Appendix M

Innovative Analysis Methods for Improved Thermal Testing

Mélanie Doolaeghe André Capitaine
(Astrium Satellites, France)

Abstract

An R&D study by ESA, led by ASTRIUM in cooperation with INTESPACE, LKE (CZ), ETS and Global Vision Systems.

Thermal testing is part of the verification process needed on a space system. Located on the critical path of the spacecraft project, thermal testing is a complex, demanding, long and expensive task. Thermal test complexity associated to the constraints in term of cost and schedule requires efficient dedicated tools for data handling, monitoring and exploitation, in real time and after the test. Improving analyses methods and tools used to ease thermal testing is in the centre of the cost and schedule reduction problematic.
The proposed presentation deals with the activity performed in the frame of ESA R&D project Innovative Analysis Methods for Improved thermal Testing (IAMITT).
In phase one, a critical analysis of current industrial practises among all industrial space thermal companies led to identify potential improvements and select those to implement into the different modules prototyped in phase 2.
The replay of Lisa PathFinder thermal test showed the efficiency and the limitations of the different IAMITT modules:

- 3D displays gather relevant information contained in the thermal test database and dynamically link them to GMM thermal model, CAD model and pictures visualisation. The possibility of real-time visualizing all the test data available aims at increasing the spacecraft safety, facilitating the thermal team understanding, and enhancing its efficiency.
- Spatial extrapolation allows estimating the temperatures of non instrumented nodes or disabled thermal sensor in function of the temperature of instrumented ones during steady-state phase as soon as all dissipations and heater status are available.
- Temporal extrapolation predicts steady-state stabilisation, leading to a better efficiency of the test monitoring, and may lead to the shortening of test phases.
- Dynaworks database is also interfaced with a dedicated tool (TMUT) to perform model correlation by regenerating predictions with measured environment conditions but also real-time model updating using genetic algorithms.

The presentation will be concluded with some validations on a previous commercial telecommunication spacecraft but also with a short description (perhaps even the first views for this application) of the validation which is on-going on ALPHASAT in the frame of ESA R&D EVATHERM.

Innovative Analysis Methods for Improved Thermal Testing (IAMITT)

26th European Space Thermal Analysis Workshop

M. Doolaeghe – A. Capitaine - EADS Astrium
22.11.12

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Innovative Analysis Methods for Improved Thermal Testing (IAMITT)

Agenda

- IAMITT project
  - Motivation and study logic
  - Design and validation (Lisa PathFinder, TLC S/C)
- IAMITT modules
  - 3D display
  - Spatial Extrapolation
  - Thermal Model updating (test conditions and model parameters)
  - Thermal Test Database
  - Temporal Extrapolation
- Operational use on TLC S/C
  - Update of predictions
  - Highlight of non conformances
- Alphasat / EVATHERM R&D
  - Objectives
  - First views – 3D display, Spatial Extrapolation
- Future IAMITT developments
  - Existing, new functionalities and connected topics
  - Industrialization

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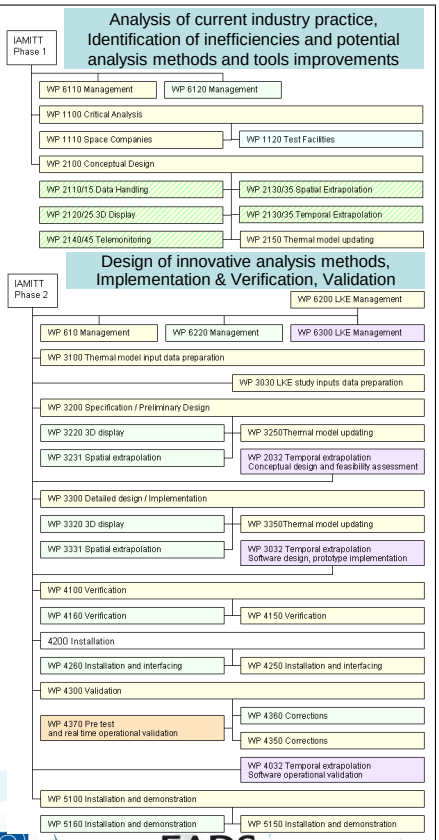
Innovative Analysis Methods for Improved Thermal Testing (IAMITT)

IAMITT project
Motivation and Study logic

- Thermal testing issues
  - Measurements
    - Management of hundreds of TCs and TMs
    - TCs localisation identification not immediate
    - Difficulty to access to some area temperatures
    - Different acquisition sources
    - Only curves
  - Length of the test
    - Long thermal tests
    - No quick status of thermal balances convergence
  - Thermal model correlation
    - No status of model correlation at the end of the test
    - Difficulties to get dissipation after test end
    - Long post test process after test for correlation
- IAMITT project
  - ESA R&D
  - Multinational cooperation
  - 2 phases
- => Significant reduction of cost and time



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Innovative Analysis Methods for Improved Thermal Testing (IAMITT)

IAMITT project - Phase 1
Critical analysis and Conceptual Design - Improvements identification

Critical analysis

- Space companies
  CNES, Dutch Space, TAS Turin, STFC RAL, Astrium ST
- Thermal test facilities
  Intespace, ETS, CSL, IABG, Thales Alenia Space Cannes
- Wide scope of space systems
  Telecommunication, observation and scientific satellites
  Space equipments, Instruments
  Launchers, ATV
- Topics related to all disciplines
  Thermal analysis and architecture
  Assembly, Integration and Testing
  Product assurance
- Main bottlenecks, gaps

Conceptual design

- Feasibility
  Definition of improvements
  Feasibility assessment (thermal & SW)
- Trade-off
  - Price / performance / constraints
  - Selection of 5 improvement modules
    3D display (3D)
    Spatial Extrapolation (SE)
    Thermal Model Updating Tool (TMUT)
    Temporal Extrapolation (TE)
    Thermal Test Database (TTD)
  - R&D thermal issues
  - Stand-alone SW modules
  - Based on Dynaworks COTS

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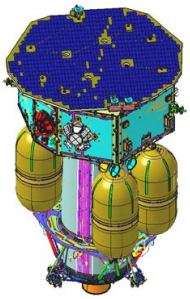
Innovative Analysis Methods for Improved Thermal Testing (IAMITT)

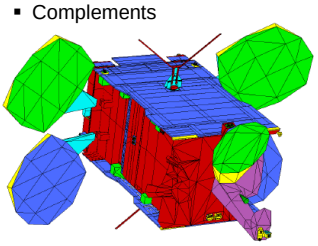
IAMITT project - Phase 2

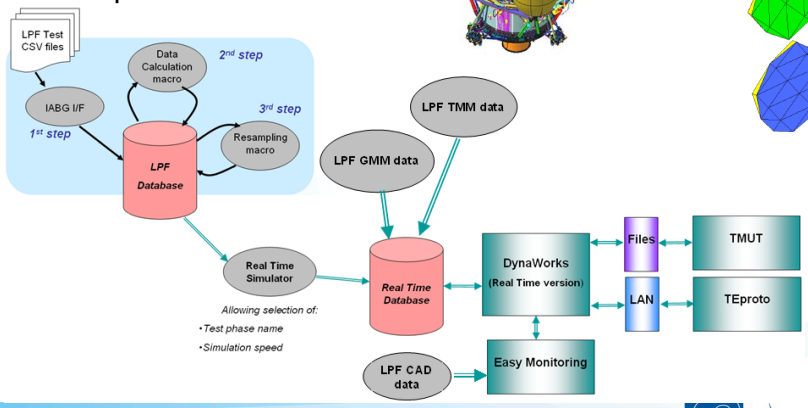
Development, Verification and Validation - Modular organization

- Validation
  - Candidates (≈ 8500 nodes)
    - Lisa PathFinder
      - 3 steps validation
      - Not fully successful
  - Operational Validation



- Telecom Spacecraft
  - Complements

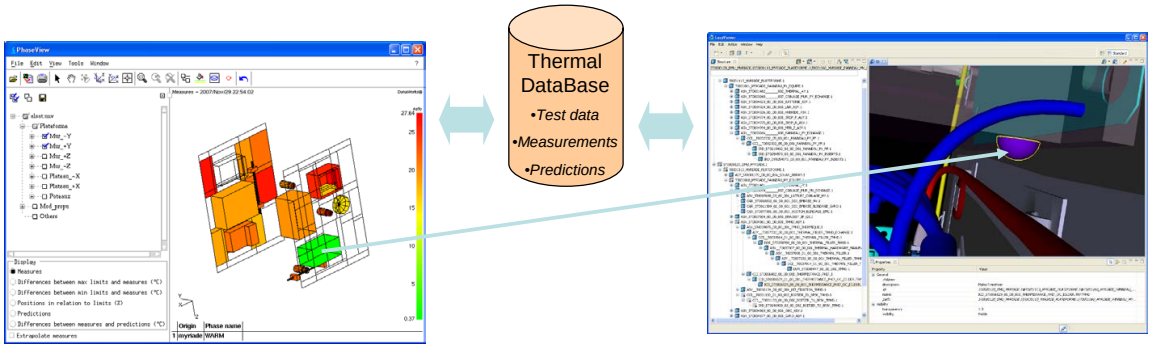




Innovative Analysis Methods for Improved Thermal Testing (IAMITT)

IAMITT modules - 3D display

Thermal / CAD models and test data

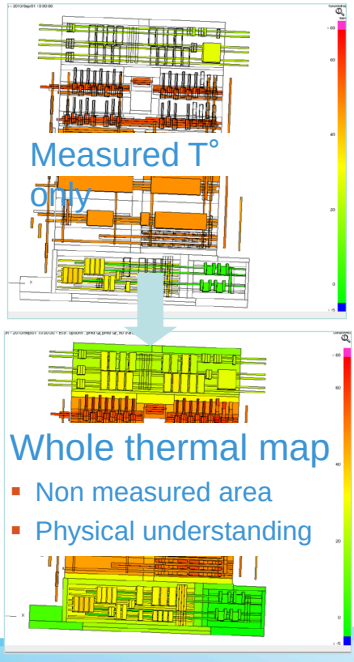


- GMM 3D display (Dynaworks)
  - Thermal data associated to nodes
    - Measured / Predicted temperatures
    - Measured / Predicted dissipations
    - Measured / Predicted heating powers
    - Differences
- CAD 3D display (EasyMonitoring)
  - Full CATIA native model
  - Specimen definition & thermal sensors
  - Link towards pictures

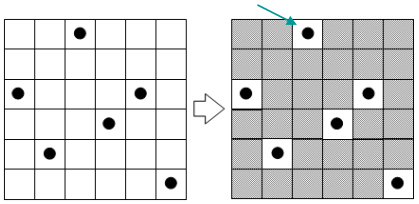
Innovative Analysis Methods for Improved Thermal Testing (IAMITT)

IAMITT modules - Spatial Extrapolation

Access to whole temperature map



Sink temperatures on instrumented nodes



k non instrumented or defective
l instrumented
extrapolated temperatures

$$T_i = \begin{pmatrix} T_l \\ T_k \end{pmatrix}$$

- Linearized thermal equation

Linearization T°

Conductive couplings

$RT^4 + LT = P$ $\quad AT = P + Q$

Radiative couplings

$$\begin{cases} A = L + 4.R.[Tl^3] \\ Q = 3.R.Tl^4 \\ P = -QI - QR + C\dfrac{dT}{dt} \end{cases}$$

Heating power

Dissipation

Transient term

Issue: no access to transient term for non instrumented nodes **(4 methods tested)**

- Return to Temperatures

measured T°

$$T_k = W_{kl} T_l + X_{kk}(P_k + Q_k)$$

$$W_{kl} = -A_{kk}^{-1} A_{kl} \quad \text{and} \quad X_{kk} = A_{kk}^{-1}$$

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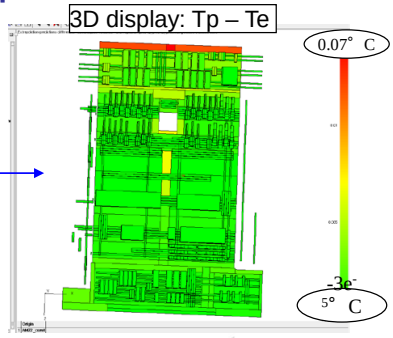
Innovative Analysis Methods for Improved Thermal Testing (IAMITT)

IAMITT modules - Spatial Extrapolation

Access to whole temperature map

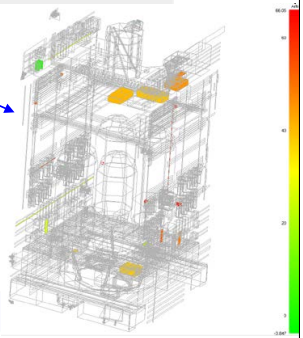
3D display: Tp – Te

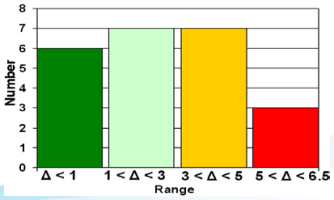


- Validation with telecom model
  - Theoretical case SE{predicted_data}
    - Theory : Te = Tp
    - Validation criteria: | Tp – Te | < 0.1° C
    - Experiment: **| Tp – Te | < 0.07° C**

    => A new thermal tool prediction?
  - Real case SE{measured_data}
    - Simulation of 23 invalid TC (randomly chosen)
    - Comparison between measurement and extrapolation

    => Error lower than 5° C for most of the TC, depending on
      - Thermal model quality
        extrapolation is better
        if prediction is good
      - Powers inputs
      - Measurement accuracy





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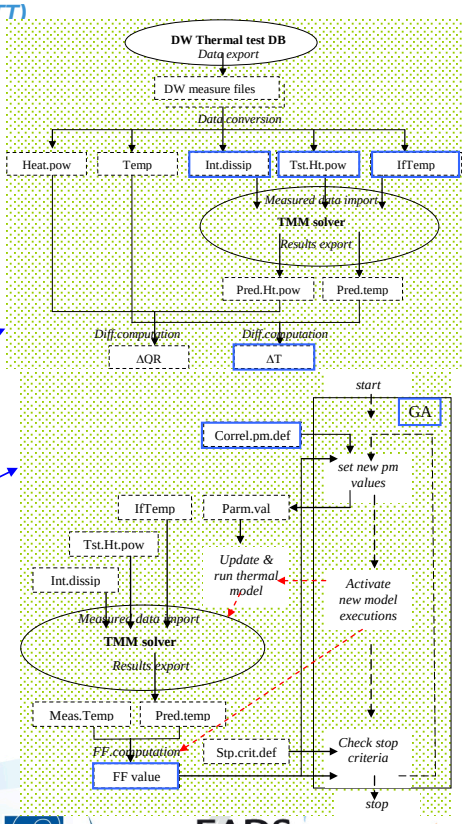
Innovative Analysis Methods for Improved Thermal Testing (IAMITT)

IAMITT modules – Thermal Model Updating Tool

Near Real Time Correlation

- Logics and assumptions
  - Steady-state conditions
  - Several cases management
  - Fitness Function FF (# Tmes-Tpred)
- **TCU** (Test Conditions Updating)
  - Real-time prediction update
  - Useful for test management
- **MPU** (Model Parameters Updating)
  - Preliminary identification of uncertain parameters with physical possible variation range
  - Automatic iteration with Genetic Algorithm to decrease the FF
- Results
  - Replay of TC S/C correlation

  => 0.5° C avg. improvement WRT best known manual solution



Innovative Analysis Methods for Improved Thermal Testing (IAMITT)

IAMITT modules - Thermal Test Database

One Single Database

- Access to all thermal test predictions and measurements data
- Needed by IAMITT modules : 3D, SE, TE, TMUT

Thermal analysis model related data

Data	Thermal nodes			
calculated from measurements	Tm(t)	QIm(t)	QRm(t)	CdTm/dt(t)
predicted or calculated from predictions	Tp(t)	QIp(t)	QRp(t)	CdTp/dt(t)
predicted constant	-	-	QRp	-
extrapolated	Te(t)			

TMM and GMM

VAR(t)

Access to acquired data

Association (Formulas depending on Labels)

Acquisition channels

Type	Notation	Acquisition device
Temperature	Ta(t)	DAS, OCOE, Thermal rack
Current	Ia(t)	OCOE, Thermal rack
Voltage	Va(t)	OCOE, Thermal rack
Unit and heating line status	Sa(t)	OCOE, Thermal rack
Pressure	Pa(t)	DAS

in DBMS
(DataBase Management System)

Functions (depending on Thermal nodes)

Objectives Alarms

out of DBMS

Innovative Analysis Methods for Improved Thermal Testing (IAMITT)

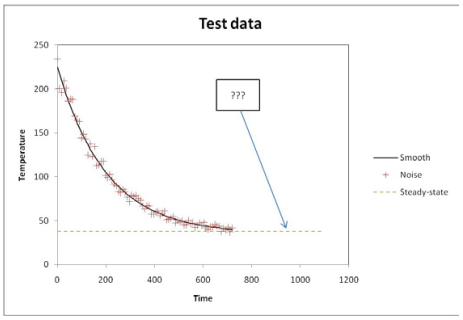
IAMITT modules - Temporal Extrapolation

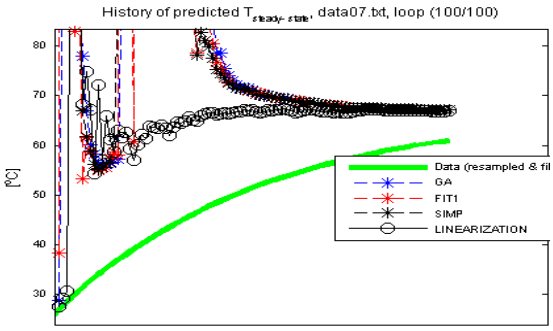
Shortening thermal balance phases

- Prediction of steady-state temperature
- Temperature curve modelled by a sum of exponential functions

$$T(t) = T_{\infty} + \sum_{j=1}^{p} \alpha_j e^{-\beta_j t}$$

- Combination of 2 methods
  - M1 - Linearization (LIN)
  - M2 - Optimization of exponential coefficients
- Results (test replay)
  - Saving ≈ 50% of phase length for 80% of 300 tested curves
  - TE quality and time depending on
    - Deviation from steady state conditions
    - Evaluation frequency





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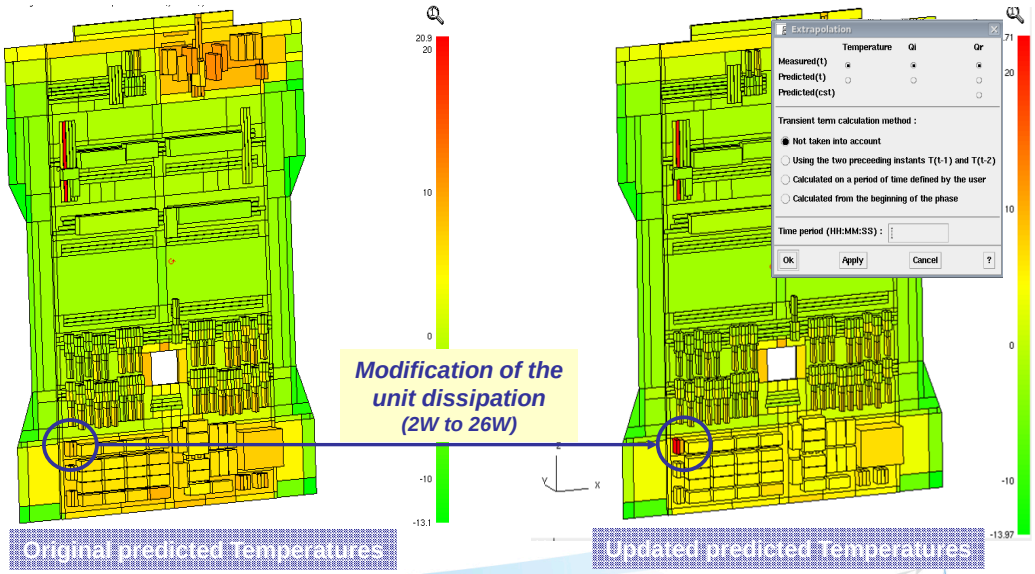
Innovative Analysis Methods for Improved Thermal Testing (IAMITT)

IAMITT applications – Use on TLC spacecraft

First industrial uses

- Capacity to update predictions in real time in Dynaworks



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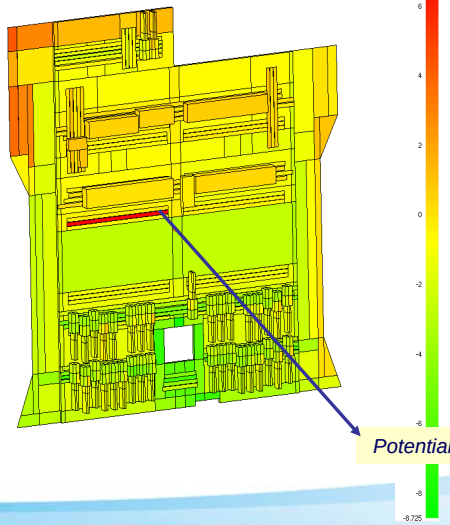
Innovative Analysis Methods for Improved Thermal Testing (IAMITT)

IAMITT applications – Use on TLC spacecraft

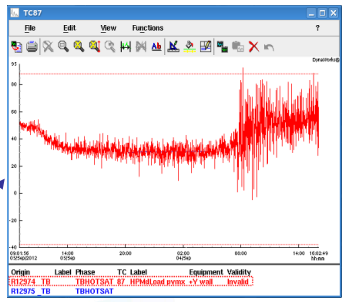
First industrial uses

- Highlight of non conformances (ex : invalid TC)

Easy comparison between predicted and extrapolated temperatures



Invalidity confirmed by 2D plot



Potential invalid TC?

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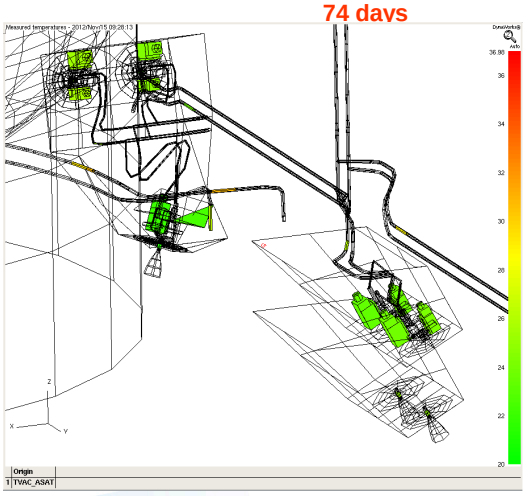
Innovative Analysis Methods for Improved Thermal Testing (IAMITT)

IAMITT applications - ALPHASAT / EVATHERM

Objectives

- Use of IAMITT modules during Alphasat Tvac
  - 3D display (GMM view)
  - Spatial Extrapolation
    Access to propulsion line temperature estimation
  - Thermal model updating in real time
    4-core laptop allows to perform more than 10 000 steady-state runs per day with this 15500 node model
- Dissipations computation
  Introduced in DW DB
- Use in parallel to operational system
  Helper tools
- Not tested for Alphasat
  - Temporal Extrapolation
  - CAD interfaces

15.500 thermal nodes
1000 acquisition channels
10 days longest phase
74 days



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Innovative Analysis Methods for Improved Thermal Testing (IAMITT)

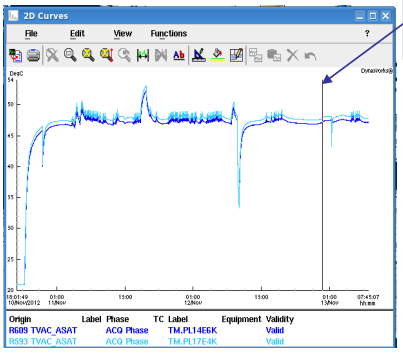
IAMITT applications - ALPHASAT / EVATHERM

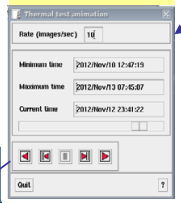
On-going – First views

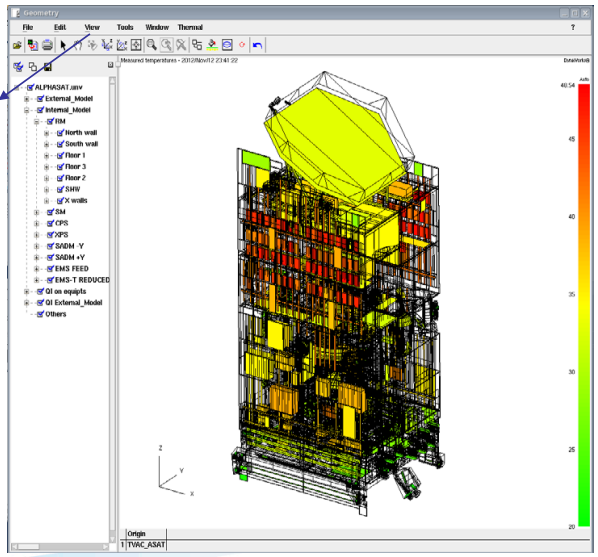
- 3D display module

Test animation

Replay a phase with the 3D module as well as 2D plots







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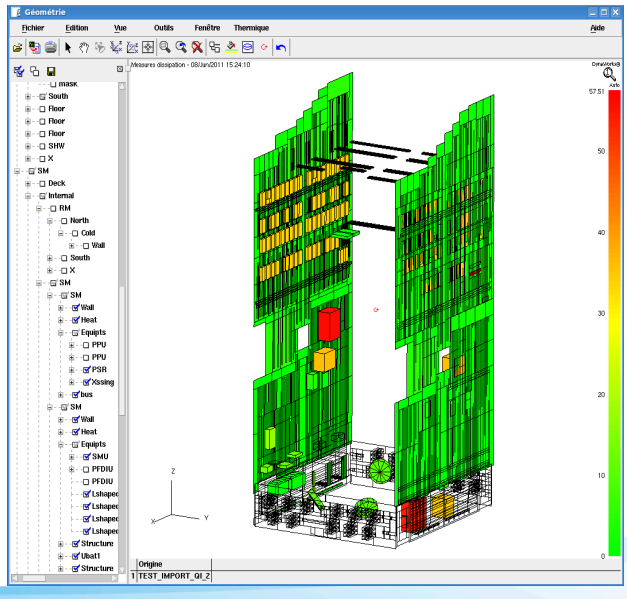
Innovative Analysis Methods for Improved Thermal Testing (IAMITT)

IAMITT applications - ALPHASAT / EVATHERM

On-going – First views

- 3D extrapolation



Final results and conclusions will be presented in the next months

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Innovative Analysis Methods for Improved Thermal Testing (IAMITT)

Future IAMITT developments

- Existing functionalities optimization
  - STEP-TAS, CAD, pictures,…
  - Spatial Extrapolation methodology optimisation (performances)
- New real time functionalities development
  - TC validity evaluation
  - Spatial Extrapolation for transient phases
  - Transient cases for TMUT
  - LKE development on Temporal Extrapolation to be optimised
  - Quick thermal solver in Dynaworks
  - Set of thermal tools
    - Real-time Thermo elastic calculation (Wave Front Errors)
    - Line of Sight or Image quality estimation
    - Estimation of duty cycles
    - Fluxes calculation
- Connected topics
  - Dissipations and heating powers computation
  - Interfaces (data, software, test devices)
  - Telemonitoring
- Industrialization within version Dynaworks V7 of the more mature IAMITT functionalities

  3D display (GMM), Spatial Extrapolation, Thermal Test Database

… And many other potential ideas after EVATHERM

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Innovative Analysis Methods for Improved Thermal Testing (IAMITT)

Thanks to ESA for their support

Thank you for your attention

Any questions?

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