WE LOOK AFTER THE EARTH BEAT

Analysis of Spacecraft qualification Sequence & Environmental Testing - Plus (ASSET+)

Final Presentation
15/June/2016

P. Messidoro, Thales Alenia Space, Italy
F. Vergès, Airbus Defence & Space, France

AIRBUS DEFENCE & SPACE

ThalesAlenia Space
A Thales / Finmeccanica Company

83230350-DOC-TAS-EN-001

Agenda

- Introduction: overview of the study (20 min)
- Methodology: how it was done (30 min)
- Results: main outcomes and their validity (60 min)
- Conclusions: final considerations and future developments (10 min)
- Final discussion: Q&A (30 min)

Introduction

AIRBUS DEFENCE & SPACE

THALES ALENIA SPACE INTERNAL

ThalesAlenia Space
A Thales / Finmeccanica Company

83230350-DOC-TAS-EN-001

- ASSET = Analysis of Spacecraft qualification Sequence and Environmental Testing (ESA TRP Study - https://exchange.esa.int/asset/)
- The main study lasted two years, from 2012 to 2014
  - Aim: to investigate the factors that influence the effectiveness of environmental testing
  - 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
  - The outcomes of the study has been disseminated inside ESA, ECSS and industry, to contribute improving practices, approaches and development of testing standards
- ASSET Study results have been presented at the last ATS* and FADAT (http://www.congrexprojects.com/2016-events/16m02)

*** B. Laine, J. Candé, P. Messidoro, M. Pasquinelli, P. Giordano, V. Ancona, V. Stefano, L. Pace, J. Buffe, P. Hugonnot, J. D'Add, F. Vergès, R. Werner - *Analysis of Spacecraft qualification Sequence and Environmental Testing* - 29th Aerospace Testing Seminar, Los Angeles, USA, Oct. 17-29, 2015**

- ***ASSET+*** (*ASSET-plus*) is the working name for an CCN of the ASSET study focused on Thermal Vacuum test (TVT)

- It started from a subset of the outcomes and considerations originating from the analysis and synthesis activity of ASSET

AIRBUS DEFENCE & SPACE

THALES ALENIA SPACE INTERNAL

ThalesAlenia Space
A Thales / Finmeccanica Company

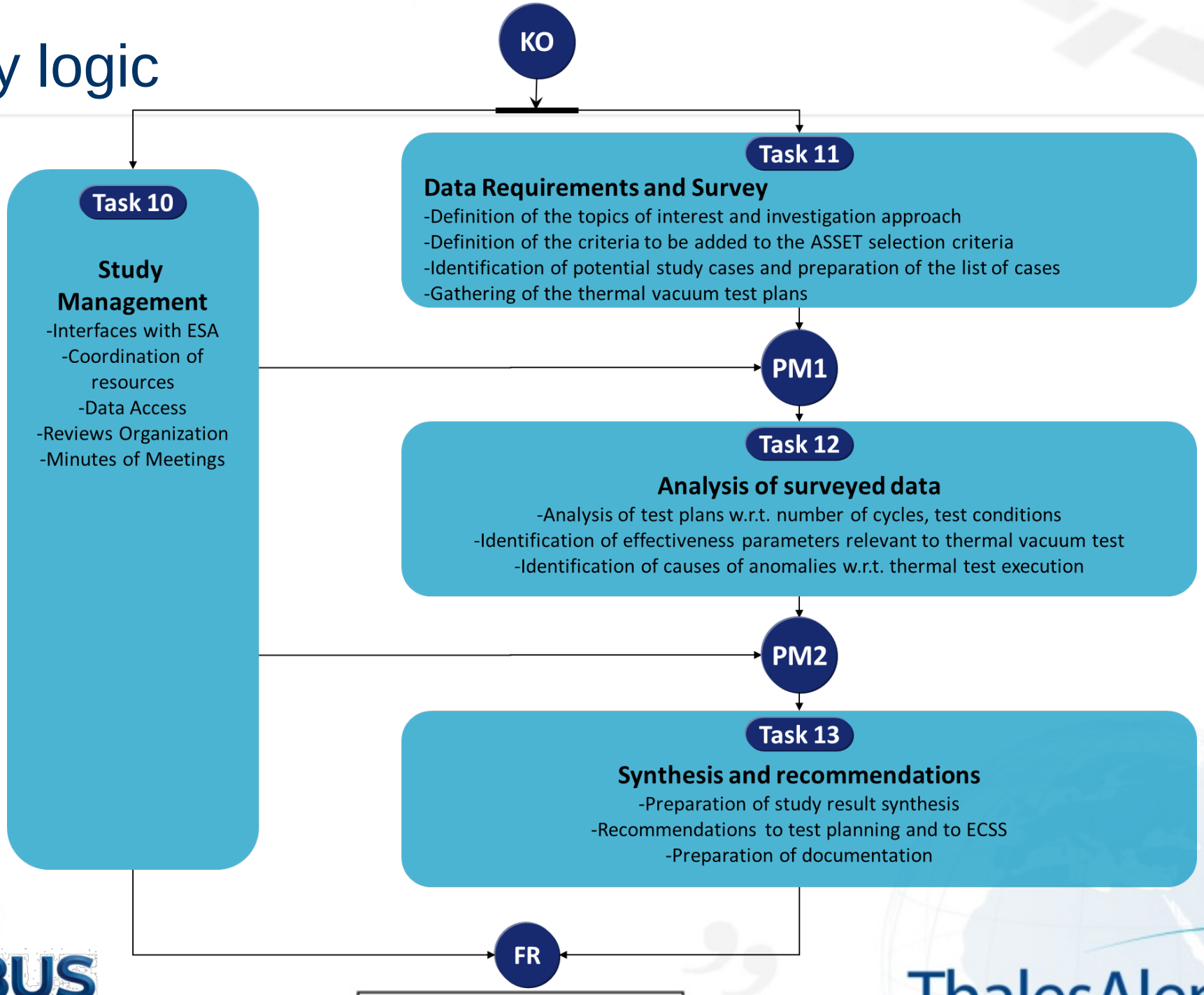
Team

- *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

Study logic



Considered programs

- The following ESA space programs have been considered* :
  - **Science**: Herschel (ADS-D), Plank (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) to provide cases in anonymous form, from the Science and Earth Observation categories, but also for Telecommunications

*** With respect to ASSET perimiter it has been decided to work only on the most recent projects suitably extended, although the full set of data of ASSET is still available**

Methodology

AIRBUS DEFENCE & SPACE

THALES ALENIA SPACE INTERNAL

ThalesAlenia Space
A Thales / Finmeccanica Company

83230350-DOC-TAS-EN-001

Methodology

- Definition of General Objectives
  - Definition of study questions
- Survey of NCRs and FAs from ESA space programs (plus cases from commercial programs provided in anonymous form, if relevant)
  - Definition of selection criteria
- Analysis of the selected cases to improve understanding and address the topics of interest
  - Thorough analysis by review of documents and/or interviews of experts having participated to anomaly processing.
  - Description of anomaly improved to make it understandable for persons not involved in the anomaly generation.
  - Thorough understanding of the root cause(s) of the anomalies
- Assessment of as-run tests
  - Questionnaires aimed at getting values for key factors in TVT

Definition of General Objectives

A. How to improve effectiveness* of TV tests?

B. Is it possible to identify the physical phenomena present only in TV allowing to precipitate/detect specific flaws during this test?

C. Why are the anomaly precipitated in TV test, even on already qualified + accepted hardware (for units)?

Test effectiveness definition
ability of a test to simulate adequately the condition expected for a given mission in order to discover the maximum number of flaws before the launch. In these terms the effectiveness of a test for a certain product or class of products may be analyzed comparing anomalies discovered during ground testing that may cause anomalies during in-flight operations and anomalies occurred in flight that may have been discovered during on ground testing.

Selection criteria

Criterion	ASSET+related
Affected Item (item failed during test)	Space segment system Space segment element/module Space segment subsystem Space segment equipment Part and Materials
Verification level (at which the test activity is performed)	Space segment system Space segment element(/module)
Severity (potential impact on mission)	Critical (loss of function, loss of mission) Major (switch to redundant, delay to operations)
Cause (Process)	Design Workmanship Part and Material Excessive Testing Not Reported
Cause (Nature)	Electrical Mechanical Thermal Others (Optical/Fluidic)
Type of test	***Thermal Vacuum Test; if interesting, keep NCR from Thermal Balance, Ambient and Cycling. Include any test (e.g. functional tests) after TVT which could have discovered TVT-related anomalies***
Verification Stages	- Qualification - Protoqualification - Acceptance

Selection criteria were used to filter inside each company databases.
All Anomalies resulting from this query were thoroughly analysed to assess relevance for ASSET+

Criterion	ASSET+related
Affected Item (item failed during operations)	Space segment system and lower tier
Severity (impact on mission)	Critical (loss of function, loss of mission) Major (switch to redundant, delay to operations)
Cause (Process)	Design Workmanship Part and Material Excessive Testing Unknown Not Reported
Cause (Nature)	Electrical Mechanical Thermal Others (Optical/Fluidic) Unknown
Type of test that would have discovered it (preliminary screening)	***TVT or Unknown (but which could be discovered in TVT according to experience)***

Study questions 1/3 - testing environment

TV1	**What is the importance of the Vacuum condition?**	*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?*
TV2	**What is the importance of thermal cycling during thermal vacuum?**	*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?*
TV3	**What is the importance of simulated radiated flux (solar/infrared)?**	*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?*

Study questions 2/3 - testing environment

TV4	**What is the impact of temperature?**	*How critical is the temperature level to precipitate flaws?* *Are the anomalies related to the extreme temperature level or could they be precipitated also with a less extreme temperature level?*
TV5		*Is there a relation between failure of functional test and test phase (hot phase/cold phase)?*
TV6	**Are intermediate temperatures or transitions important in thermal vacuum?**	*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?*

Study questions 3/3 - testing facilities and operations

TV7	**What is the impact of facilities and operations?**	*Are there anomalies that are not related to a spacecraft flaw, but are due to operations/facility?*

Test 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? (value)
5	Has infrared flux been simulated? (value)
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?

Test reports were scanned to get an overview of anomalies occurred during test but not selected due to not fitted database filter, and to exploit as many pieces of information as possible.

Results

AIRBUS DEFENCE & SPACE

THALES ALENIA SPACE INTERNAL

ThalesAlenia Space
A Thales / Finmeccanica Company

83230350-DOC-TAS-EN-001

Considerations on the results

- A preliminary consideration on the outcomes of ASSET+ is that the amount of cases (NCRs and FLAs) that could provide useful clues to the improvement of thermal test effectiveness is not so large.
- As a consequence, a proper statistical analysis is not possible.
- On the other hand, this condition has allowed to perform a case by case analysis, with a deeper understanding of each anomaly.
- The proposed outcomes are valid in the frame of ASSET and ASSET+ studies perimeter (mainly - but not exclusively - PFM approach, no constellations); nevertheless, interesting points can be valid for the overall approach in thermal testing

Summary of cases

- 52 anomalies (NCR and FLA) have been kept as relevant cases after the initial screening and initial analysis
  - 42 ground anomalies (NCR)
  - 10 flight anomalies (FLA)

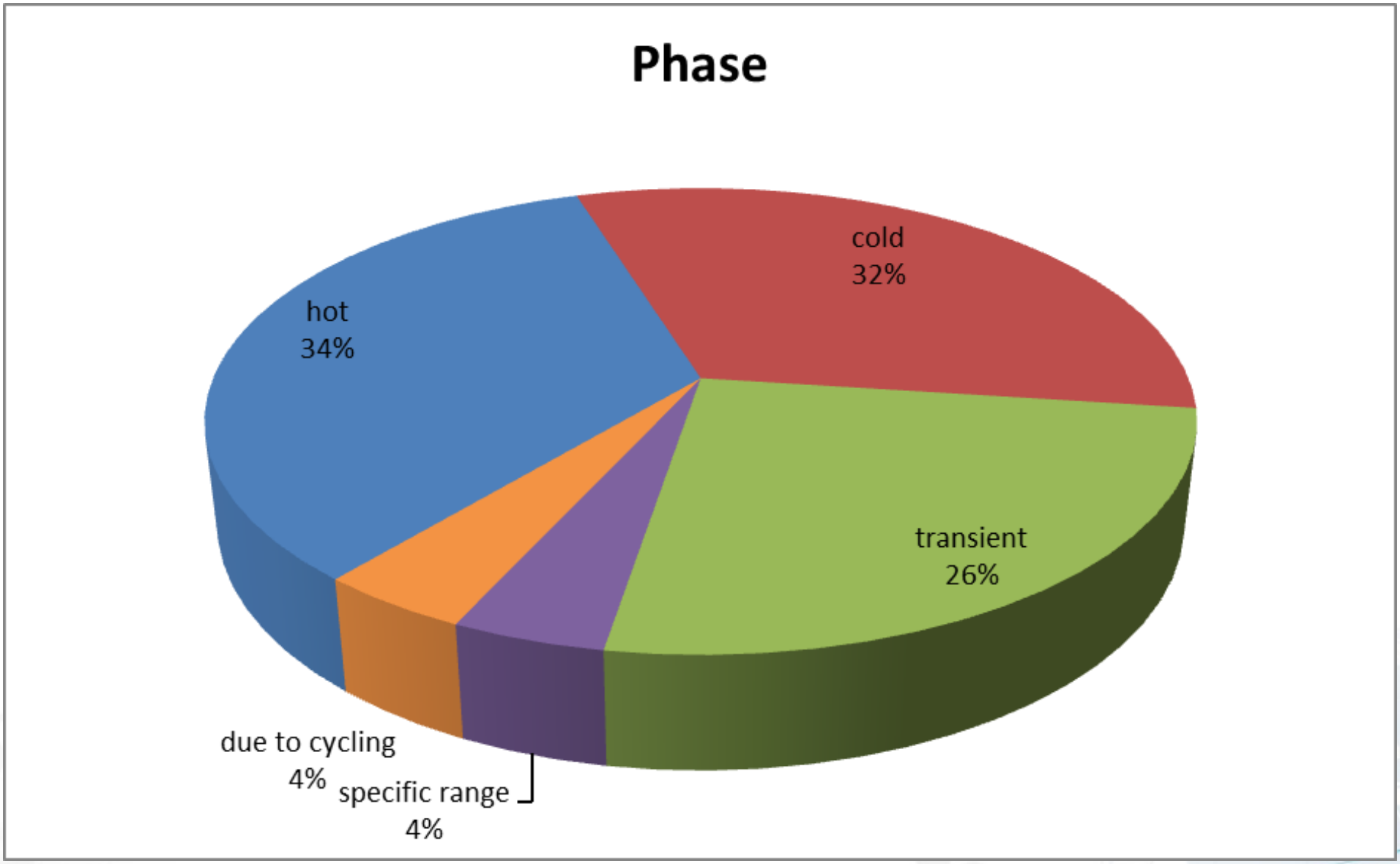
Level detail:	
Equipment related	14
Integrated element	32
undetermined	6

Cycle of occurrence (NCR)	
1	30
2	0
3	1
undetermined	11

Level of the anomaly (system/equipment)

- Of the clearly identified anomalies, a majority are linked to a system level issue, which means that *a test at lower level would not permit to observe the anomalous behavior*
  - this category includes failures in integrated subsystems (mostly the Thermal Control Subsystem) and harness, interface problems and several integration or workmanship errors
  - This fact is a confirmation of the role of TVT as a test able to identify (for the first time in the AIV process) non-conformances on the complete integrated system (including on-board software), especially on protoflight (PFM) and flight models (FM) .
- Some anomalies are linked to equipment level failures, which means that such non-conformances escaped lower level testing. This can be a feedback on equipment and unit level testing, requiring improvement, but also an indication that *system level TVT is useful also to act as safety net wrt some possible low-level testing inadequacies*.
- Other anomalies have not been clearly identified in terms of level of the failure, or are linked to testing procedure or facility.

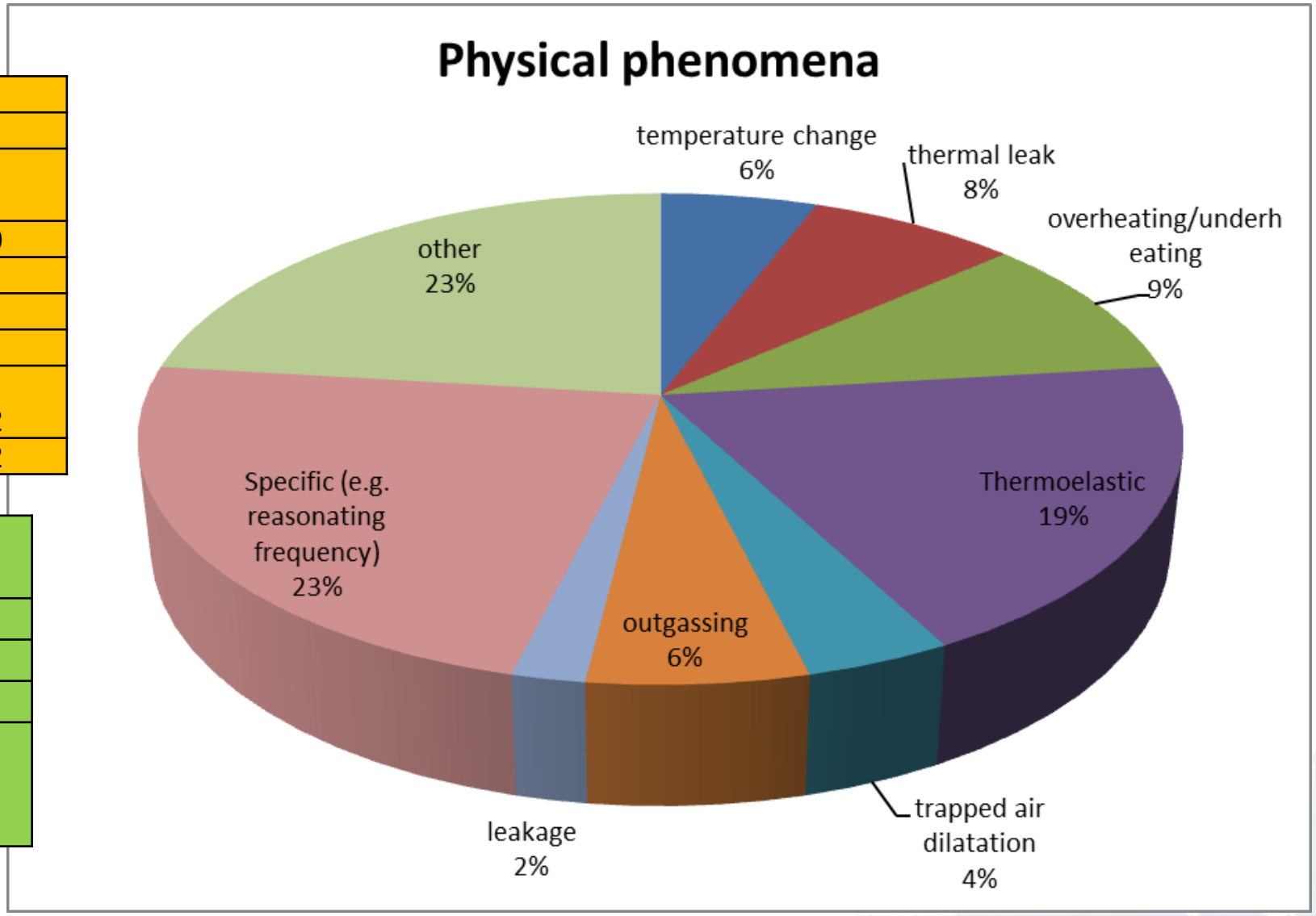
Phase of occurrence



Physical phenomena

temperature change	3
thermal leak	4
overheating/ underheating	5
Thermoelastic	10
trapped air dilatation	2
outgassing	3
leakage	1
Specific (e.g. reasonating frequency)	12
Other (no Physical Ph.)	12

thermoelastic details :	
MLI design	2
Alignment	2
Broken part	3
Distorsion with impact on function	3



Vacuum condition 1/2

- The vacuum condition shows to be the driving phenomenon to roughly 75% (25 out of 34 don't considering FLA and facility related NCR's) of the selected cases. This covers different aspects:
  - impact on heat transfer and temperature distribution (lack of convection)
  - pressure-related effects: leakage and outgassing
  - other vacuum-related phenomena, as corona effects, were not observed among the selected cases.
- Most remaining anomalies can be found thanks to vacuum, so to have the condition to observe the anomaly (e.g. cold conditions can be reached only in vacuum; specific temperature distributions are linked to absence of convection)

Vacuum condition 2/2

- **Is it possible to replace TVT with Thermal Ambient?**
- **NO**
- As it is as it is a required condition for half of the anomalies

Thermal conditions

- The *temperature plays a major role* in more 70% (24 of 34 don't considering FLA and facility related NCR's) anomalies, at both hot and cold conditions. The overall outcome is that it is important to reach the predicted extreme operating temperatures. No indication emerges that going beyond those levels contributes significantly to detect NCRs.

- 16 of above 34 anomalies are linked to the functional test performed at certain TVT phases (more often hot plateau). This can be a confirmation of the *importance of having a thorough functional testing at TV predicted temperatures.*

Amount of thermal cycles 1/3

- Scarce evidence of the impact of cycling appear from the analyses: just 3 NCRs/FLAs have thermal cycling among their contributing factors
- There is no evidence to require to perform 3 cycles

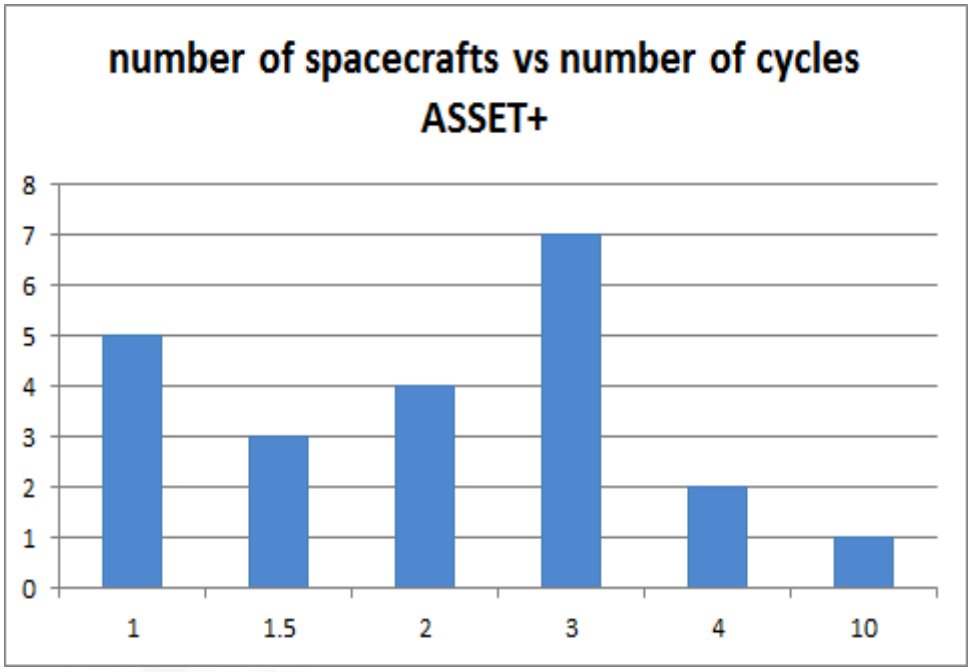
- For a consistent amount of cases, the cycle of occurrence was not available -> feedback on reporting, to provide a thorough understanding of phenomena and conditions

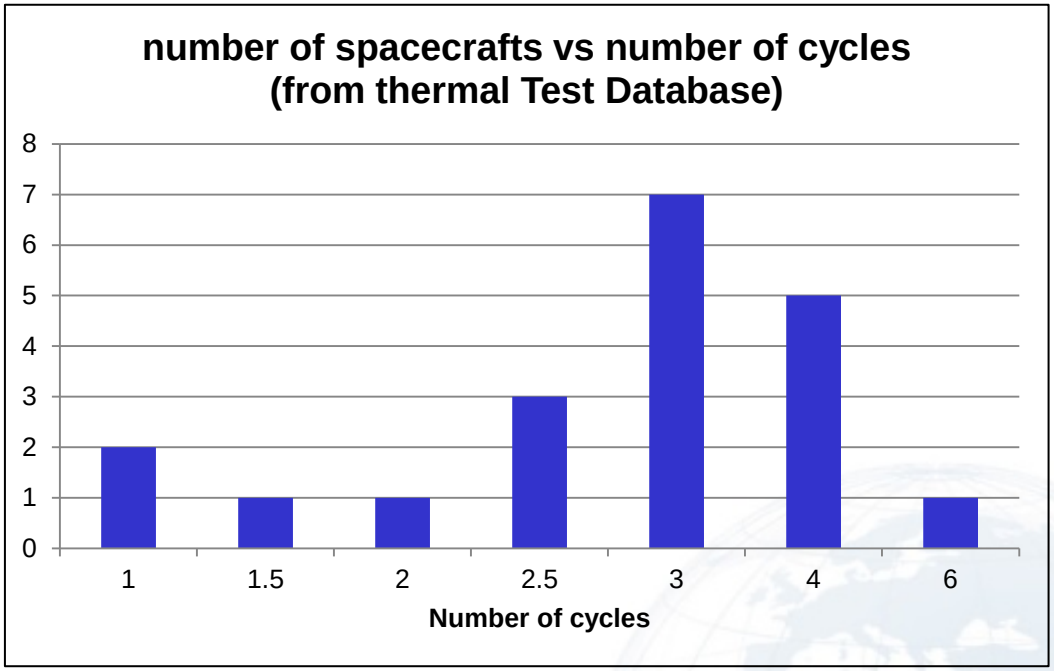
Amount of thermal cycles 2/3

- **Why we cannot be sure (i.e. provide analytical evidence) that cycling does not trigger failures?**
- All the anomalies with a known cycle of occurence precipitated at the 1st cycle, or the first time the functionality was tested (1 such case at the 3rd cycle)
- If an anomaly occurs on the Nth cycle without having been tested before, it is impossible to say that it would have been observed already on the 1st cycle, neither it is possible to assert that N cycles are necessary. A recommendation could be to test starting from the 1st cycle, so to understand the phenomenon.
- Considering the test effectiveness of test programs in the ASSET+ perimeter (half TVT with one/two cycles) it is possible to underline that **1,5 cycles** (guaranteeing both types of thermal transient) cannot be linked to an increase of FLA

Amount of thermal cycles (3/3)

- ASSET + distribution compared to one coming from different ESA study (Thermal Test Database 2011)





Overheating/underheating and thermal leaks

- *5 of 34 anomalies are linked to over/under heating*
- *4 of 34 anomalies are linked to thermal leaks*
- Despite all precautions, the thermal model may overlook some effects on the thermal environment/spacecraft thermal behavior.
- There is both the need to validate the model w.r.t. reality, but also to validate the as built vs as modeled (which means make sure that what has been built is what has been modelled, to be done before testing)

Testing for cryogenic missions

- Particular attention must be paid to the scale of the phenomena involved: at S/C level the thermal balance is of the order of hundreds of watts, but at P/L model for cryogenic applications the thermal balance can be of the scale of few watts, so the test setup must be devised accordingly. Combining the two levels of thermal balance in the same test can be tricky,

- In such cases, it might be good to consider testing both P/L and S/C level configurations

Intermediate temperatures

- *9 of 52 anomalies occurred at temperatures far from extremes.* 12 occurred during transients (but in some of these cases, it happened near to the cold or hot plateau) and 2 at specific temperature ranges.
- Inside this group of anomalies, it is possible to find behavior of components that occur at specific temperature ranges (in some cases this can be already observed at equipment level). There are also anomalies linked to the effect of thermal gradients created by the transient, and to thermo-elastic effects.

Facility and operations

- *8 of 42 NCRs were not due to defects on the S/C*. This kind of anomaly was generally discarded on principle, however some were selected because of the relevance of specific issues and then properly assessed only during the analysis phase.
- Also, from the data provided in questionnaires, facility- and operations-related NCRs seem to make up a significant amount of the total TVT NCRs.

Conclusions

AIRBUS DEFENCE & SPACE

THALES ALENIA SPACE INTERNAL

ThalesAlenia Space
A Thales / Finmeccanica Company

83230350-DOC-TAS-EN-001

Conclusions

- ASSET+ showed that the major anomalies escaped from thermal vacuum testing are few, evidencing that current practice is good overall (high test effectiveness)
- Some margins of improvement have been individuated and consolidated into recommendations
- A deeper understanding of the involved phenomena has been provided, supporting further considerations and developments
- Further investigation areas may include:
  - Experimental activities oriented to substantiate the optimum Number of Cycles necessary to precipitate defects
  - Improvement of methodologies to collect more details on Number of Cycles through the NCR process
  - Analysis of “waste” during AIT (i.e. NCR’s not linked to S/C but to Test Facilities, tools and operations)


WE LOOK AFTER THE EARTH BEAT
Thank you for your attention!
Any questions?
AIRBUS
DEFENCE & SPACE
THALES ALENIA SPACE INTERNAL
ThalesAlenia
A Thales / Finmeccanica Company Space
83230350-DOC-TAS-EN-001