TEC point of contact and co-ordination of TEC-WebMUST:
  Elena.Tremolizzo@esa.int
- dedicated point of contact for TEC-WebMUST in TEC-M:
  Benoit.Laine@esa.int

Questions?

ESA- Failure, Test & Operations Data (FADAT) Initiative

Panel Discussion



Questions to the Panel & Participants

We invite you to discuss and shape the FADAT Initiative

- TEC to devise strategy to improve/implement anomaly root cause identification process (RCA) in ARTS.
- How can we best establish a data feedback process at ESA?
- What are your recommendations to us? What are your needs for improvement?
- Have you identified synergies or gaps among the initiatives?
- What should be the next step?
- Conclusions