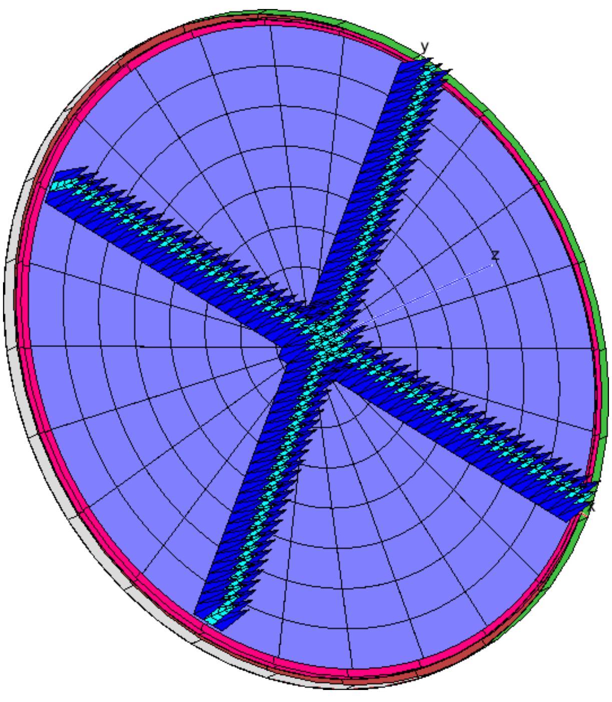
ESA-WPP-346
December 2017

Proceedings of the

31st European Space Thermal Analysis Workshop

ESA/ESTEC, Noordwijk, The Netherlands

24–25 October 2017



courtesy: Katherine Ostojic, RAL Space

European Space Agency
Agence spatiale européenne

Abstract

This document contains the presentations of the 31st European Space Thermal Analysis Workshop held at ESA/ESTEC, Noordwijk, The Netherlands on 24–25 October 2017. The final schedule for the Workshop can be found after the table of contents. The list of participants appears as the final appendix. The other appendices consist of copies of the viewgraphs used in each presentation and any related documents.
Proceedings of previous workshops can be found at http://www.esa.int/TEC/Thermal_control under 'Workshops'.

⇒ Please note that text like this are clickable hyperlinks in the document.
⇒ This document contains video material. By (double) clicking on picture of a video the movie file is copied to disk and then played with an external viewer. This has been tested with Adobe Reader 9 in Windows and Linux using vlc as external viewer. Other pdf readers may not work automatically. As a last resort the user can manually extract the movie attachment from the file and play it separately.

Contents

Appendices

Programme Day 1

9:00 Registration

9:45 **Welcome and introduction**

Harrie Rooijackers (ESA/ESTEC, The Netherlands)

10:00 **A proposition for updating the environmental standards using real Earth Albedo and Earth IR Flux for Spacecraft Thermal Analysis**

Romain Peyrou-Lauga (ESA/ESTEC, The Netherlands)

10:30 **JUICE Thermal Analysis Challenges**

Alejo Ares (Airbus Toulouse, France)

10:55 **Thermal Modelling of Luna 27 Landing Site**

Hannah Rana & Vito Laneve & Philipp Hager & Thierry Tirolien (ESA/ESTEC, The Netherlands)

11:20 Coffee break in the Foyer

11:45 **Construction of a reduced thermal model of a Traveling Wave Tube with a modal method**

Martin Raynaud (Thales Alenia Space, France)
Quentin Malartic & Frederic Joly & Alain Neveu (Universite Evry Val Essone, France)

12:10 **Baseplate Pyramid Modelling of the Calibration Target for the MetOp-SG Microwave Sounder Instrument (MWS)**

Katherine Ostojic (RAL Space, United Kingdom)

12:35 **Enhancement of Loop Heat Pipe module for thermal analysis**

Ludovic Zurawski (Airbus Toulouse, France)
Patrick Hugonnot & Paul Atinsounon (Thales-Alenia Space, France)
James Etchells (ESA/ESTEC, The Netherlands)

13:00 Lunch in the ESTEC Restaurant

14:00 **Improved Integrated Way of Post-processing Thermal Model Data**

Nicolas Bures (ITP Engines UK, United Kingdom)

14:25 **Thermal Analysis of Electrochromic Radiators on Sentinel 2**

Oliver Kluge & Alexander Zwiebler & Dr. Tino Schmiel & Prof. Dr. Martin Tajmar
(Dresden University of Technology, Germany)
Martin Altenburg (Airbus Defence and Space, Germany)

14:50 **Thermal analysis approach for finding Bepi Colombo MTM SA wing generated PV power**

Niels van der Pas (Airbus Defence and Space, The Netherlands)

15:15 **Time-Varying Thermal Dynamics Modeling of the Prototype of the REMS Wind Sensor**

Maria-Teresa Atienza & Lukasz Kowalski & Sergi Gorreta & Vicente Jiménez & Manuel Domínguez-Pumar
(Universitat Politecnica d'Catalunya, Spain)

15:40 Coffee break in the Foyer

16:15 **A MLI model based on transient model correlation**
Jan Klement & Lena Bötsch & Jonas Klose & Christian Walker (Tesat-Spacecom GmbH, Germany)

16:40 **Methods to Improve Thermal Test Efficiency (MITTE)**
Patrick Coutal (Airbus Toulouse, France)
James Etchells (ESA/ESTEC, The Netherlands)

17:05 **Thermal Modelling of EarthCARE Instruments' Electronics Boxes**
Allan Dowell (Thales Alenia Space, United Kingdom)

17:30 Social Gathering in the Foyer

19:30 Dinner in *Blu Beach*

Programme Day 2

9:00 **Quality assessment for parameters obtained with model correlation**
Jan Klement (Tesat-Spacecom GmbH, Germany)

9:25 **FiPS®** — Thermal Fluid-Structure Interaction
Patricia Netzlaf (Ariane Group, Germany)

9:50 **Multi-dimensional Ablation and Thermal Response Program for atmospheric entries**
Viola Renato (University of Strathclyde, Scotland UK)

10:15 **ESATAN Thermal Modelling Suite** — Product Developments
Chris Kirtley (ITP Engines UK, United Kingdom)

10:40 **Data exchange for thermal analysis** — a status update
James Etchells & Duncan Gibson & Harrie Rooijackers & Matthew Vaughan (ESA/ESTEC, The Netherlands)

10:50 Coffee break in the Foyer

11:20 **SYSTEMA - THERMICA**
Antoine Caugant & Rose Nerriere & Tomothée Soriano (Airbus Defence and Space SAS, Toulouse, France)

11:45 **Model correlation of Meteosat Third Generation Platform STM**
Emmanuelle Fluck (OHB System AG, Germany)

12:10 **Development of a Modularized and Scalable Thermal Model for Small Satellites**
Alexander Zwiebler & Oliver Kluge & Claudius Birkefeld & Dr. Tino Schmiel & Prof. Dr. Martin Tajmar
(Dresden University of Technology, Germany)

12:35 **DySCo** — improvement of thermal vacuum test monitoring and exploitation in real time
Guillaume Pelissier (Airbus Toulouse, France)

13:00 Closure

13:10 Lunch in the ESTEC Restaurant

Appendix A

Welcome and introduction

Harrie Rooijackers
(ESA/ESTEC, The Netherlands)


esa
31st European Space Thermal Analysis Workshop
Harrie Rooijackers
2017-10-24
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Workshop objectives
esa
• To promote the exchange of views and experiences amongst the users of European thermal engineering analysis tools and related methodologies
• To provide a forum for contact between end users and software developers
• To present developments on thermal engineering analysis tools and to solicit feedback
• To present new methodologies, standardisation activities, etc.
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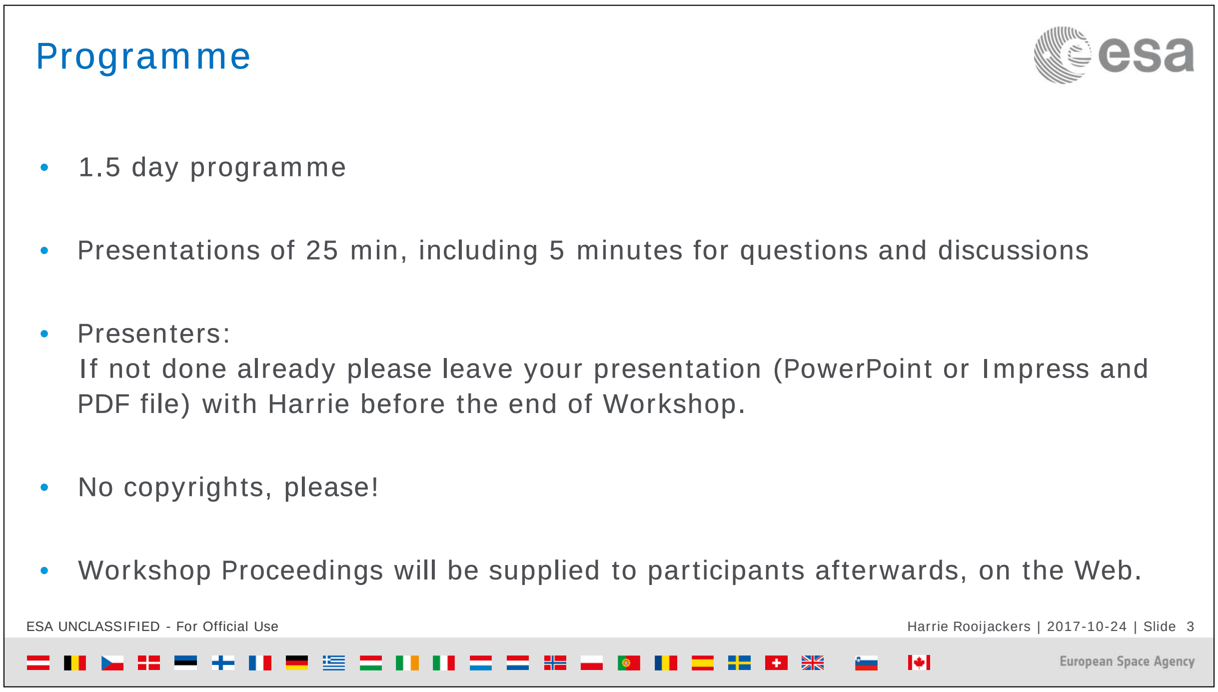
Programme
esa
1.5 day programme
Presentations of 25 min, including 5 minutes for questions and discussions
Presenters:
If not done already please leave your presentation (PowerPoint or Impress and PDF file) with Harrie before the end of Workshop.
No copyrights, please!
Workshop Proceedings will be supplied to participants afterwards, on the Web.
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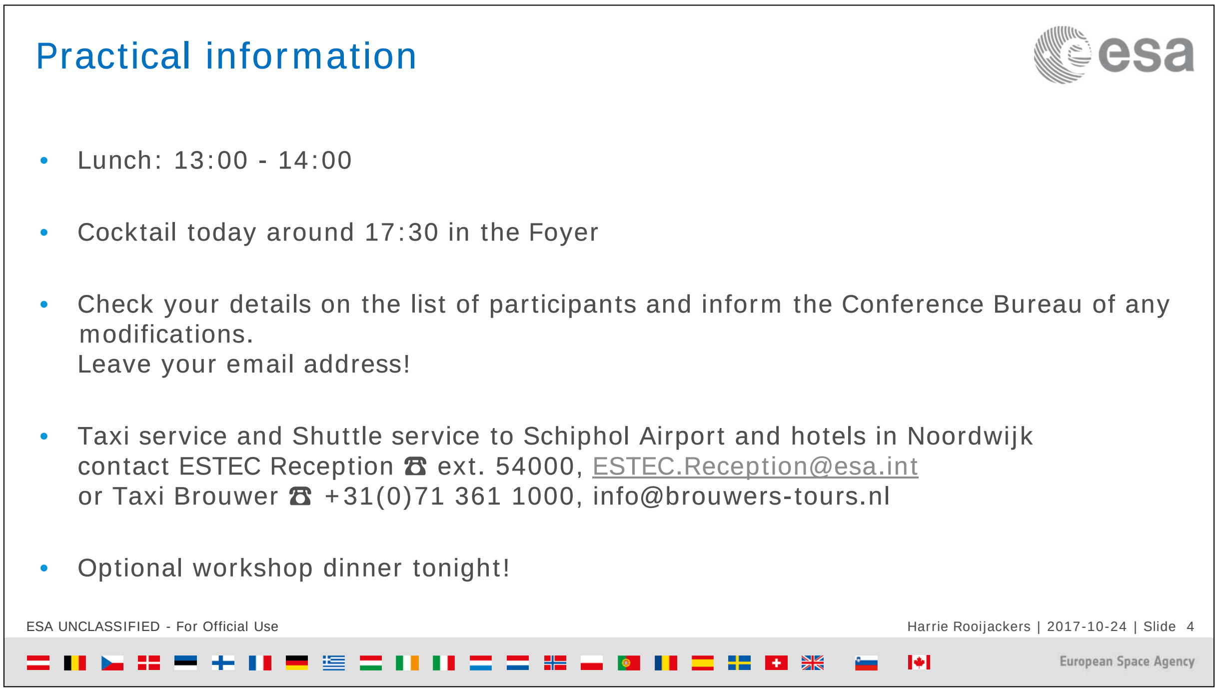
Practical information
esa
Lunch: 13:00 - 14:00
Cocktail today around 17:30 in the Foyer
Check your details on the list of participants and inform the Conference Bureau of any modifications.
Leave your email address!
Taxi service and Shuttle service to Schiphol Airport and hotels in Noordwijk
contact ESTEC Reception ☎ ext. 54000, ESTEC.Reception@esa.int
or Taxi Brouwer ☎ +31(0)71 361 1000, info@brouwers-tours.nl
Optional workshop dinner tonight!
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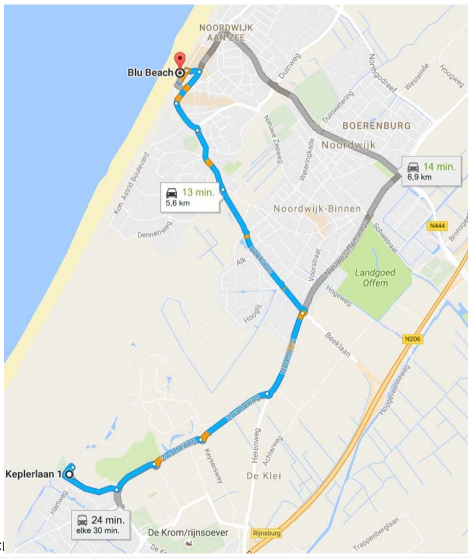
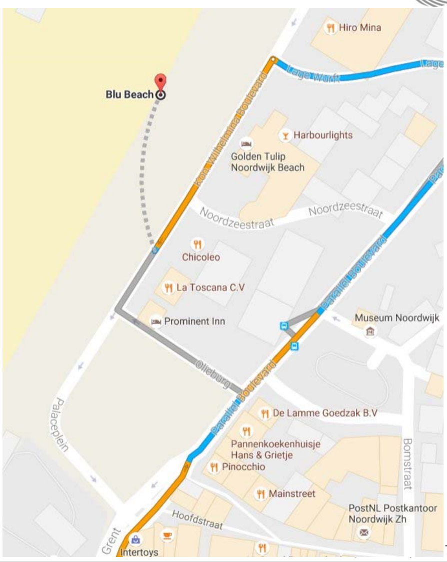
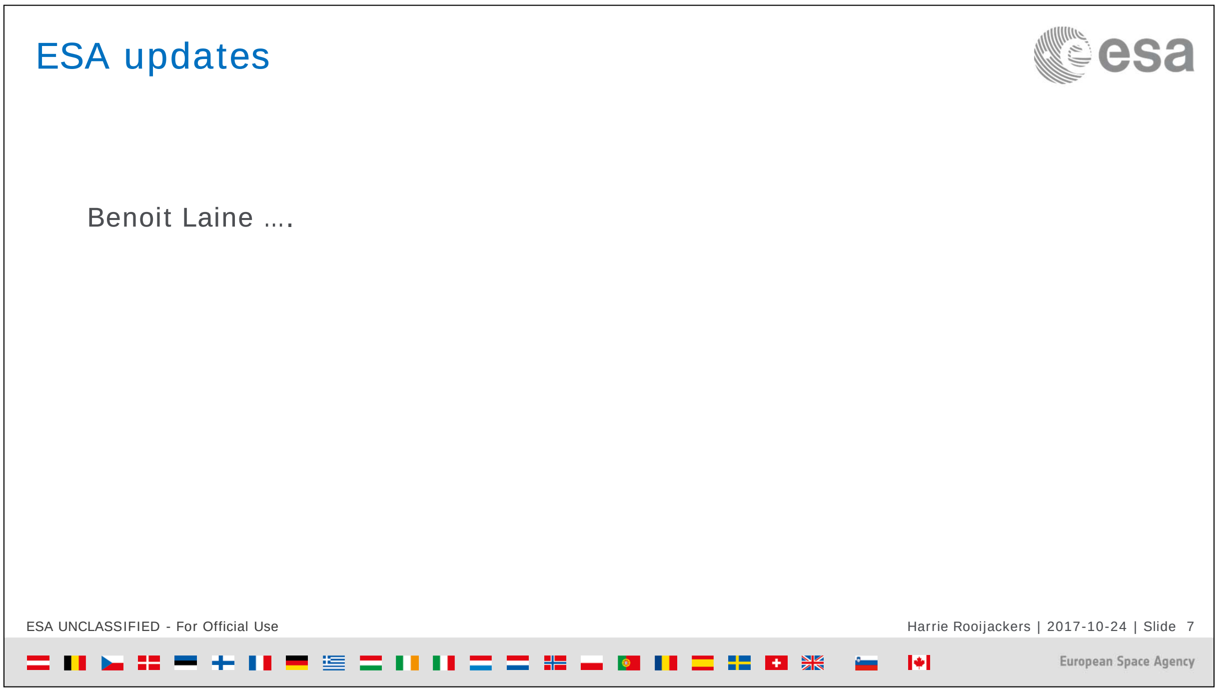
Workshop dinner

- in “Blu Beach", Koningin Wilhemina Boulevard 104, Strandafrit 12, 2202 GW Noordwijk, ☎ +31(0)71 3620 490
- fixed menu with choice of main course (fish, meat or vegetarian) for €35,00 drinks are charged individually.
- Restaurant booked today for 19:30
- Please arrange your own transport – carpooling possible
- "Dutch" dinner == to be paid by yourself
- If you would like to join, then fill in the form on the last page of your hand-outs and drop it at the registration desk today before 13:00, to let the restaurant know what to expect

Blu Beach






ESA updates
esa
Benoit Laine ….
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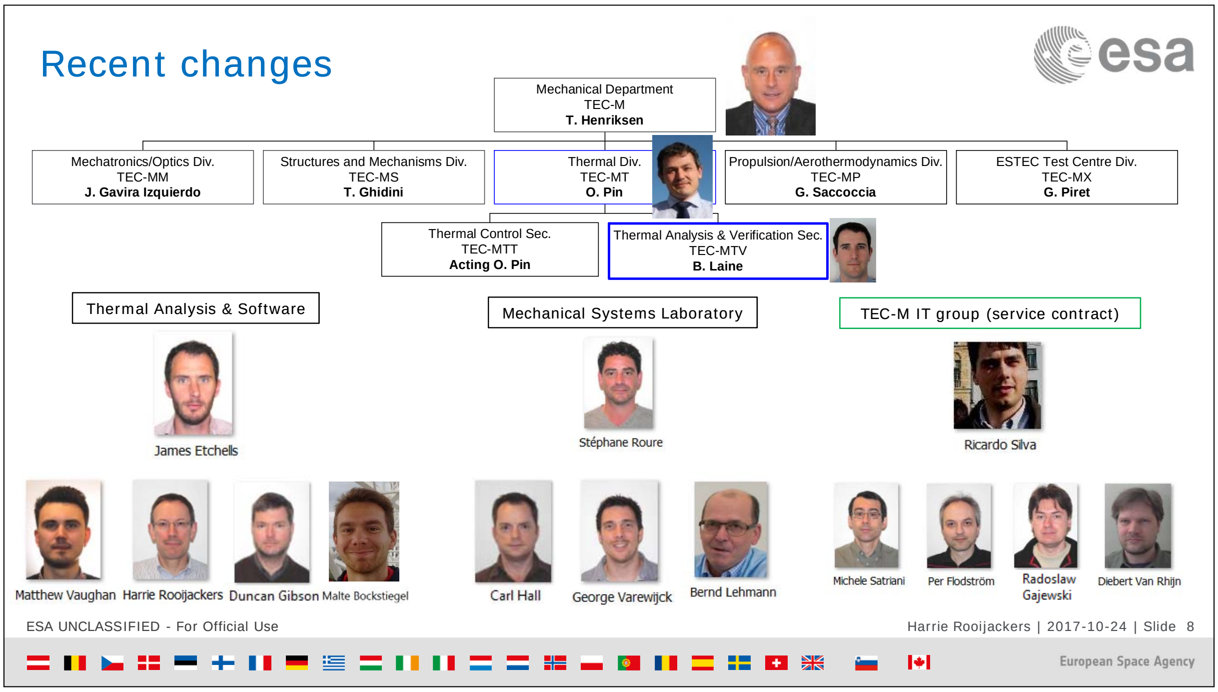
Recent changes
esa
Mechanical Department
TEC-M
T. Henriksen
Mechatronics/Optics Div.
TEC-MM
J. Gavira Izquierdo
Structures and Mechanisms Div.
TEC-MS
T. Ghidini
Thermal Div.
TEC-MT
O. Pin
Propulsion/Aerothermodynamics Div.
TEC-MP
G. Saccoccia
ESTEC Test Centre Div.
TEC-MX
G. Piret
Thermal Control Sec.
TEC-MTT
Acting O. Pin
Thermal Analysis & Verification Sec.
TEC-MTV
B. Laine
Thermal Analysis & Software
Mechanical Systems Laboratory
TEC-M IT group (service contract)
James Etchells
Stéphane Roure
Ricardo Silva
Matthew Vaughan
Harrie Rooijackers
Duncan Gibson
Malte Bockstiegel
Carl Hall
George Varewijck
Bernd Lehmann
Michele Satriani
Per Flodström
Radoslaw Gajewski
Diebert Van Rhijn
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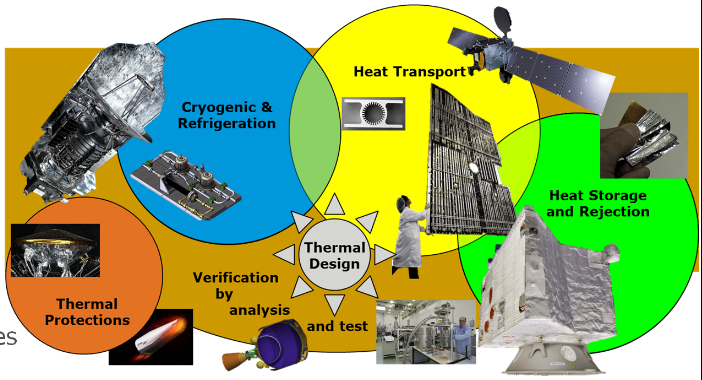
ESA Thermal Division

- Part of the Mechanical Department / Directorate of Technology, Engineering and Quality
- Technical centre of expertise in thermal and covering the **complete temperature range**
- **Functional expert technical support** to all ESA projects and programmes
- **R&D** and harmonisation programmes:
  - thermal design and hardware products
  - thermal analysis (software) tools and methodologies
  - analysis and verification methods
- Mechanical Systems Laboratory
  e.g. thermal cycling / thermal balance, vibrations, thermal conductivity, MLI, CTE
- Two sections (**Thermal Control, Thermal Analysis and Verification**)
- Around 35 thermal engineers + trainees



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Other events

7th European Space Cryogenics Workshop

4-6 April 2018, ESA/ESTEC

- Deadline for submitting abstracts: 16th February 2018
- Contact: thierry.tirolien@esa.int

15th European Conference on Spacecraft Structures, Materials & Environmental Testing

28 May - 1 June 2018, ESA/ESTEC

Deadline for submitting abstracts: 1 December 2017

48th International Conference on Environmental Systems (ICES)

8-12 July 2018, Albuquerque, New Mexico, USA.

- Deadline for submitting abstracts: 19 November 2017
- For details see: https://www.ices.space

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Other events

Space Engineering and Technology Final Presentation Days

21-22 November 2017, ESA/ESTEC

Extract of the programme for 21 Nov:

Assessment of materials and processes design margins for spacecraft and launchers	Shumit Das (TEC-QEE)
Breadboard development for in-orbit demonstration of additive layer manufacturing technologies	Ugo Lafont (TEC-QEE)
2-stage cooler for detector cooling between 30K and 50K	Thierry Tirolien (TEC-MTT)
Passive by-pass valve for single and two phase mechanical pumped fluid loops	Stephane Lapensee (TEC-MTT)
Deployable & Inflatable Heatshield & Hypersonic Decelerator Concepts - Phase 1	Heiko Ritter (TEC-MTT)
Development of a rigid conformal ablator for extreme heat flux applications	Heiko Ritter (TEC-MTT)
``ReGS``: A resistive grid TPS recession sensor	Heiko Ritter (TEC-MTT)
Calibration in a traceable manner of a radiometer (Kendall type) used for 10 solar constants and above	Alessandro Cozzani (TEC-MXE)

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Building on the success of our Workshop!

ESA Thermal Division will organise **from 30 October to 1 November 2018** a

European Space Thermal Engineering Workshop

(combined with our usual 32nd European Space Thermal Analysis Workshop)

- Same approach (workshop, networking, opportunities for exchange, dinner) & one extra day to cover even **more thermal topics** such as:
  - thermal design (for platforms, instruments etc.)
  - thermal analysis and S/W (in-line with the current event)
  - thermal testing
  - (generic) thermal control technologies
  - two-phase heat transport technology
  - interfaces between TPS and thermal control
  - thermal technologies and methodologies related to small satellites and CubeSats
- First announcement expected for mid November and please mark it in your agendas!

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esa
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Benoit Laine
Head of Thermal Analysis & Verification Section
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Thermal/Heat Transport Engineer
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Thermal Analysis Engineer
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Stéphane Roure – Mechanical Systems Laboratory
Mechanical Verification Engineer
Stephane.Roure@esa.int
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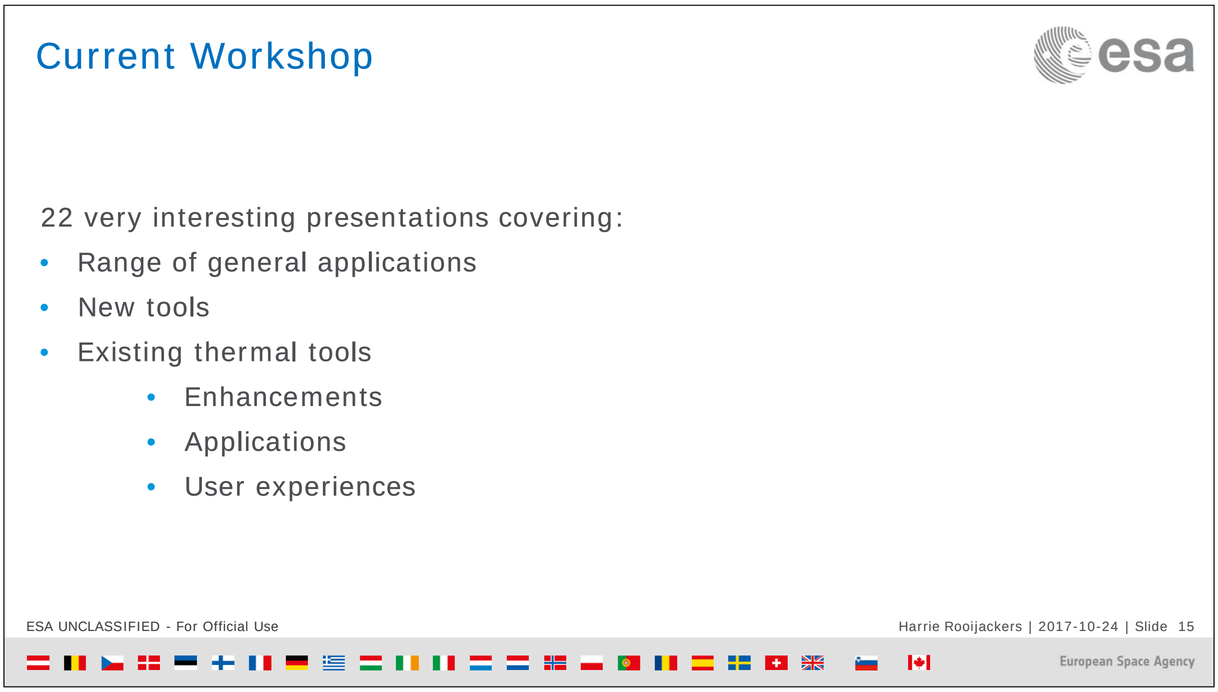
Europe from space:
borderless
esa
United Space in Europe


Current Workshop
esa
22 very interesting presentations covering:
• Range of general applications
• New tools
• Existing thermal tools
• Enhancements
• Applications
• User experiences
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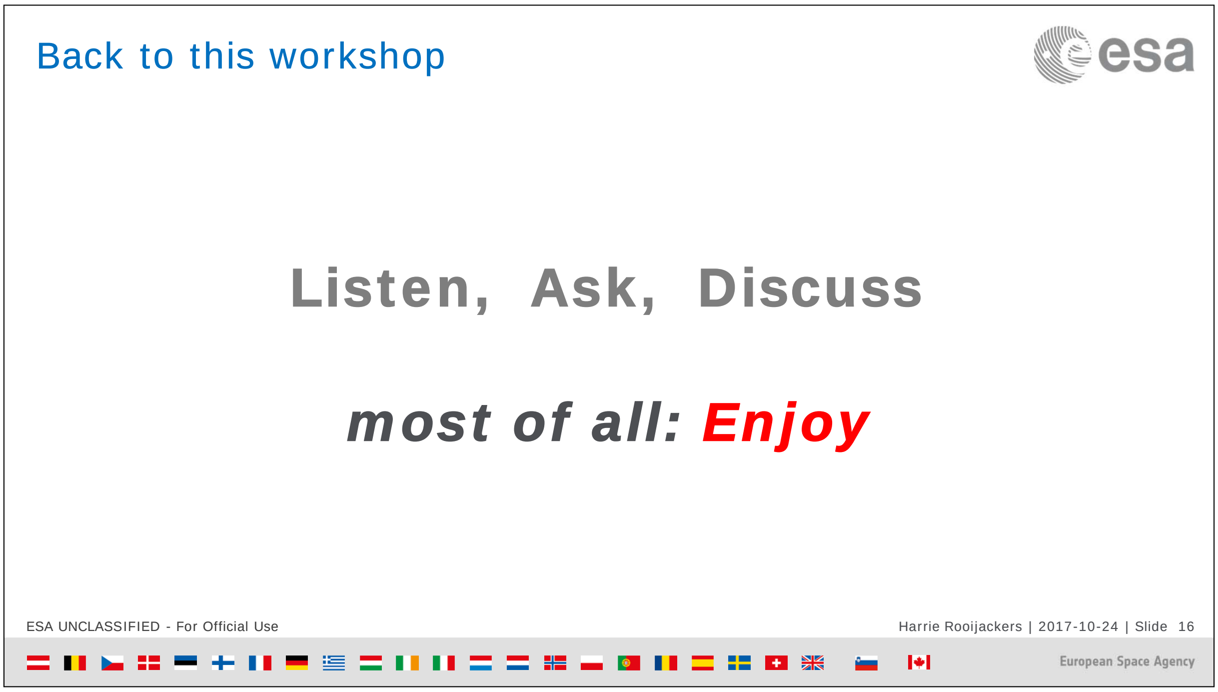
Back to this workshop
esa
Listen, Ask, Discuss
most of all: Enjoy
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Appendix B

A proposition for updating the environmental standards using real Earth Albedo and Earth IR Flux for Spacecraft Thermal Analysis

Romain Peyrou-Lauga
(ESA/ESTEC, The Netherlands)

Abstract

This presentation aims at recreating a link between real Earth Albedo and Earth IR Flux measurement (by CERES instruments) and Earth environment assumptions used for Earth orbiting spacecraft thermal analysis. It will compare the common Earth albedo and Earth Infrared flux hypotheses (coming from the standards, and past or current projects) with the real measured Earth radiated energy. From such comparison, one can assess if the current hypotheses cover properly the reality or how to quantify the margin potentially contained in these usual assumptions. As an ultimate goal, this presentation will open the discussion whether the usual hypotheses need to be updated.


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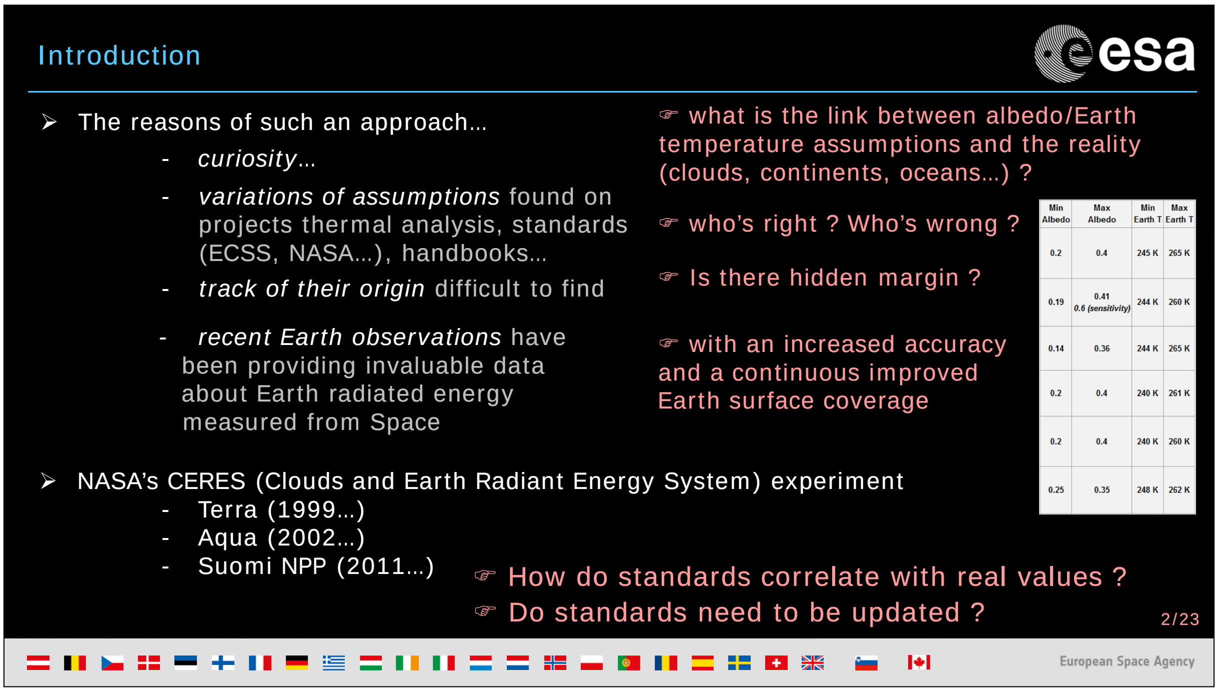
Using real Earth Albedo
and Earth IR Flux
for Spacecraft Thermal Analysis
Romain Peyrou-Lauga
ESA UNCLASSIFIED - For Official Use
ESTEC Thermal Workshop, 24 Oct. 2017
European Space Agency


Introduction
esa
The reasons of such an approach…
- curiosity…
- variations of assumptions found on projects thermal analysis, standards (ECSS, NASA…), handbooks…
- track of their origin difficult to find
- recent Earth observations have been providing invaluable data about Earth radiated energy measured from Space
what is the link between albedo/Earth temperature assumptions and the reality (clouds, continents, oceans…) ?
who's right ? Who's wrong ?
Is there hidden margin ?
with an increased accuracy and a continuous improved Earth surface coverage
Min Albedo | Max Albedo | Min Earth T | Max Earth T
0.2 | 0.4 | 245 K | 265 K
0.19 | 0.41 0.6 (sensitivity) | 244 K | 260 K
0.14 | 0.36 | 244 K | 265 K
0.2 | 0.4 | 240 K | 261 K
0.2 | 0.4 | 240 K | 260 K
0.25 | 0.35 | 248 K | 262 K
NASA's CERES (Clouds and Earth Radiant Energy System) experiment
- Terra (1999…)
- Aqua (2002…)
- Suomi NPP (2011…)
How do standards correlate with real values ?
Do standards need to be updated ?
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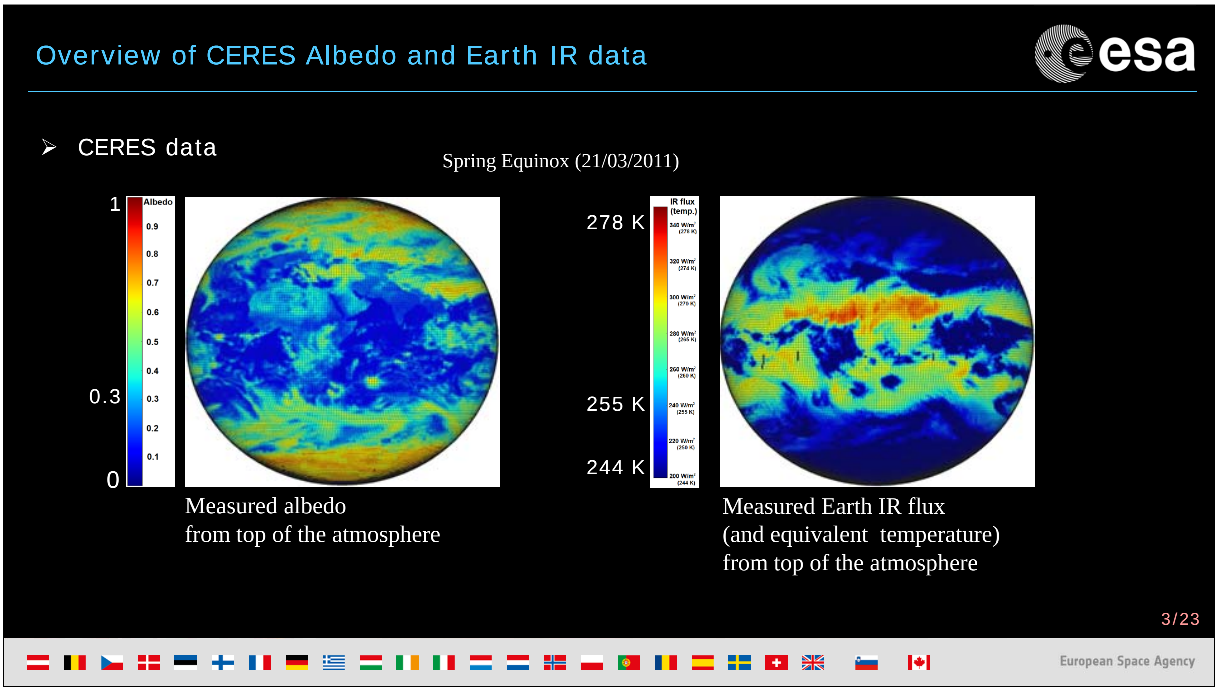
Overview of CERES Albedo and Earth IR data
esa
CERES data
Spring Equinox (21/03/2011)
1
Albedo
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.3
0
278 K
255 K
244 K
IR flux (temp.)
Measured albedo
from top of the atmosphere
Measured Earth IR flux
(and equivalent temperature)
from top of the atmosphere
3/23
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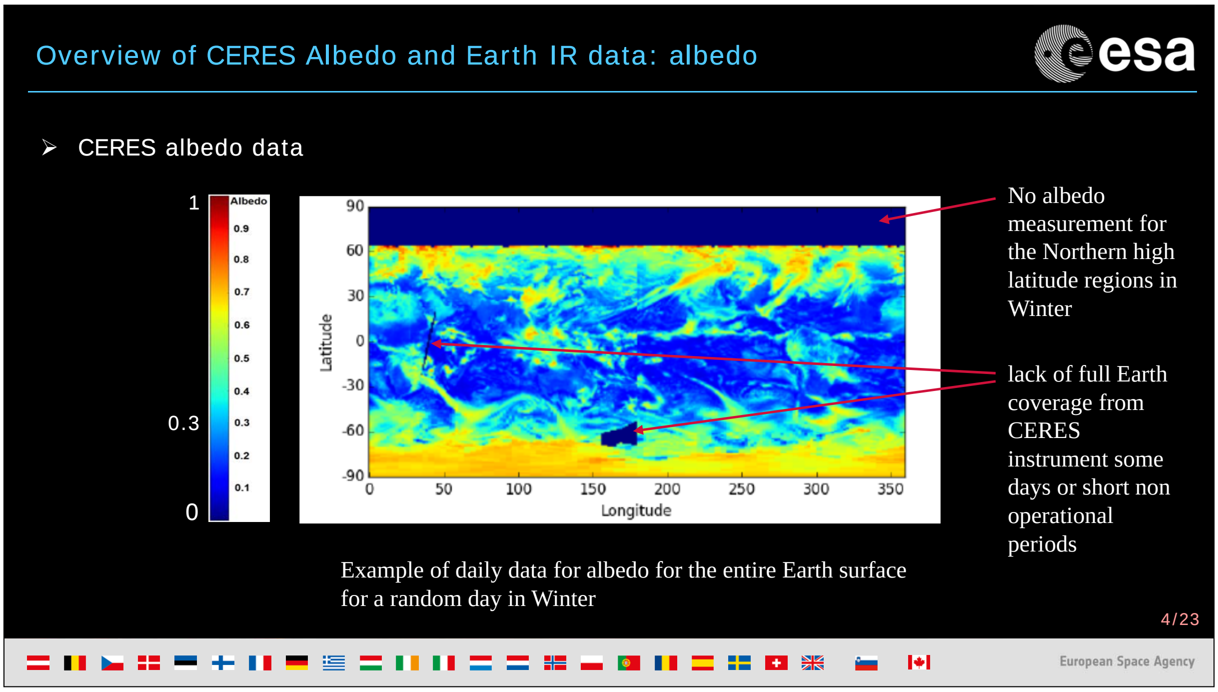
Overview of CERES Albedo and Earth IR data: albedo
esa
CERES albedo data
1
Albedo
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.3
0
90
60
30
0
-30
-60
-90
Latitude
0
50
100
150
200
250
300
350
Longitude
No albedo measurement for the Northern high latitude regions in Winter
lack of full Earth coverage from CERES instrument some days or short non operational periods
Example of daily data for albedo for the entire Earth surface
for a random day in Winter
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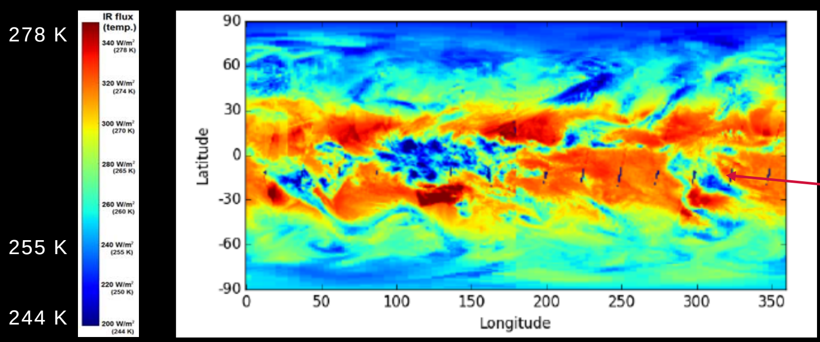
Overview of CERES Albedo and Earth IR data: albedo

- CERES Infra-Red flux data



lack of full Earth coverage from CERES instrument some days or short non operational periods

Example of daily data for Infra-Red for the entire Earth surface for a random day in Winter

5/23

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1st step: Average monthly albedo and Earth IR flux: albedo

- 5 years of data (from 01/01/2007 to 31/12/2011)
- Repeatability from a year to another can be checked

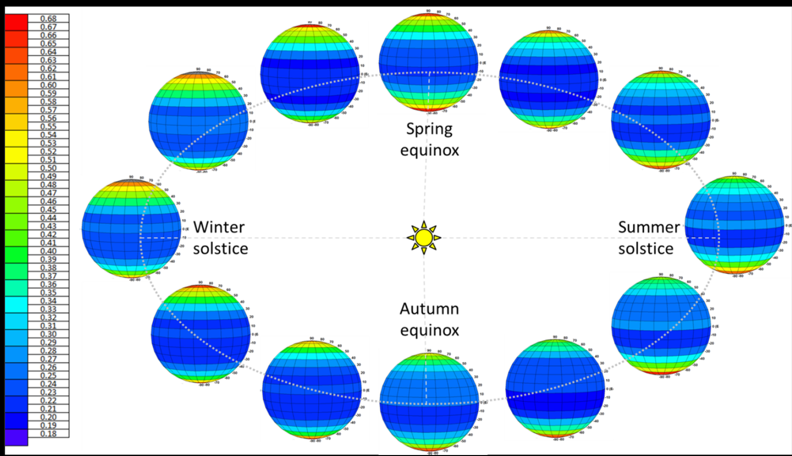
Average Latitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	*Ave. over 2007*	*Ave. over 2008*	*Ave. over 2009*	*Ave. over 2010*	*Ave. over 2011*	Average over 5-year
85°	nan	nan	0.64	0.62	0.62	0.57	0.50	0.52	0.58	0.65	nan	nan	*0.59*	*0.58*	*0.59*	*0.59*	*0.58*	**0.59**
75°	nan	0.66	0.62	0.60	0.58	0.49	0.43	0.44	0.49	0.57	0.65	nan	*0.55*	*0.55*	*0.55*	*0.55*	*0.55*	**0.55**
65°	0.59	0.55	0.53	0.51	0.45	0.38	0.36	0.38	0.42	0.50	0.56	0.59	*0.49*	*0.49*	*0.48*	*0.48*	*0.49*	**0.49**
55°	0.50	0.48	0.44	0.39	0.37	0.35	0.35	0.36	0.37	0.41	0.48	0.51	*0.42*	*0.42*	*0.42*	*0.42*	*0.42*	**0.42**
45°	0.45	0.42	0.38	0.34	0.33	0.32	0.31	0.30	0.30	0.34	0.40	0.45	*0.36*	*0.36*	*0.36*	*0.37*	*0.36*	**0.36**
35°	0.36	0.35	0.32	0.30	0.28	0.27	0.25	0.24	0.26	0.28	0.32	0.36	*0.30*	*0.29*	*0.30*	*0.30*	*0.30*	**0.30**
25°	0.28	0.26	0.25	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.26	0.28	*0.25*	*0.25*	*0.25*	*0.25*	*0.25*	**0.25**
15°	0.22	0.20	0.20	0.20	0.21	0.23	0.25	0.25	0.25	0.23	0.23	0.23	*0.22*	*0.22*	*0.22*	*0.22*	*0.23*	**0.22**
5°	0.24	0.22	0.22	0.23	0.25	0.26	0.26	0.25	0.25	0.24	0.25	0.25	*0.24*	*0.24*	*0.24*	*0.25*	*0.25*	**0.24**
-5°	0.24	0.23	0.22	0.22	0.21	0.21	0.21	0.21	0.21	0.22	0.23	0.23	*0.22*	*0.22*	*0.22*	*0.22*	*0.22*	**0.22**
-15°	0.23	0.23	0.21	0.20	0.20	0.21	0.21	0.21	0.21	0.22	0.23	0.23	*0.22*	*0.21*	*0.22*	*0.22*	*0.22*	**0.22**
-25°	0.22	0.21	0.22	0.23	0.25	0.26	0.25	0.23	0.23	0.23	0.23	0.23	*0.23*	*0.23*	*0.23*	*0.24*	*0.23*	**0.23**
-35°	0.24	0.25	0.26	0.29	0.31	0.33	0.32	0.30	0.29	0.27	0.27	0.26	*0.28*	*0.28*	*0.28*	*0.28*	*0.28*	**0.28**
-45°	0.32	0.33	0.35	0.37	0.40	0.41	0.40	0.37	0.35	0.33	0.33	0.33	*0.36*	*0.36*	*0.36*	*0.36*	*0.36*	**0.36**
-55°	0.40	0.40	0.42	0.45	0.48	0.51	0.49	0.46	0.44	0.41	0.41	0.40	*0.44*	*0.44*	*0.44*	*0.44*	*0.44*	**0.44**
-65°	0.49	0.49	0.51	0.55	0.60	0.61	0.64	0.63	0.61	0.59	0.55	0.51	*0.56*	*0.57*	*0.57*	*0.57*	*0.57*	**0.57**
-75°	0.63	0.64	0.65	0.68	0.74	nan	nan	0.73	0.70	0.69	0.66	0.64	*0.68*	*0.67*	*0.68*	*0.67*	*0.67*	**0.68**
-85°	0.67	0.68	0.69	0.74	nan	nan	nan	nan	0.72	0.70	0.68	0.67	*0.69*	*0.69*	*0.69*	*0.69*	*0.69*	**0.69**
Total	**0.32**	**0.32**	**0.32**	**0.31**	**0.31**	**0.30**	**0.30**	**0.30**	**0.31**	**0.31**	**0.32**	**0.32**	*0.31*	*0.31*	*0.31*	*0.31*	*0.31*	**0.31**

☞ *Data published:*
Ref. : Earth Albedo and Earth IR Temperature definition based on CERES measurements (ESA-TECMTT-TN-001975)

6/23

European Space Agency

1st step: Average monthly albedo and Earth IR flux: albedo



7/23

European Space Agency

1st step: Average monthly albedo and Earth IR flux: Earth temperature

- 5 years of data (from 01/01/2007 to 31/12/2011)
- Repeatability from a year to another can be checked

Average Latitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	*Ave. over 2007*	*Ave. over 2008*	*Ave. over 2009*	*Ave. over 2010*	*Ave. over 2011*	Average over 5-year
85°	233	236	235	241	247	251	252	250	245	240	236	234	*242*	*242*	*242*	*242*	*242*	**242**
75°	235	236	237	242	248	251	253	251	247	242	238	236	*243*	*243*	*243*	*244*	*243*	**243**
65°	237	238	241	245	249	253	254	252	249	244	240	237	*245*	*245*	*245*	*245*	*245*	**245**
55°	241	242	244	248	251	253	255	254	251	248	244	242	*248*	*248*	*248*	*248*	*248*	**248**
45°	245	246	247	250	253	256	258	259	257	252	249	246	*252*	*252*	*251*	*251*	*252*	**252**
35°	251	251	253	254	257	259	262	262	261	258	255	252	*257*	*257*	*256*	*256*	*256*	**256**
25°	261	261	262	262	262	262	262	262	262	263	262	261	*262*	*262*	*262*	*262*	*262*	**262**
15°	264	265	265	263	261	258	256	255	256	259	261	263	*261*	*261*	*261*	*261*	*260*	**261**
5°	258	259	258	255	254	254	254	255	255	255	256	257	*256*	*255*	*256*	*256*	*256*	**256**
-5°	255	255	255	256	259	261	261	262	261	260	258	257	*258*	*258*	*258*	*258*	*259*	**258**
-15°	257	257	259	262	264	265	265	266	265	263	260	258	*262*	*262*	*262*	*262*	*262*	**262**
-25°	261	262	262	261	261	260	262	262	262	261	260	260	*261*	*261*	*261*	*261*	*261*	**261**
-35°	260	260	259	257	255	254	254	255	255	256	256	258	*257*	*256*	*256*	*257*	*257*	**257**
-45°	254	254	253	251	250	249	248	249	249	251	252	253	*251*	*251*	*251*	*251*	*251*	**251**
-55°	249	249	248	246	245	244	243	243	244	246	247	249	*246*	*246*	*246*	*246*	*246*	**246**
-65°	247	246	244	241	239	237	237	236	238	241	244	246	*242*	*241*	*242*	*241*	*241*	**241**
-75°	244	240	235	230	228	225	224	224	226	231	238	243	*233*	*232*	*233*	*232*	*233*	**233**
-85°	242	236	229	224	222	219	218	216	219	226	235	242	*228*	*228*	*228*	*228*	*228*	**228**
Average	**254**	**254**	**254**	**254**	**255**	**255**	**256**	**256**	**255**	**255**	**254**	**254**	*255*	*255*	*255*	*255*	*255*	**255**

☞ *Data published:*
Ref. : Earth Albedo and Earth IR Temperature definition based on CERES measurements (ESA-TECMTT-TN-001975)

8/23

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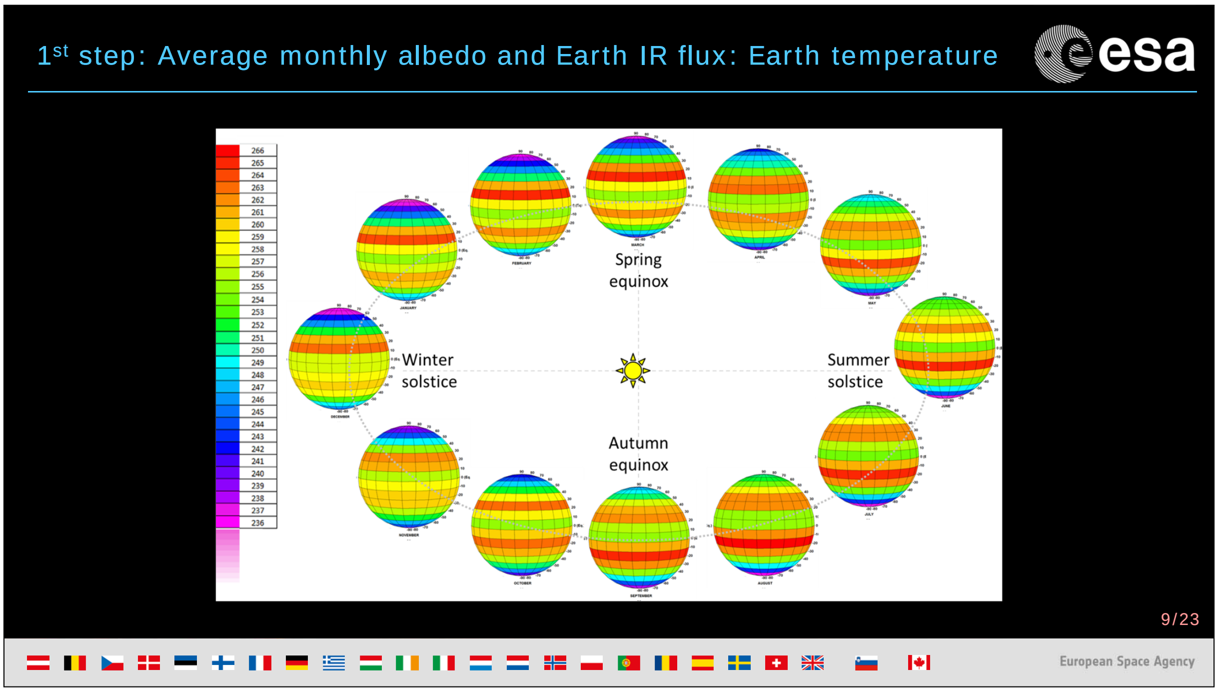
1st step: Average monthly albedo and Earth IR flux: Earth temperature
esa
Spring equinox
Winter solstice
Summer solstice
Autumn equinox
266
265
264
263
262
261
260
259
258
257
256
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9/23
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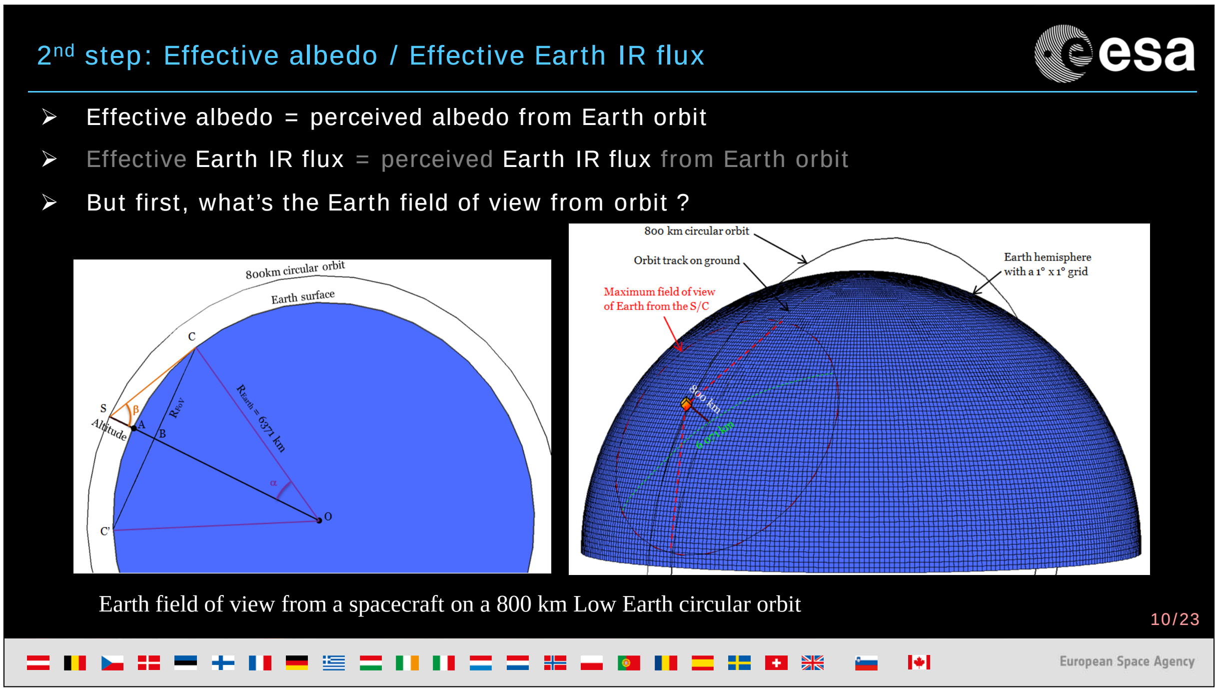
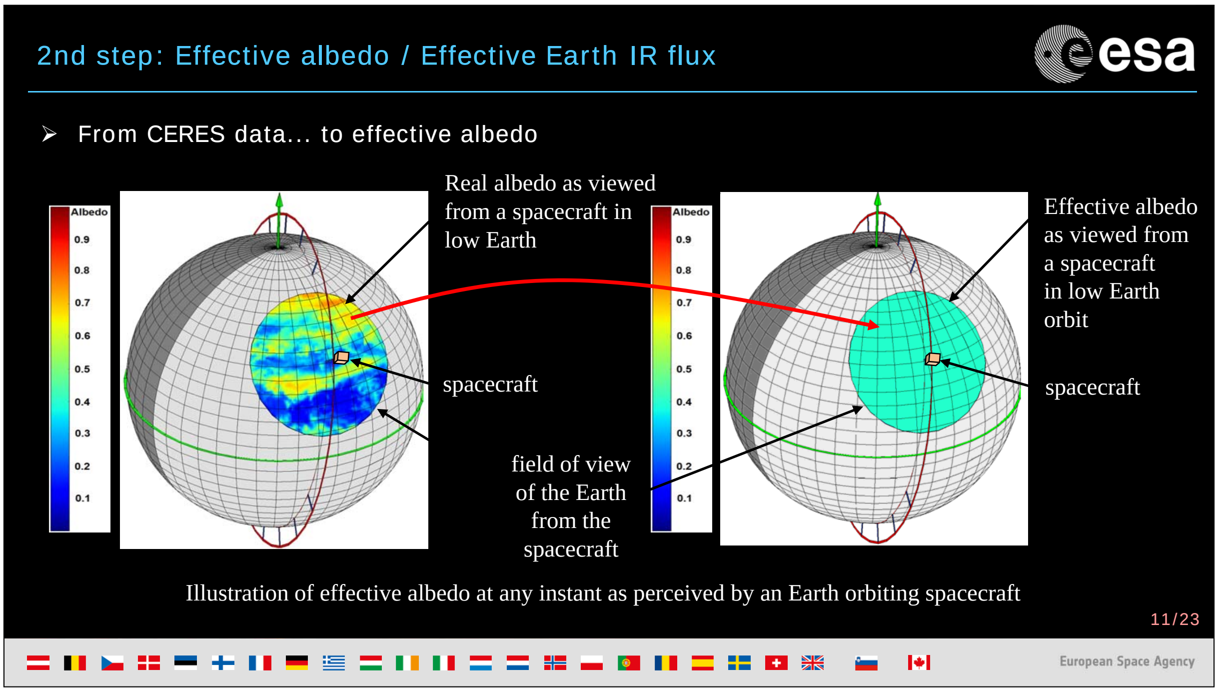
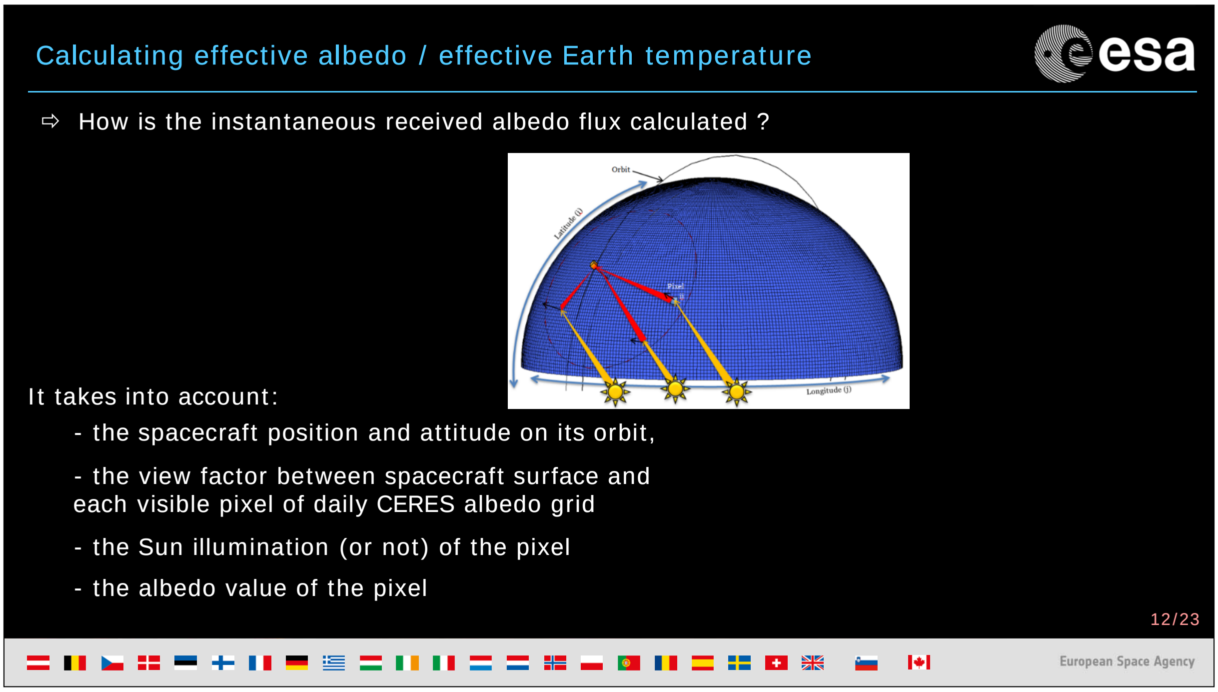
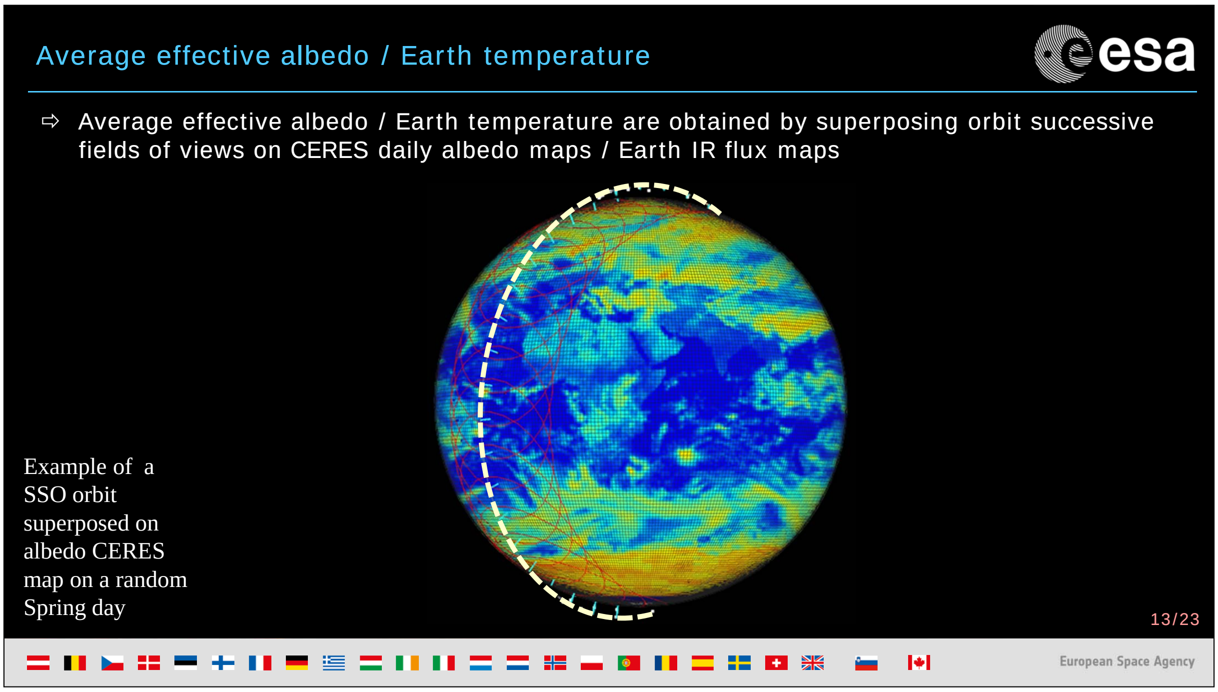
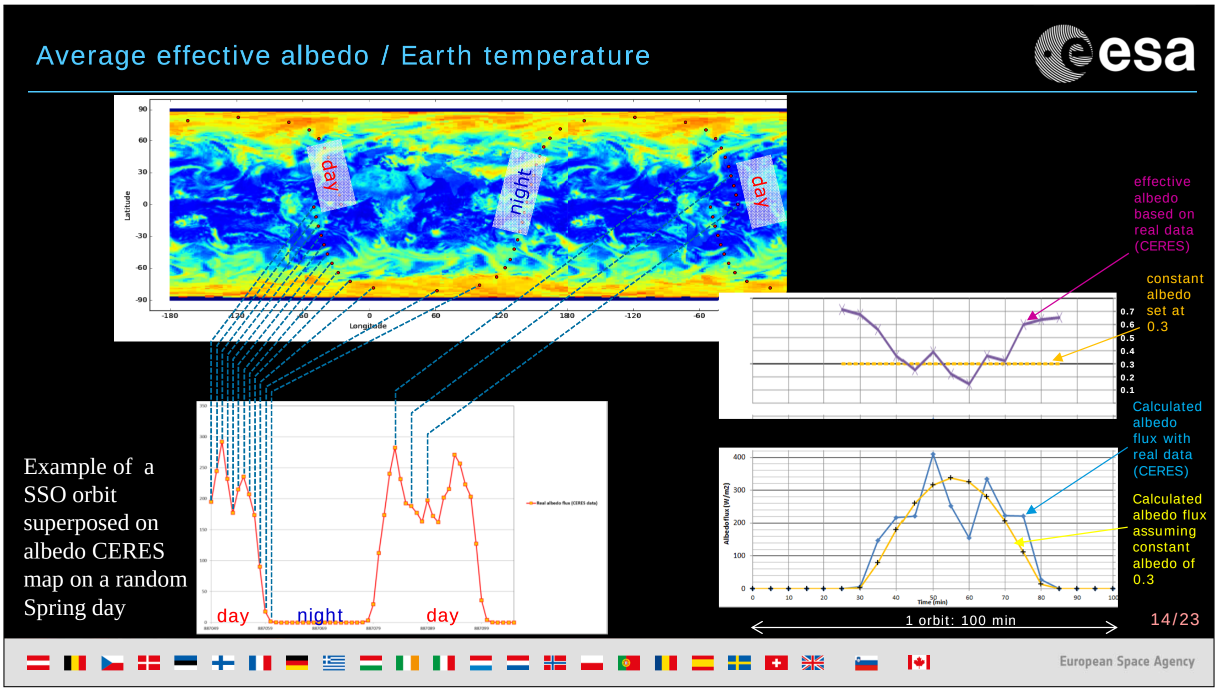

2nd step: Effective albedo / Effective Earth IR flux
esa
➢ Effective albedo = perceived albedo from Earth orbit
➢ Effective Earth IR flux = perceived Earth IR flux from Earth orbit
➢ But first, what's the Earth field of view from orbit ?
800km circular orbit
Earth surface
C
S
Altitude
A
B
O
C'
R_{earth} = 6371 km
800 km circular orbit
Orbit track on ground
Earth hemisphere with a 1° x 1° grid
Maximum field of view of Earth from the S/C
800 km
Earth field of view from a spacecraft on a 800 km Low Earth circular orbit
10/23
European Space Agency


2nd step: Effective albedo / Effective Earth IR flux
esa
➢ From CERES data... to effective albedo
Albedo
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Real albedo as viewed from a spacecraft in low Earth
spacecraft
field of view of the Earth from the spacecraft
Effective albedo as viewed from a spacecraft in low Earth orbit
spacecraft
Illustration of effective albedo at any instant as perceived by an Earth orbiting spacecraft
11/23
European Space Agency


Calculating effective albedo / effective Earth temperature
esa
⇨ How is the instantaneous received albedo flux calculated ?
It takes into account:
- the spacecraft position and attitude on its orbit,
- the view factor between spacecraft surface and each visible pixel of daily CERES albedo grid
- the Sun illumination (or not) of the pixel
- the albedo value of the pixel
12/23
European Space Agency


Average effective albedo / Earth temperature
esa
⇨ Average effective albedo / Earth temperature are obtained by superposing orbit successive fields of views on CERES daily albedo maps / Earth IR flux maps
Example of a SSO orbit superposed on albedo CERES map on a random Spring day
13/23
European Space Agency


Average effective albedo / Earth temperature
esa
day
night
day
Latitude
Longitude
effective albedo based on real data (CERES)
constant albedo set at 0.3
Calculated albedo flux with real data (CERES)
Calculated albedo flux assuming constant albedo of 0.3
Example of a SSO orbit superposed on albedo CERES map on a random Spring day
day
night
day
Albedo flux (W/m2)
Time (min)
1 orbit: 100 min
14/23
European Space Agency

Average orbital effective albedo and Earth IR flux for various orbits

⇨ Synthesis of average effective albedo / Earth temperature over an orbit for several LEO orbits

Type of orbit	Altitude	Inclination	LTAN	Range of average albedo over 1 orbit	Range of average Earth temperature over 1 orbit
SSO	800 km	98.6°	06:00	0.25 – 0.40	246 K – 256 K
			12:00	0.25 – 0.40	246 K – 256 K
			18:00	0.25 – 0.40	246 K – 256 K
			20:00	0.24 – 0.40	246 K – 256 K
			21:00	0.25 – 0.40	246 K – 256 K
			22:00	0.25 – 0.40	246 K – 256 K
ISS	400 km	51.6°	drifting	0.19 – 0.40	250 K – 260 K
Tropical	800 km	20°	drifting	0.16 – 0.34	253 K – 264 K
Equatorial	800 km	6°	drifting	0.15 – 0.31	253 K – 260 K

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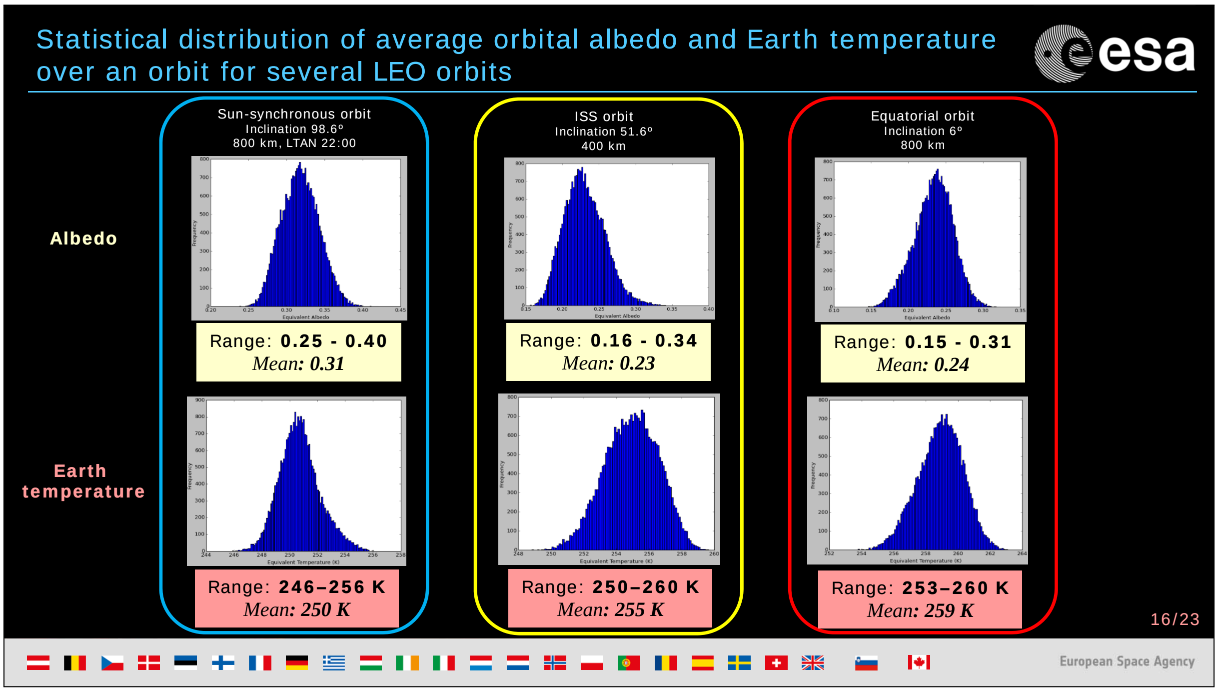
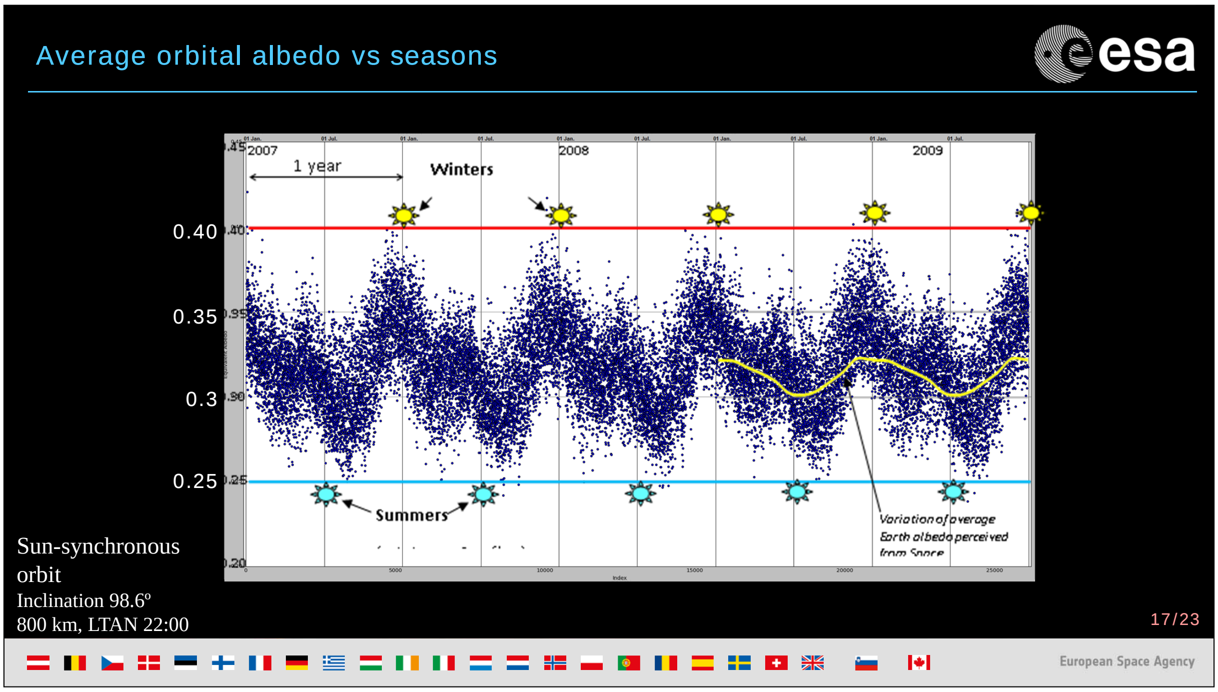
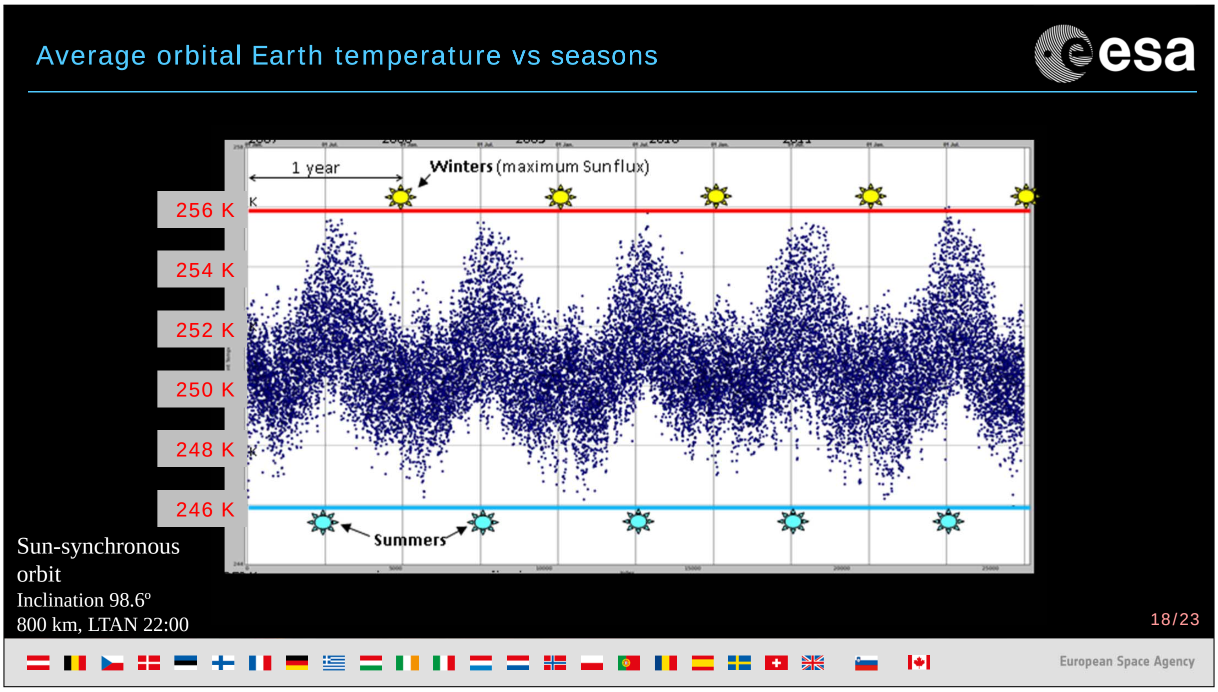
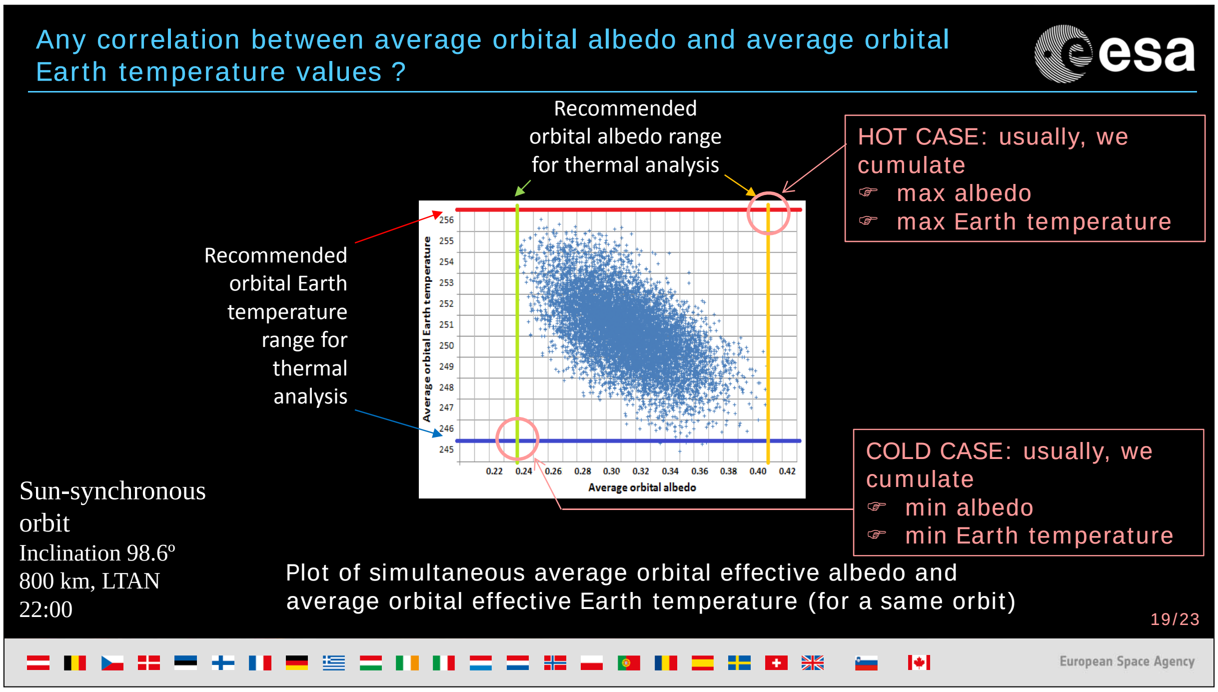
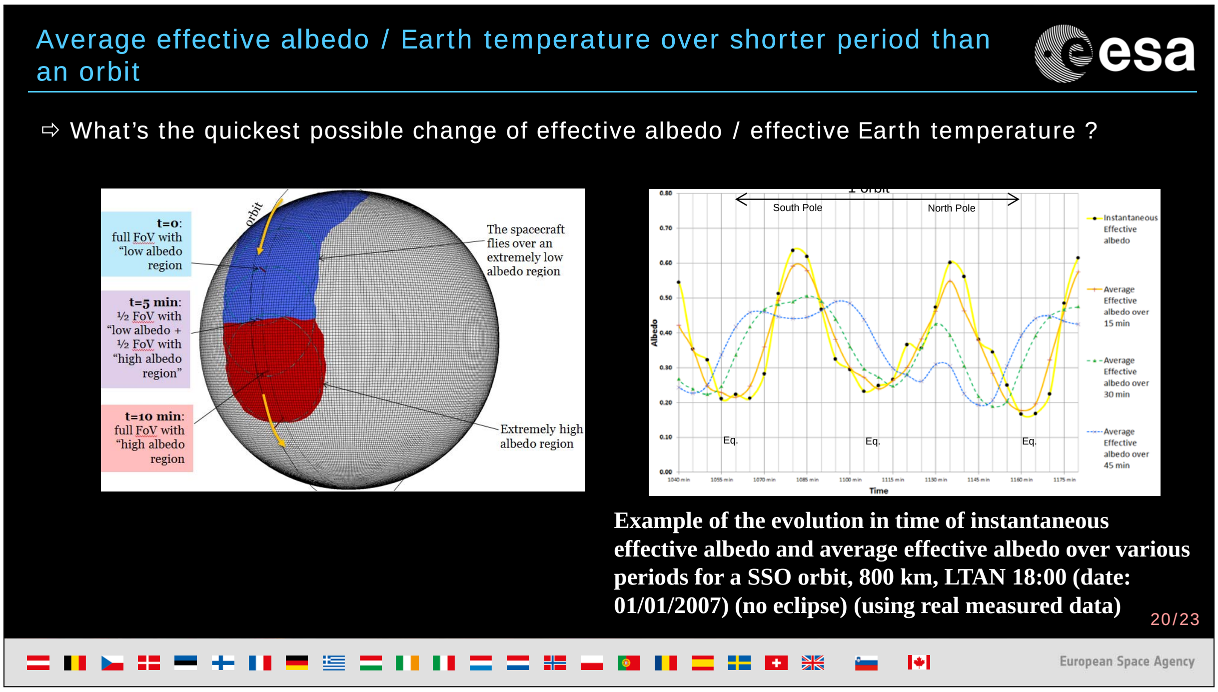


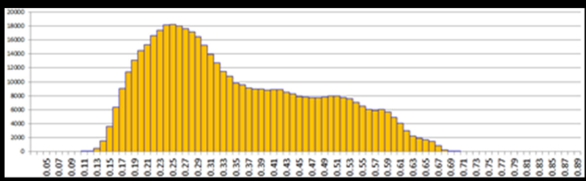

Average orbital albedo vs seasons
esa
2007
2008
2009
1 year
Winters
0.40
0.35
0.3
0.25
Summers
Variation of average Earth albedo perceived from Space
Sun-synchronous orbit
Inclination 98.6º
800 km, LTAN 22:00
17/23
European Space Agency


Average orbital Earth temperature vs seasons
esa
1 year
Winters (maximum Sun flux)
256 K
254 K
252 K
250 K
248 K
246 K
Summers
Sun-synchronous orbit
Inclination 98.6º
800 km, LTAN 22:00
18/23
European Space Agency

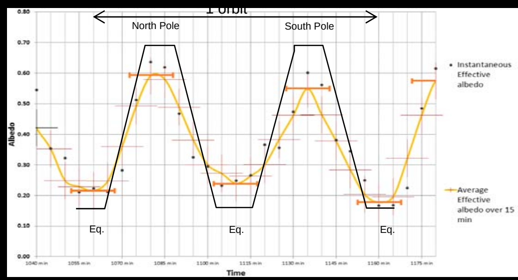

Any correlation between average orbital albedo and average orbital Earth temperature values ?
Recommended orbital albedo range for thermal analysis
HOT CASE: usually, we cumulate
max albedo
max Earth temperature
Recommended orbital Earth temperature range for thermal analysis
Average orbital Earth temperature
Average orbital albedo
COLD CASE: usually, we cumulate
min albedo
min Earth temperature
Sun-synchronous orbit
Inclination 98.6º
800 km, LTAN 22:00
Plot of simultaneous average orbital effective albedo and average orbital effective Earth temperature (for a same orbit)
19/23
European Space Agency


Average effective albedo / Earth temperature over shorter period than an orbit
⇨ What's the quickest possible change of effective albedo / effective Earth temperature ?
t=0: full FoV with "low albedo region
t=5 min: ½ FoV with "low albedo + ½ FoV with "high albedo region"
t=10 min: full FoV with "high albedo region
orbit
The spacecraft flies over an extremely low albedo region
Extremely high albedo region
South Pole
North Pole
Eq.
Albedo
Time
Instantaneous Effective albedo
Average Effective albedo over 15 min
Average Effective albedo over 30 min
Average Effective albedo over 45 min
Example of the evolution in time of instantaneous effective albedo and average effective albedo over various periods for a SSO orbit, 800 km, LTAN 18:00 (date: 01/01/2007) (no eclipse) (using real measured data)
20/23
European Space Agency

Variation of short term average albedo / Earth temperature values



Distribution of average effective albedo over a period of 15 min for a SSO orbit, 800 km, LTAN 18:00 (using real measured data from 2007 to 2011 (CERES mission))



Worst case profile of the evolution of average effective albedo over various periods for an SSO orbit, 800 km, LTAN 18:00

☞ Already used
Ref. : Definition of Earth thermal environment for TIRI (Thermal Infra-Red Instrument) mission (ESA-TECMTT-TN-004247)

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Conclusion

- clear link between real observations and assumptions used for spacecraft thermal analysis.
- provide useful and realistic inputs to simulate Earth environment, including finding worst cases of thermal conditions changes, which are mainly needed for temperature stability of sensitive instrument or radiators.
- Recommended albedo and Earth temperature over an orbit for the main LEO orbits:

Type of orbit	Altitude	Inclination	LTAN	Range of average albedo over 1 orbit	Range of average Earth temperature over 1 orbit
SSO	650 km - 850 km	~98-99°	any	0.24 – 0.40	246 K – 256 K
ISS	400 km	51.6°	drifting	0.19 – 0.40	250 K – 260 K
Tropical	800 km	20°	drifting	0.16 – 0.34	253 K – 264 K
Equatorial	800 km	6°	drifting	0.15 – 0.31	253 K – 260 K

- Future activities: developing the tool with a more statistical approach covering a larger range of orbits
- Proposing standard update for albedo and IR Earth temperature

22/23

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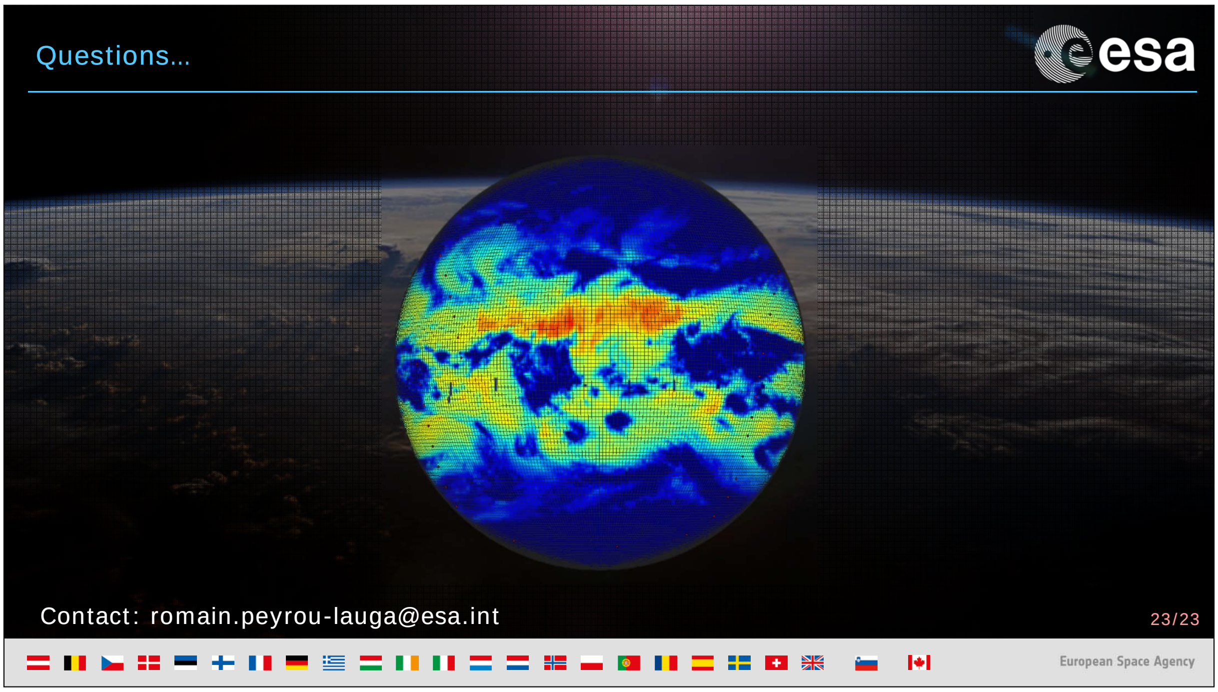

Questions...
esa
Contact: romain.peyrou-lauga@esa.int
23/23
European Space Agency

Appendix C

JUICE Thermal Analysis Challenges

Alejo Ares
(Airbus Toulouse, France)

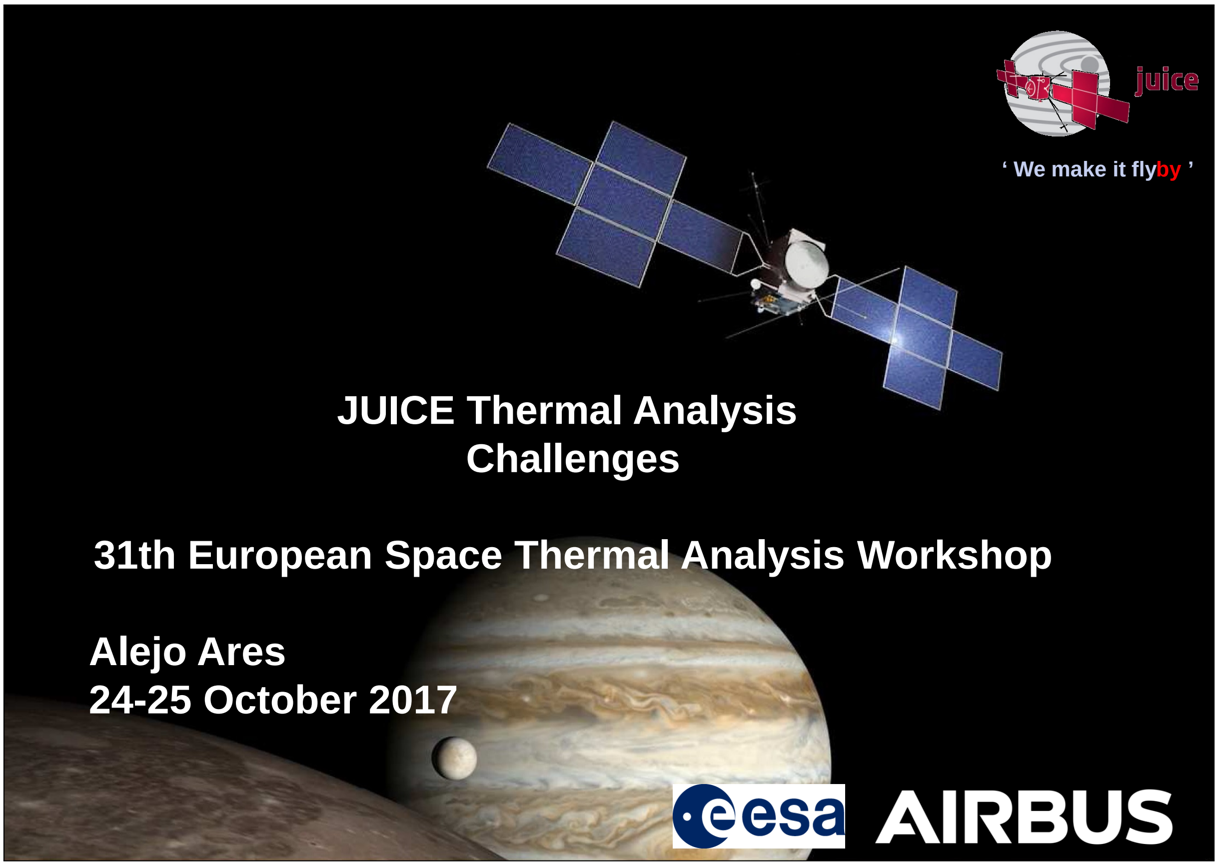
Abstract

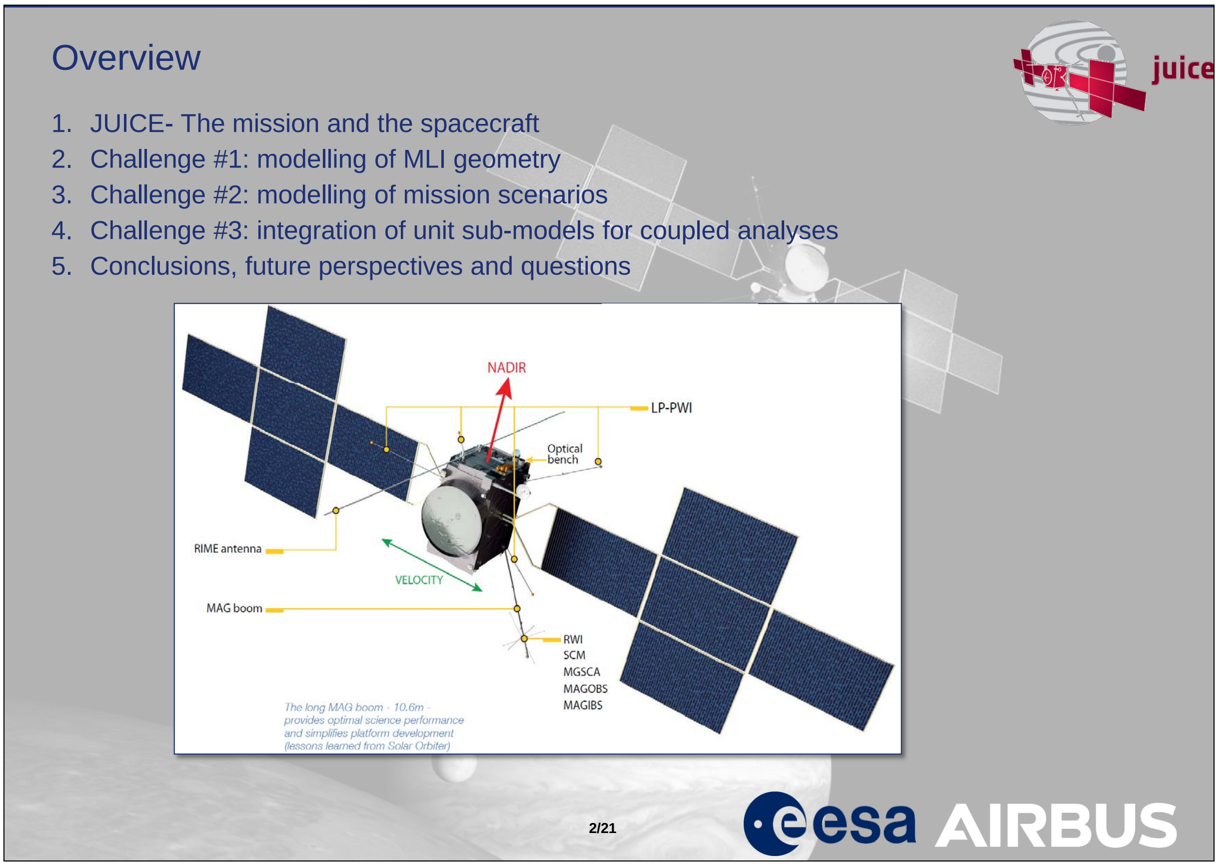
JUICE - JUpiter ICy moons Explorer - is the first large-class mission in ESA's Cosmic Vision 2015- 2025 programme. The spacecraft will explore the Jovian system focusing on Jupiter and three of its Galilean moons: Ganymede, Callisto, and Europa. Detailed investigations will be conducted on Ganymede, as a planetary body potentially able to support life. The mission also plans fly-bys of Europa and Callisto to complete a comparative study of Galilean moons. A total of ten state-of-the-art instruments will be carried on the spacecraft to address all mission objectives.

The system-level thermal analysis of the whole spacecraft is being carried out by Airbus Defence and Space, the mission prime contractor. Several challenges are faced, including:

- The accurate modelling of the S/C trajectory and thermal environment during planetary and Jovian Moon fly-bys.
- The modelling of a critical and complex MLI blanket geometry, which will be validated through a dedicated and specific Thermal Development Model (TDM) test.
- The management of dissipation timelines for the equipment and instruments.
- The integration of instruments and units thermal models from new actors in European space thermal engineering, and coupled instrument analyses supporting trade-off studies.

This presentation will describe these challenges and the methods and tools used to deal with them.


juice
‘ We make it flyby ’
JUICE Thermal Analysis
Challenges
31th European Space Thermal Analysis Workshop
Alejo Ares
24-25 October 2017
esa
AIRBUS


Overview
juice
1. JUICE- The mission and the spacecraft
2. Challenge #1: modelling of MLI geometry
3. Challenge #2: modelling of mission scenarios
4. Challenge #3: integration of unit sub-models for coupled analyses
5. Conclusions, future perspectives and questions
NADIR
LP-PWI
Optical bench
RIME antenna
VELOCITY
MAG boom
RWI
SCM
MGSCA
MAGOBS
MAGIBS
The long MAG boom - 10.6m - provides optimal science performance and simplifies platform development (lessons learned from Solar Orbiter)
2/21
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AIRBUS

JUICE – The mission (1/3)

- JUpiter ICy moons Explorer
- First large-class mission in ESA's Cosmic Vision 2015-2025
- *"The objective of the JUICE mission is the investigation of Jupiter and its icy moons, Callisto, Ganymede and Europa. It addresses the question of whether possible habitats of life are provided underneath the surfaces of the icy satellites as well as Jupiter's atmosphere & magnetosphere"*

Characterize the Jovian atmosphere & magnetosphere.	Jupiter tour (with especially the Jupiter high latitudes phase) & orbits around Ganymede
Study the Jovian satellites and ring system.	
Explore Europa's recently active zones.	Europa fly-bys
Characterize Ganymede as a planetary object and a possible habitat.	Ganymede fly-bys / Elliptical & circulars orbit around Ganymede
Study Callisto as a remnant of the early Jovian system.	Callisto fly-bys

- 10 state-of-the art instruments carried + 1 ground-based experiment
- Tour of Jovian system: Jovian tour with flybys (Europa, Callisto) + orbital observation of Ganymede
- Preliminary Design Review successful (March 2017)
- **Launch date: 20th May 2022**

Mission | Spacecraft | MLI | Scenarios | Models | Conclusion

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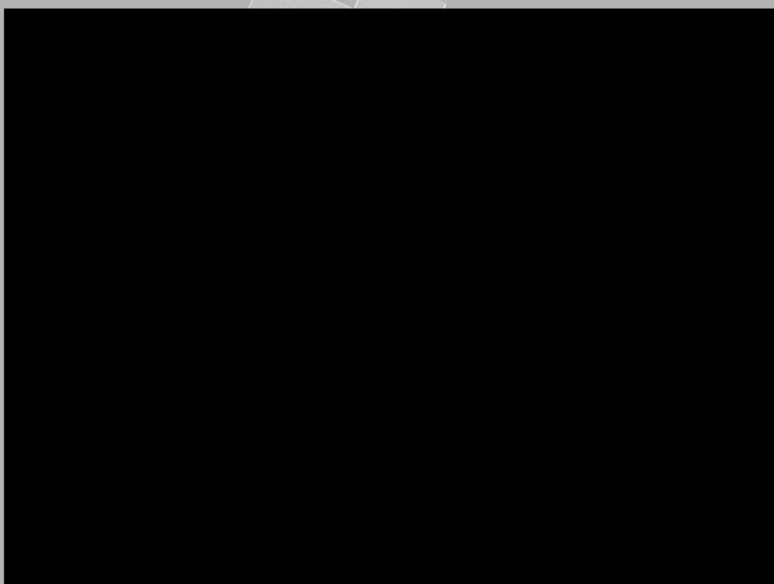
JUICE – The mission (2/3)

A small appetizer…



Mission | Spacecraft | MLI | Scenarios | Models | Conclusion

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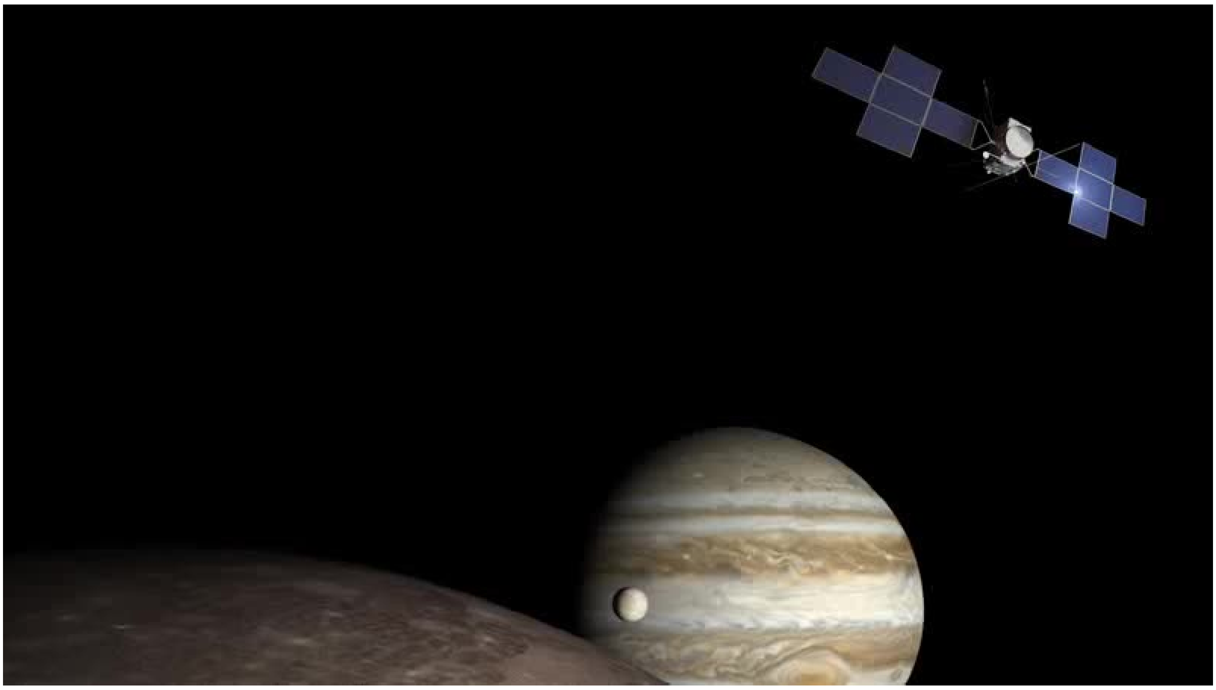
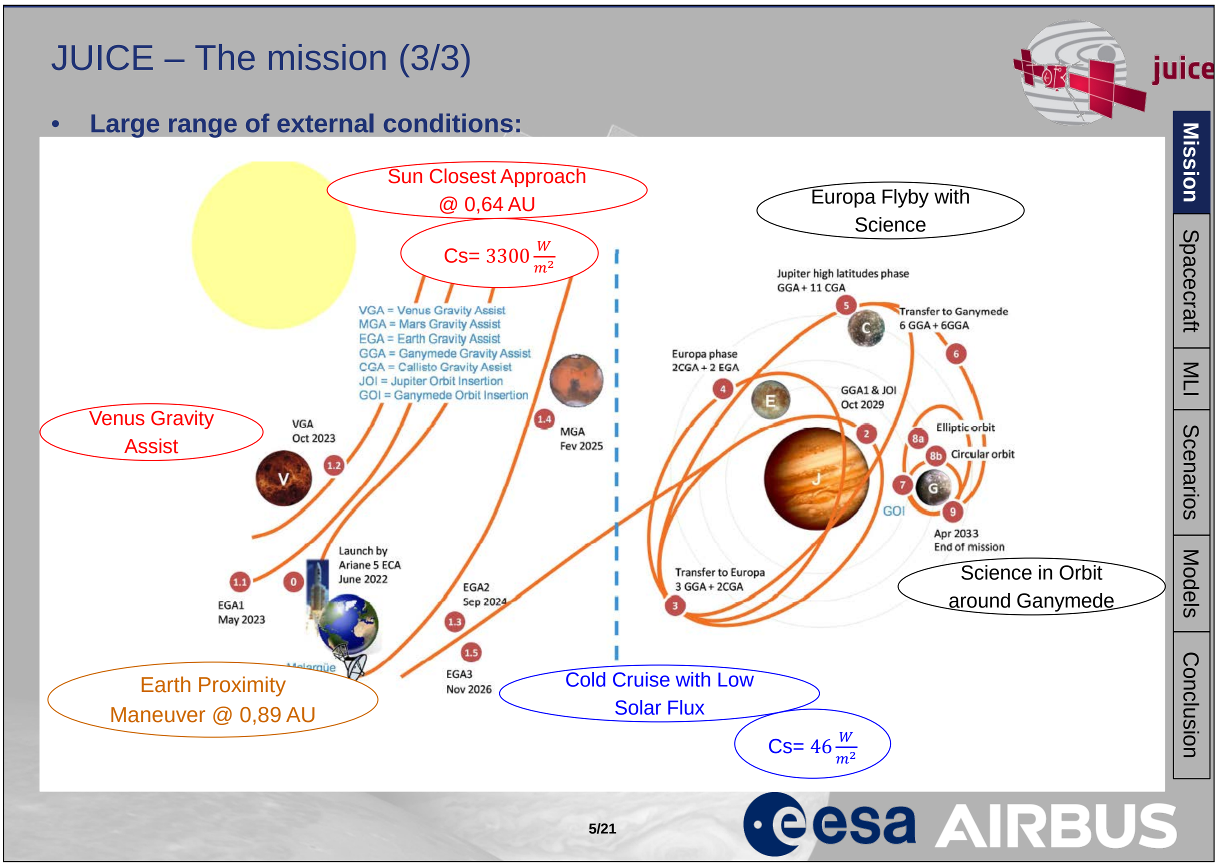
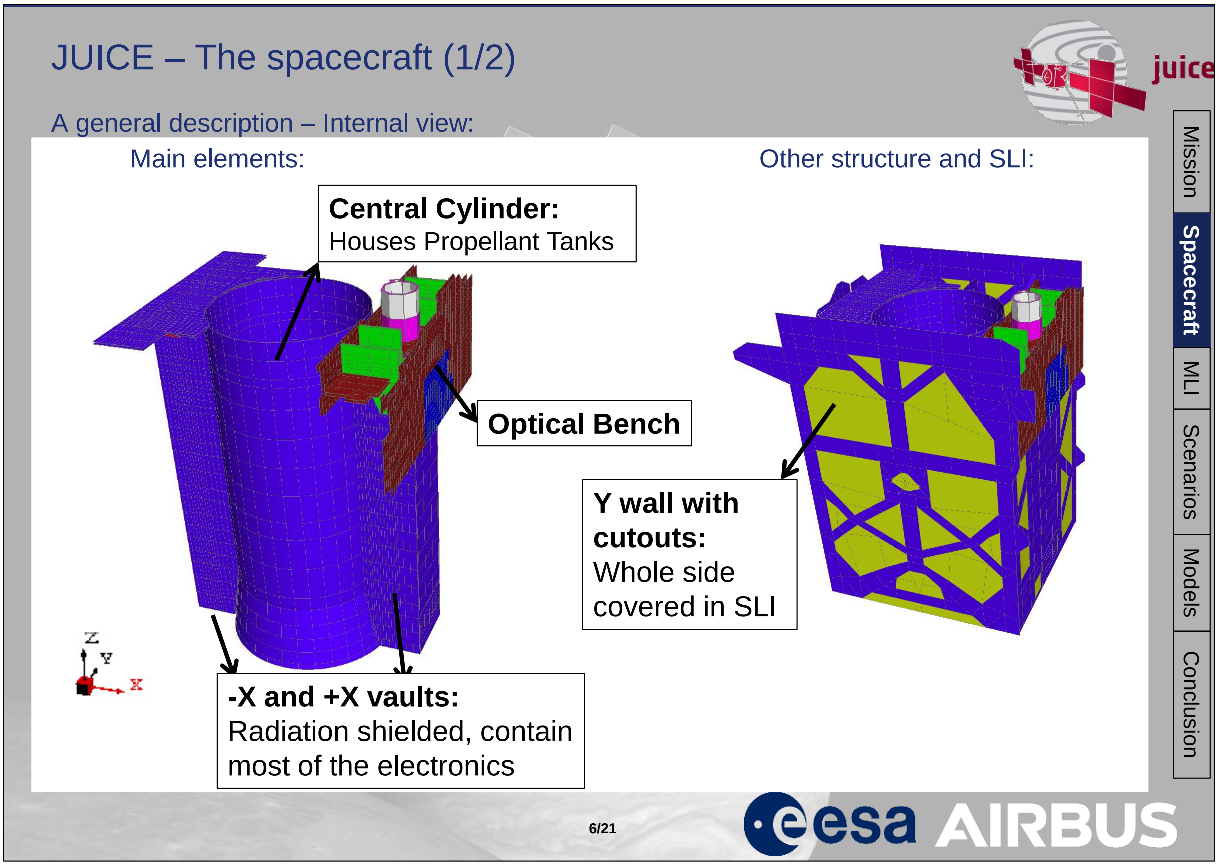
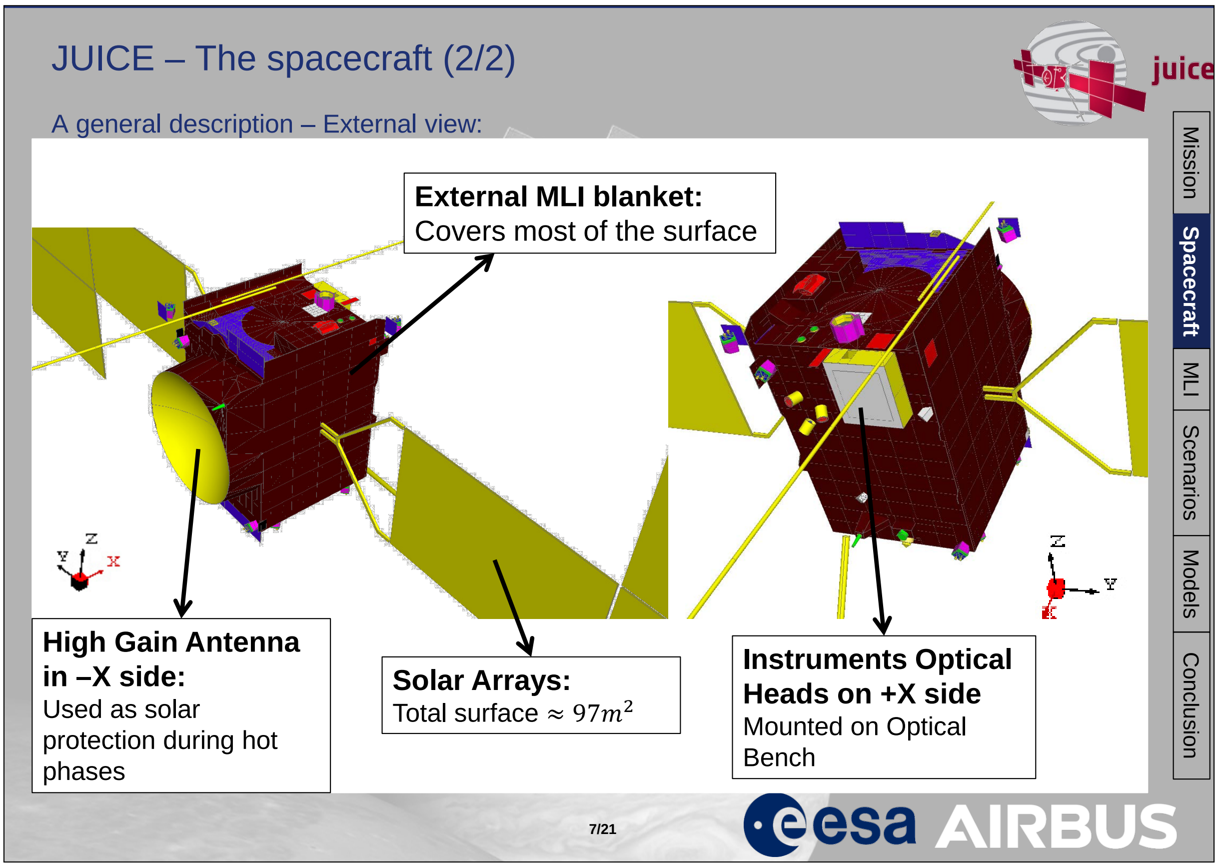


Save the attachment to disk or (double) click on the picture to run the movie.




JUICE – The spacecraft (1/2)
juice
A general description – Internal view:
Main elements:
Other structure and SLI:
Central Cylinder:
Houses Propellant Tanks
Optical Bench
Y wall with cutouts:
Whole side covered in SLI
-X and +X vaults:
Radiation shielded, contain most of the electronics
Mission
Spacecraft
MLI
Scenarios
Models
Conclusion
6/21
esa AIRBUS


JUICE – The spacecraft (2/2)
juice
A general description – External view:
External MLI blanket:
Covers most of the surface
High Gain Antenna in –X side:
Used as solar protection during hot phases
Solar Arrays:
Total surface ≈ $97m^2$
Instruments Optical Heads on +X side
Mounted on Optical Bench
Mission
Spacecraft
MLI
Scenarios
Models
Conclusion
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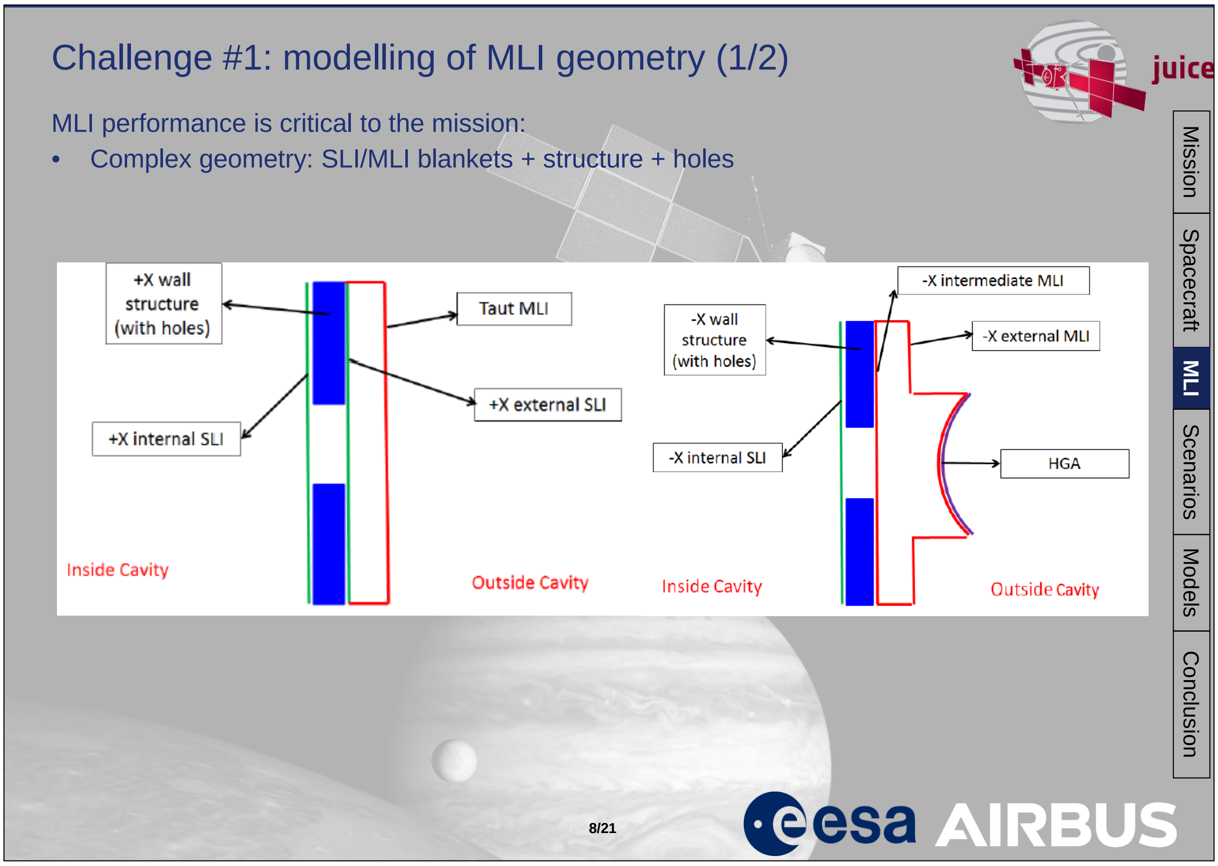
Challenge #1: modelling of MLI geometry (1/2)
MLI performance is critical to the mission:
• Complex geometry: SLI/MLI blankets + structure + holes
+X wall structure (with holes)
Taut MLI
+X external SLI
+X internal SLI
Inside Cavity
Outside Cavity
-X intermediate MLI
-X wall structure (with holes)
-X external MLI
-X internal SLI
HGA
Inside Cavity
Outside Cavity
juice
Mission
Spacecraft
MLI
Scenarios
Models
Conclusion
8/21
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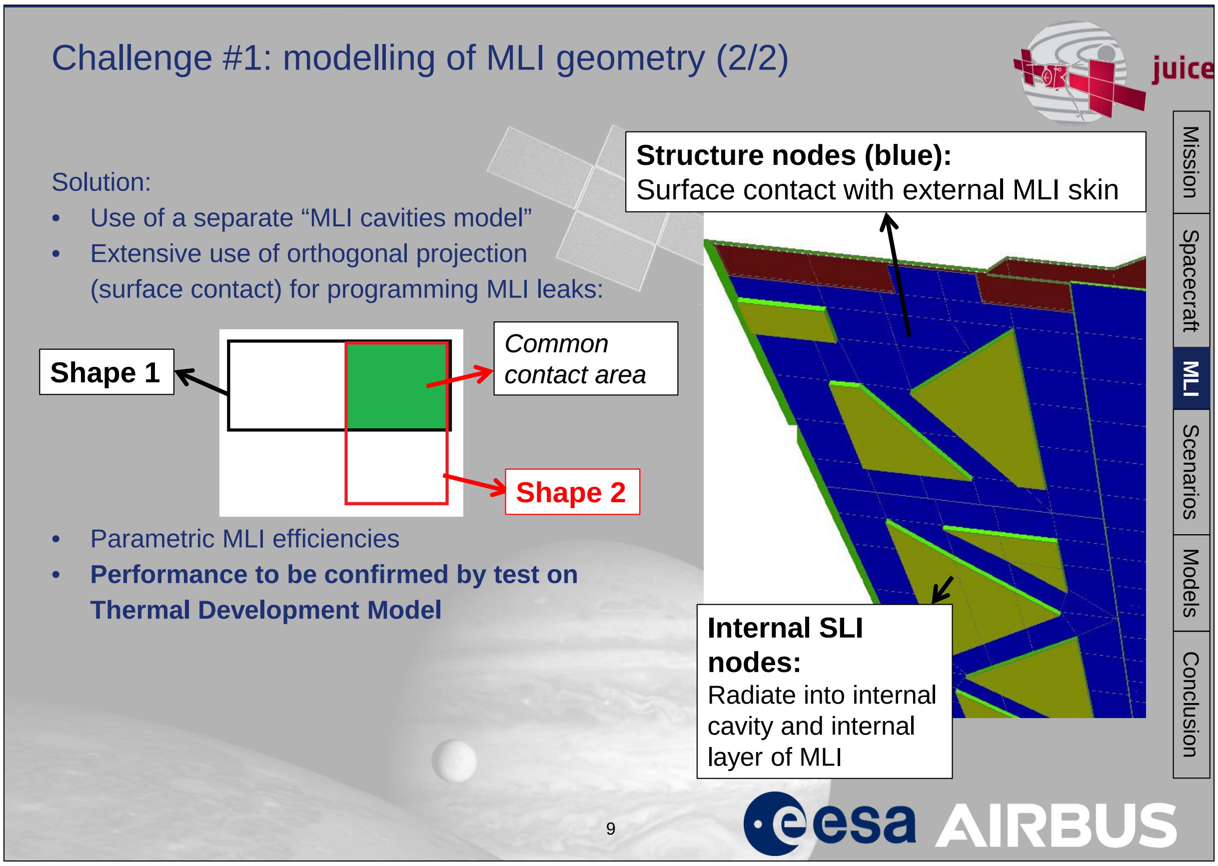
Challenge #1: modelling of MLI geometry (2/2)
Solution:
• Use of a separate "MLI cavities model"
• Extensive use of orthogonal projection (surface contact) for programming MLI leaks:
Shape 1
Common contact area
Shape 2
• Parametric MLI efficiencies
• Performance to be confirmed by test on Thermal Development Model
Structure nodes (blue):
Surface contact with external MLI skin
Internal SLI nodes:
Radiate into internal cavity and internal layer of MLI
juice
Mission
Spacecraft
MLI
Scenarios
Models
Conclusion
9
esa AIRBUS

JUICE – Thermal design – more information

Thermal architecture and design a very interesting topic on its own…
For more information, you can refer to:

"JUICE thermal architecture and performance"
Romain Peyrou-Lauga (ESA/ESTEC)
Anthony Darel (AIRBUS Toulouse)
47th International Conference on Environmental Systems
16-20 July 2017, Charleston, South Carolina

Mission | Spacecraft | MLI | Scenarios | Models | Conclusion

10/21

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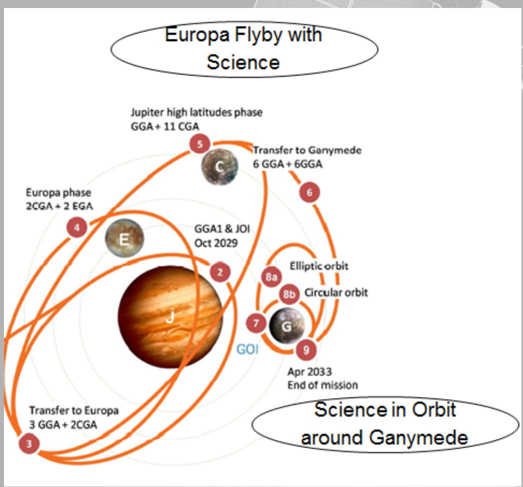
Challenge #2: modelling the mission profile (1/5)

- **Large range of external conditions:**
  Large range of scenarios, science scenarios unusual
- **Three aspects of simulation:** external fluxes, dissipations, timing



Mission | Spacecraft | MLI | Scenarios | Models | Conclusion

11/21

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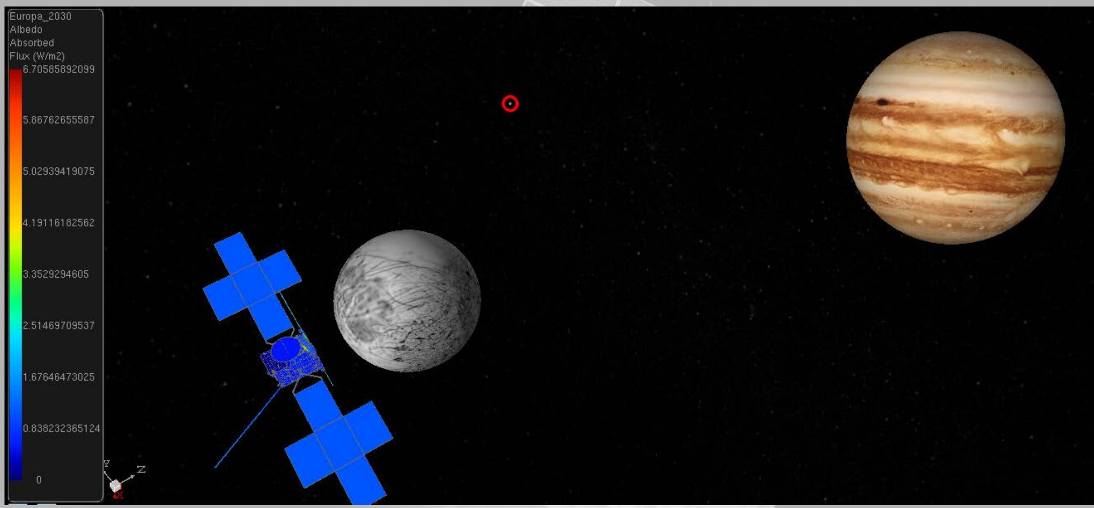
Challenge #2: modelling the mission profile (2/5)

Large range of environmental conditions and mission parameters:

- Large set of unusual environments:
  Europa Flyby:



Computed using Systema v4.8.0

Mission | Spacecraft | MLI | **Scenarios** | Models | Conclusion

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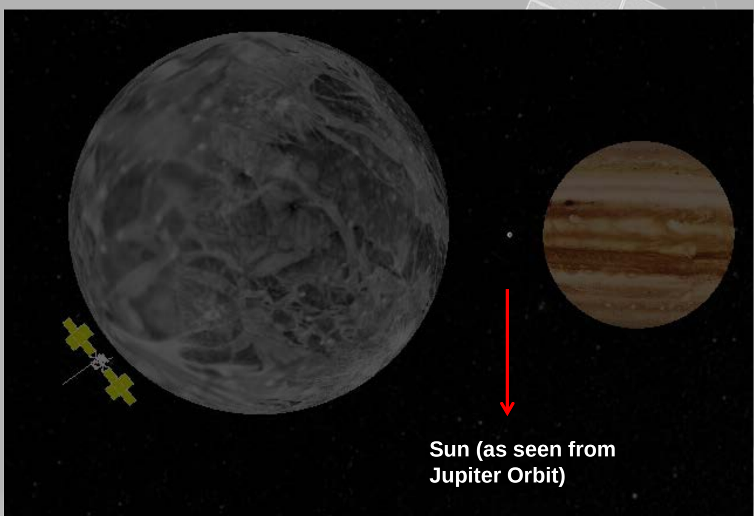
12/21

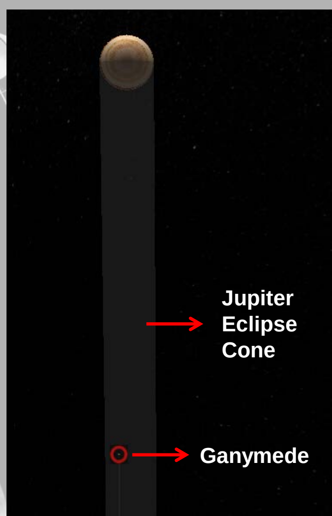
Challenge #2: modelling the mission profile (3/5)

Large range of environmental conditions and mission parameters:

- Large set of unusual environments:

Eclipse during Ganymede Orbit:





Computed using Systema v4.8.0

Mission | Spacecraft | MLI | **Scenarios** | Models | Conclusion

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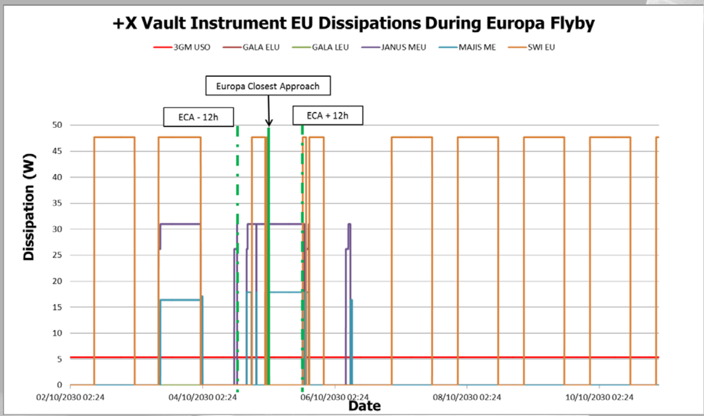
13/21

Challenge #2: modelling the mission profile (4/5)

Large range of environmental conditions and mission parameters:

- Matching of three different timelines:
  - Trajectory timeline and ephemerides
  - Science scenarios provided by ESA, used for instrument dissipation
  - System power budget timeline for platform units dissipation
- Development of scripts to code dissipations:
  - Written as time-dissipation vector
  - Automatic detection of transition (small scenario timestep)
  - Instrument mode (ON/STBY/OFF) as a function of time



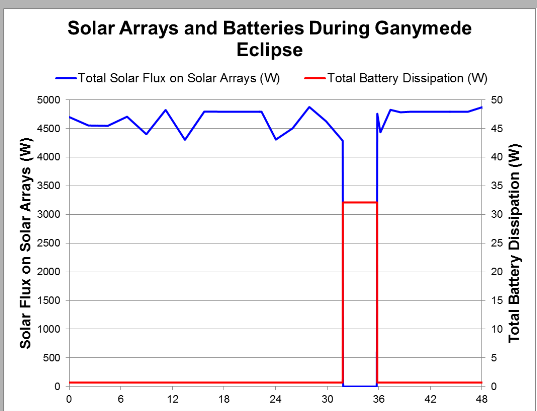
Mission | Spacecraft | MLI | Scenarios | Models | Conclusion

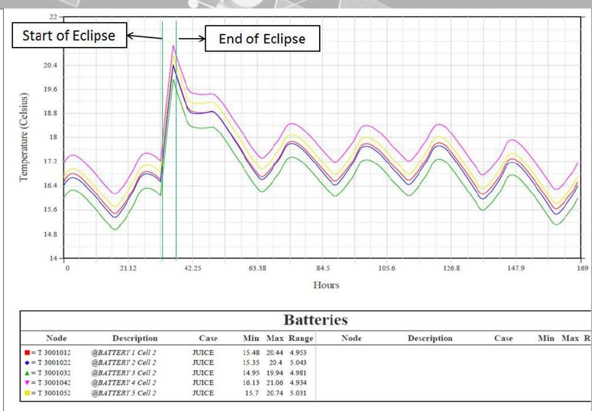
14/21

Challenge #2: modelling the mission profile (5/5)

Large range of environmental conditions and mission parameters:

- Verification of timeline consistency:
  - Match between trajectory timeline and dissipation timeline:
  - Cross-consistency verification:





Mission | Spacecraft | MLI | Scenarios | Models | Conclusion

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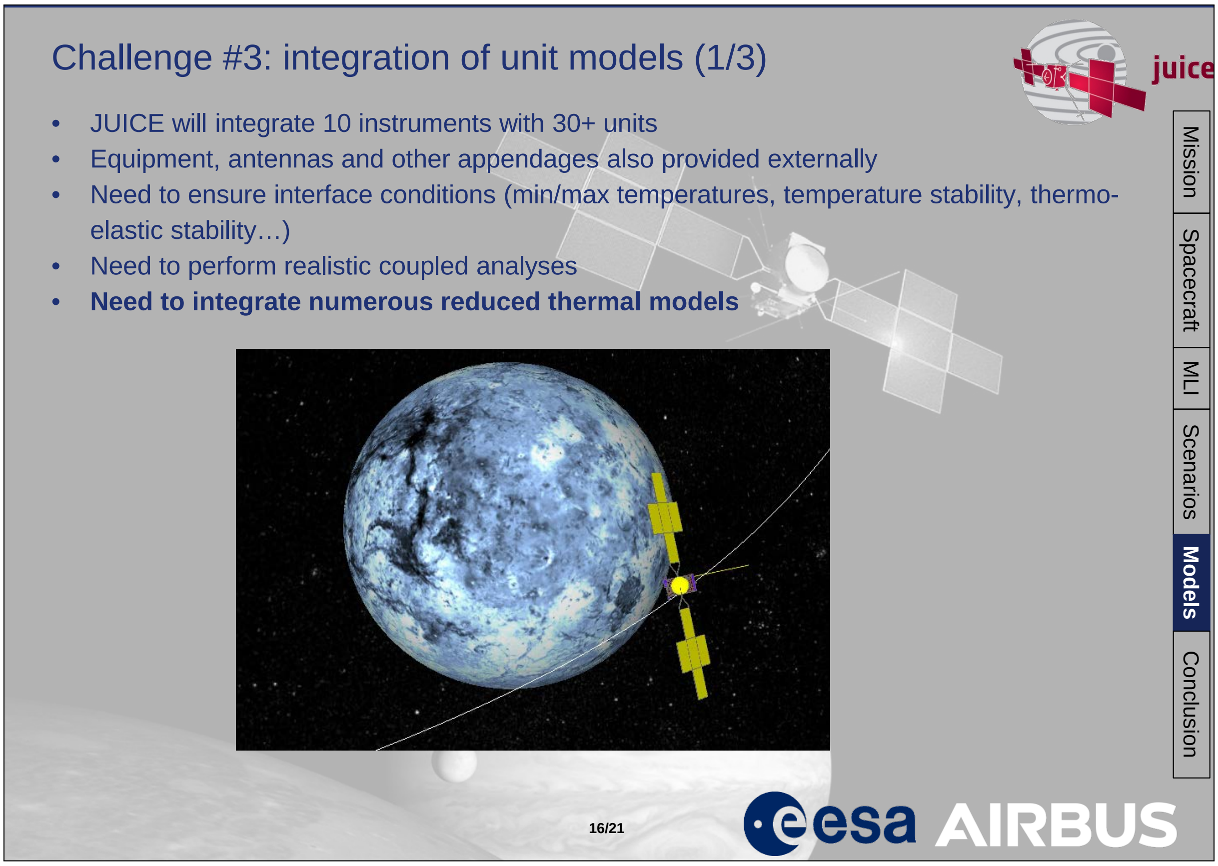
Challenge #3: integration of unit models (1/3)
juice
• JUICE will integrate 10 instruments with 30+ units
• Equipment, antennas and other appendages also provided externally
• Need to ensure interface conditions (min/max temperatures, temperature stability, thermo-elastic stability…)
• Need to perform realistic coupled analyses
• Need to integrate numerous reduced thermal models
Mission
Spacecraft
MLI
Scenarios
Models
Conclusion
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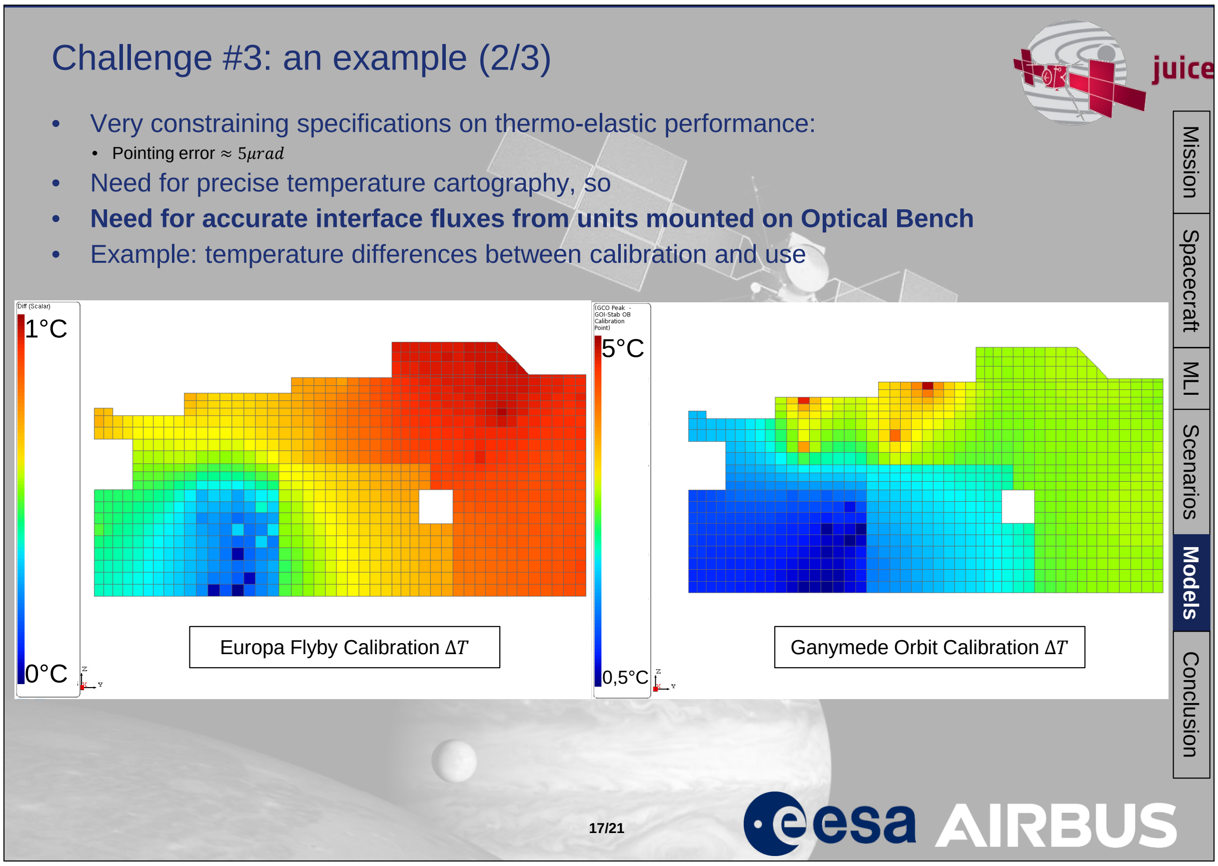
Challenge #3: an example (2/3)
juice
• Very constraining specifications on thermo-elastic performance:
• Pointing error ≈ 5μrad
• Need for precise temperature cartography, so
• Need for accurate interface fluxes from units mounted on Optical Bench
• Example: temperature differences between calibration and use
1°C
0°C
Europa Flyby Calibration ΔT
5°C
0,5°C
Ganymede Orbit Calibration ΔT
Mission
Spacecraft
MLI
Scenarios
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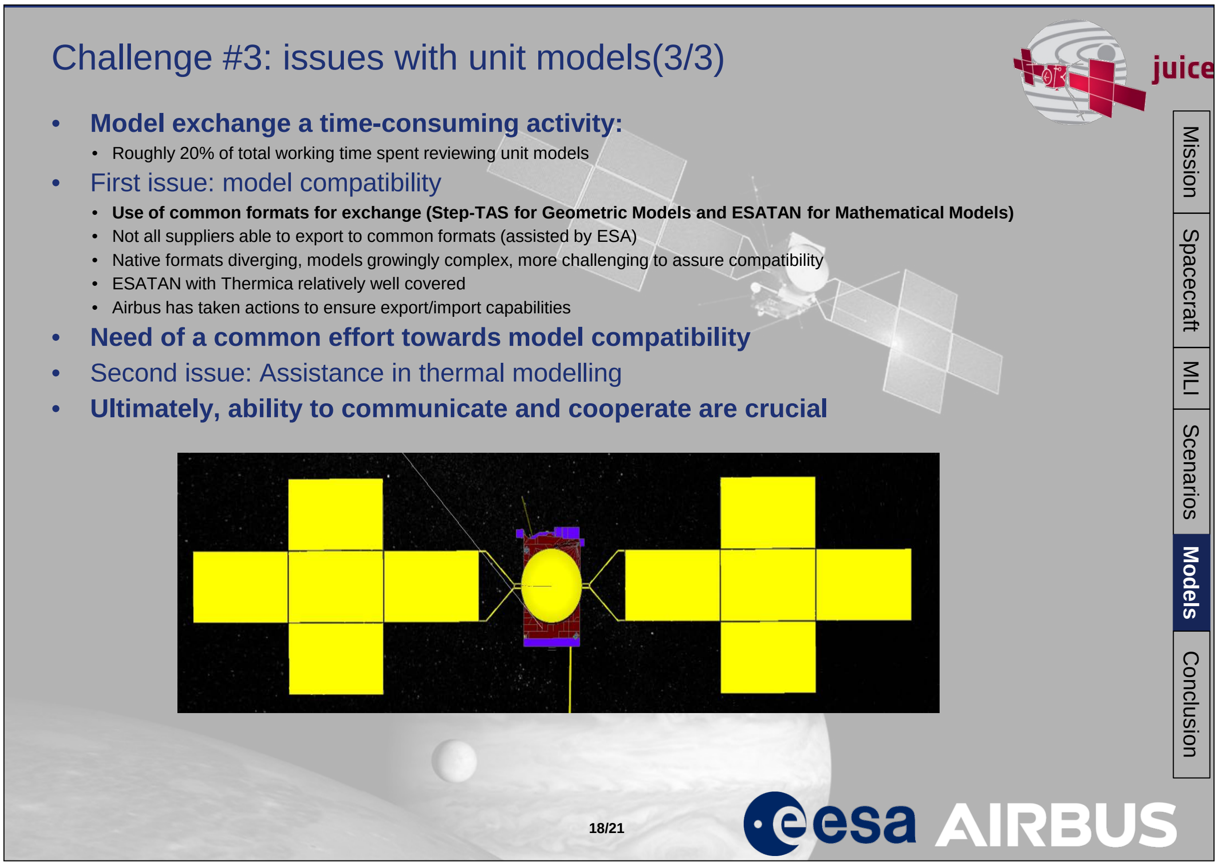
Challenge #3: issues with unit models(3/3)
juice
Model exchange a time-consuming activity:
Roughly 20% of total working time spent reviewing unit models
First issue: model compatibility
Use of common formats for exchange (Step-TAS for Geometric Models and ESATAN for Mathematical Models)
Not all suppliers able to export to common formats (assisted by ESA)
Native formats diverging, models growingly complex, more challenging to assure compatibility
ESATAN with Thermica relatively well covered
Airbus has taken actions to ensure export/import capabilities
Need of a common effort towards model compatibility
Second issue: Assistance in thermal modelling
Ultimately, ability to communicate and cooperate are crucial
Mission
Spacecraft
MLI
Scenarios
Models
Conclusion
18/21
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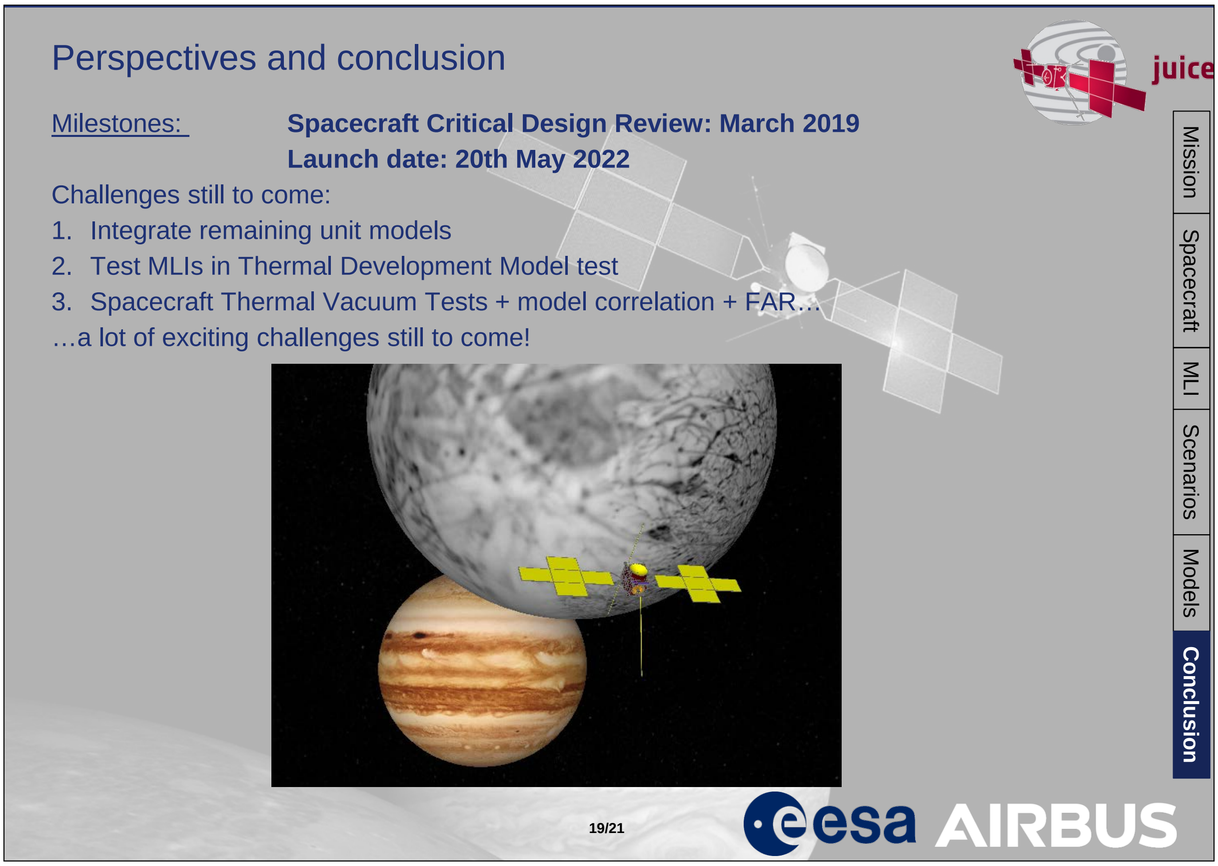
Perspectives and conclusion
juice
Milestones: Spacecraft Critical Design Review: March 2019
Launch date: 20th May 2022
Challenges still to come:
1. Integrate remaining unit models
2. Test MLIs in Thermal Development Model test
3. Spacecraft Thermal Vacuum Tests + model correlation + FAR…
…a lot of exciting challenges still to come!
Mission
Spacecraft
MLI
Scenarios
Models
Conclusion
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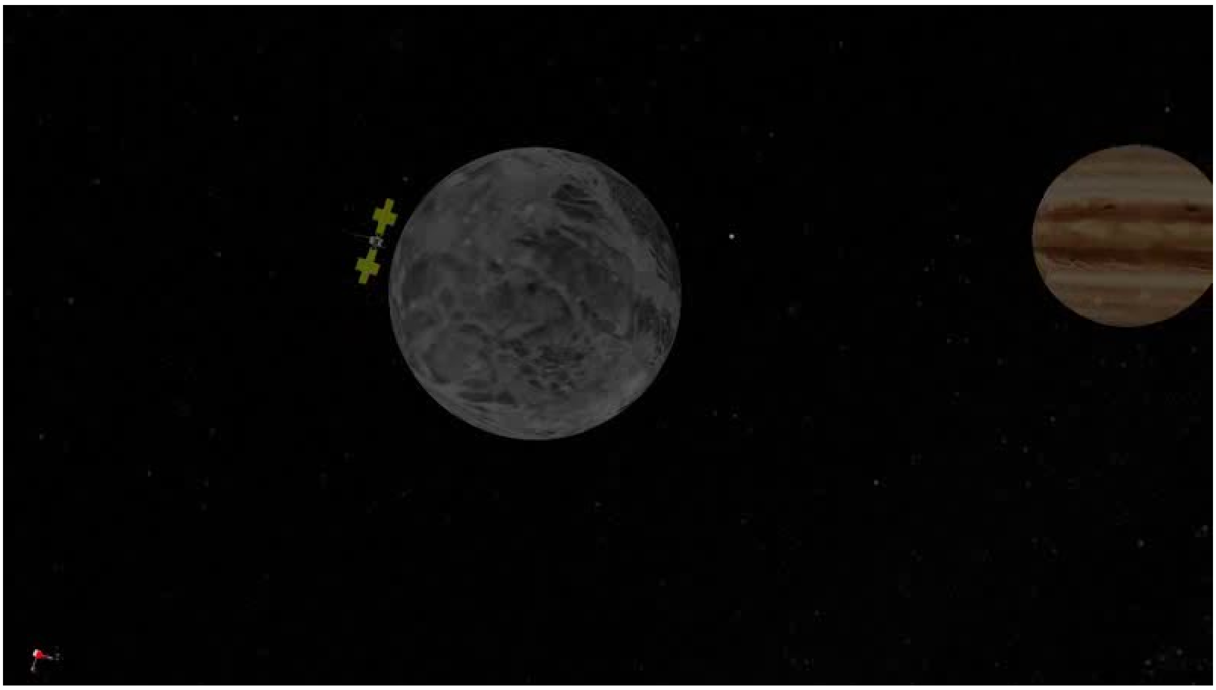
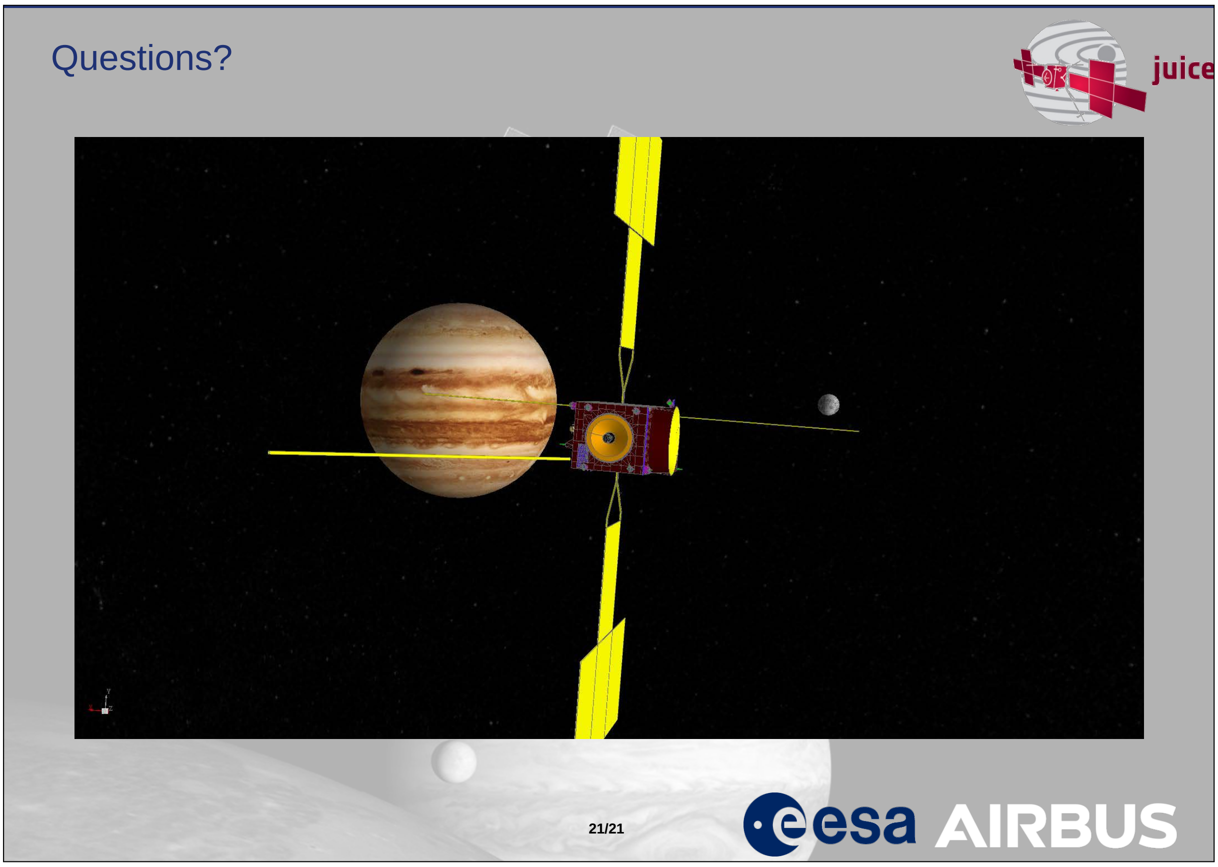
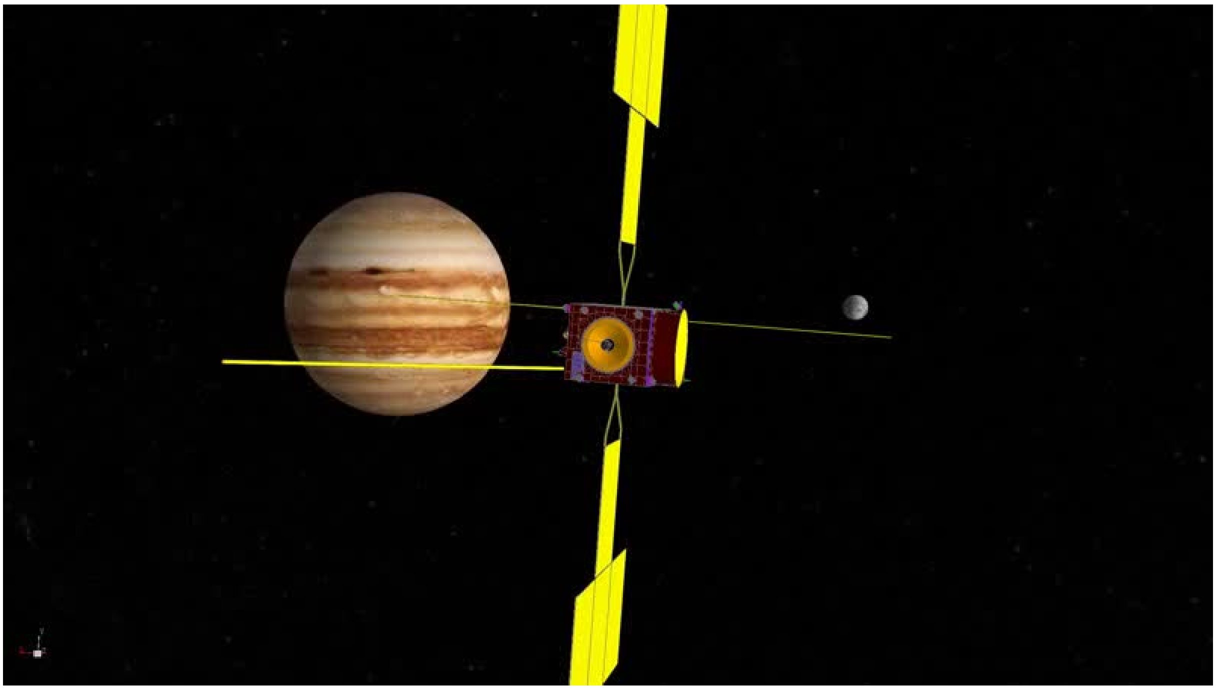


Save the attachment to disk or (double) click on the picture to run the movie.





Save the attachment to disk or (double) click on the picture to run the movie.

Appendix D

Thermal Modelling of Luna 27 Landing Site

Hannah Rana Vito Laneve Philipp Hager Thierry Tirolien
(ESA/ESTEC, The Netherlands)

Abstract

Luna 27, also known as the Lunar Resource Lander, is the Russian-ESA collaborative mission to the permanently shadowed craters at the south pole of the moon. In this study, the thermal environment of the potential landing site of the lander is assessed with the use of ESATAN-TMS. A series of modelling approaches are explored in order to address the different factors that may impact the thermal environment affecting the lander, namely surface infrared, direct impingent solar flux, the transient cases of sunrise and sunset, and the lunar topography. The effect of the orientation of the lander was further considered with regards to the on-board European units PILOT and PROSPECT. The models were then assessed in light of theoretical flux balances, empirical lunar regolith temperature correlations, and data from NASA's Lunar Reconnaissance Orbiter.


esa
Thermal Modelling of Luna 27 Landing Site
Hannah Rana, Vito Laneve, Philipp Hager, Thierry Tirolien
European Space Agency
2017-10-24
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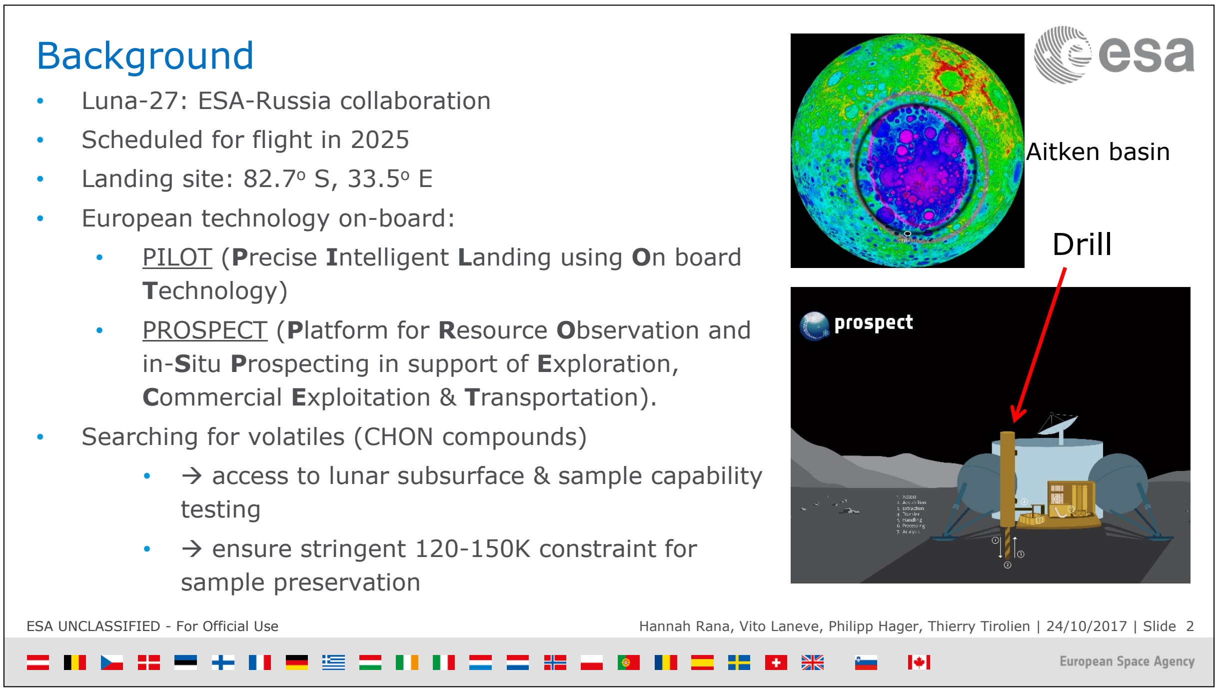
European Space Agency


Background
Luna-27: ESA-Russia collaboration
Scheduled for flight in 2025
Landing site: 82.7º S, 33.5º E
European technology on-board:
PILOT (Precise Intelligent Landing using On board Technology)
PROSPECT (Platform for Resource Observation and in-Situ Prospecting in support of Exploration, Commercial Exploitation & Transportation).
Searching for volatiles (CHON compounds)
→ access to lunar subsurface & sample capability testing
→ ensure stringent 120-150K constraint for sample preservation
esa
Aitken basin
Drill
prospect
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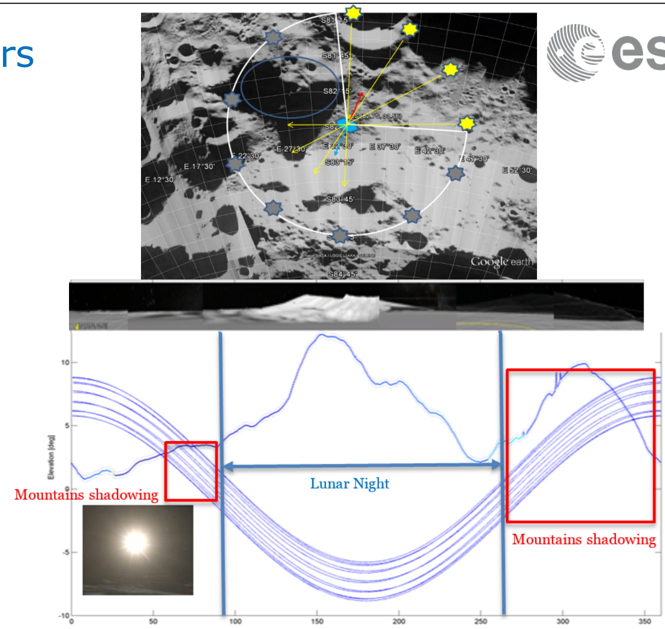
Thermal Modelling Drivers

- Light & dark phases
- Sunrise/Sunset cases
- Topographical impact of landing region
- Verify ESATAN-TMS capability for lunar surface model



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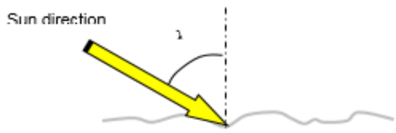
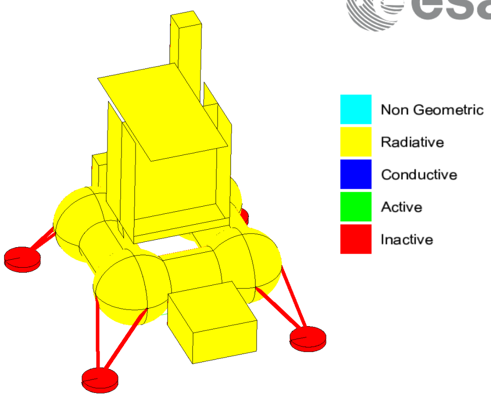
Initial Assessment of Landing Site

- Phase B1 of project
- Thermo-optical properties of lunar surface regolith ε=0.97, α=0.93
- IR steady state flux of 707 W/m^2 for hot case





- Illuminated: $T_{moon} = ((1\text{-}a).\ Cs.\ \cos(\lambda)/(\varepsilon.\sigma) + (2.3+3.1^*\cos(lat)^{1/4})/(\varepsilon.\sigma))^{(1/4)}$
- Non illuminated: $T_{moon} = ((2.3+3.1^*\cos(lat)^{1/4})/(\varepsilon.\sigma))^{(1/4)}$

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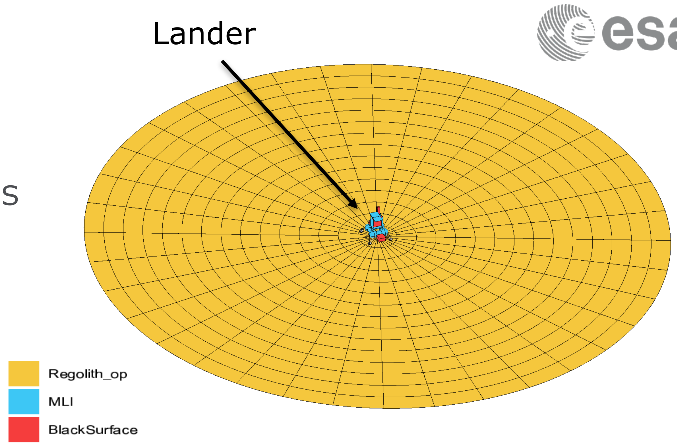
Disc Model

- Multi-node 30m radius disc
- Scaled down horizon
- 'Planet Surface' in ESATAN-TMS
- Defining moon as planetary body
- Surface without capacity; only positioning in space



Optical Finish	IR Emissivity	Solar Absorptivity
Lunar Regolith	0.97	0.93
MLI	0.6	0.4
Black Surface	1.0	1.0

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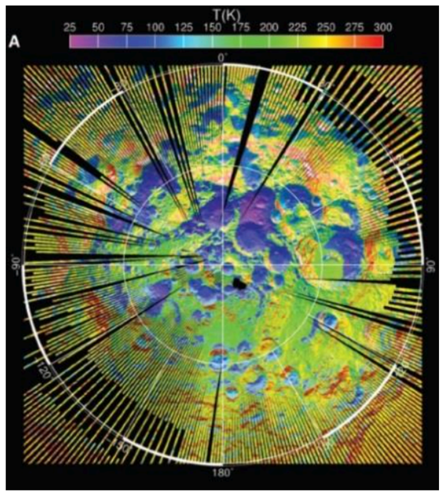
Lunar Topography

- Several mountains in region; might radiate heat to lander
- Lunar surface close to black body
- 90º incident angle of sun; surface heating to 300-400K (right)
- Southern pole slopes
- Mountains 20-100km may be significant
- Concerned with temperature development of samples being drilled



[Paige et al. 2010b]

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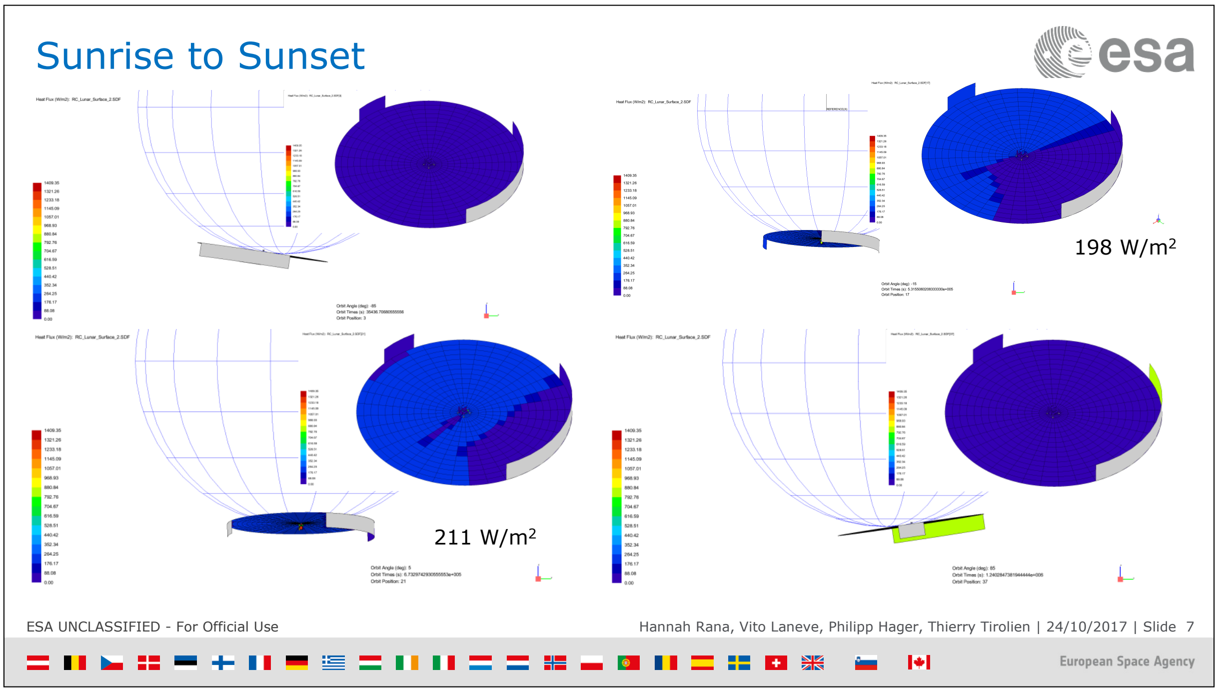
Sunrise to Sunset
esa
198 W/m²
211 W/m²
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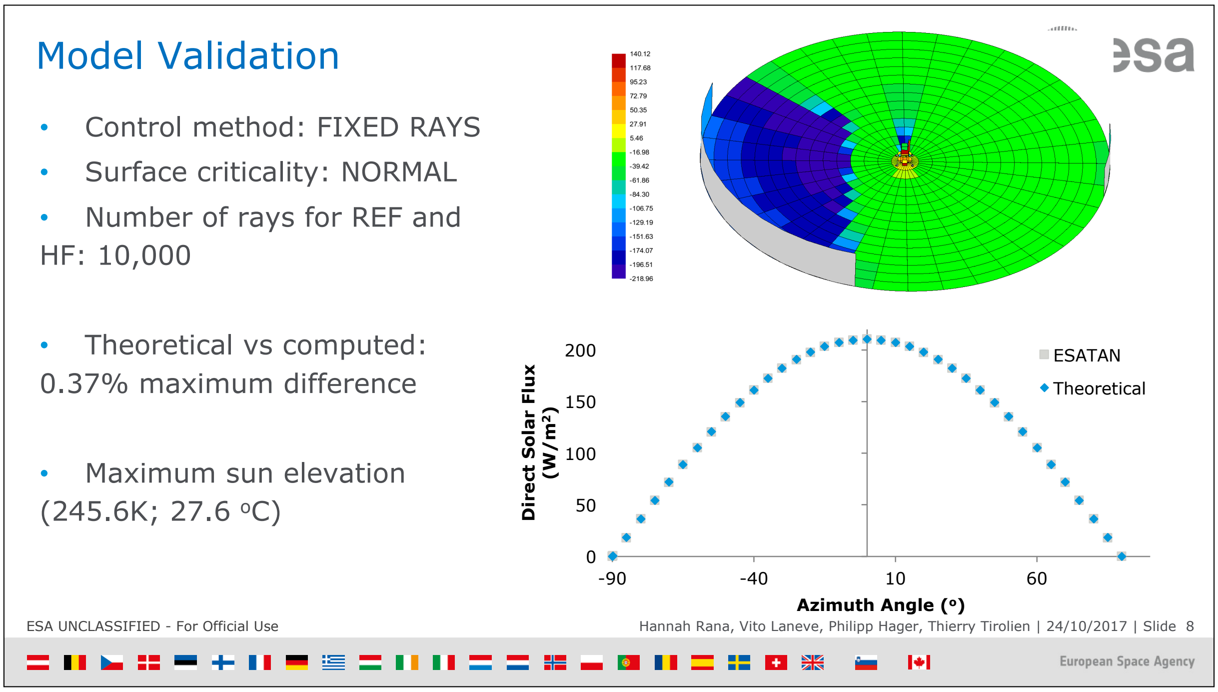
Model Validation
esa
• Control method: FIXED RAYS
• Surface criticality: NORMAL
• Number of rays for REF and HF: 10,000
• Theoretical vs computed: 0.37% maximum difference
• Maximum sun elevation (245.6K; 27.6 °C)
140.12
117.68
95.23
72.79
50.35
27.91
5.46
-16.98
-39.42
-61.86
-84.30
-106.75
-129.19
-151.63
-174.07
-196.51
-218.96
Direct Solar Flux (W/m²)
200
150
100
50
0
-90
-40
10
60
Azimuth Angle (°)
ESATAN
Theoretical
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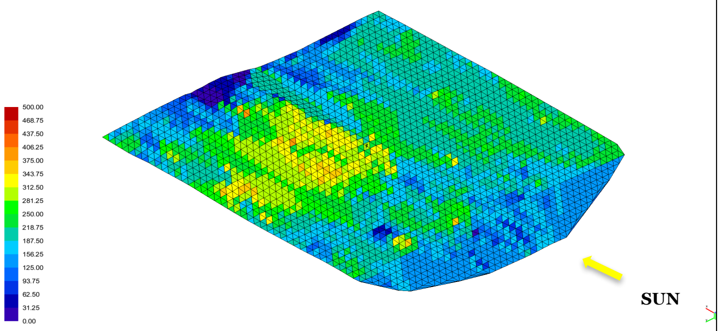
Topography Model – 1km x 1km

- 1 km x 1 km from LRO (maximum sun elevation)
- Lander modelled as black cube
- PROSPECT Node (facing away from sun) considered
- Comparable results to disc model - Q_s and Q_{IR} impingent on lander



Heat Load	Surface - Disc	Surface - Topography
Q_S	6.38 W	10.47 W
Q_{IR}	45.66 W	60.28 W

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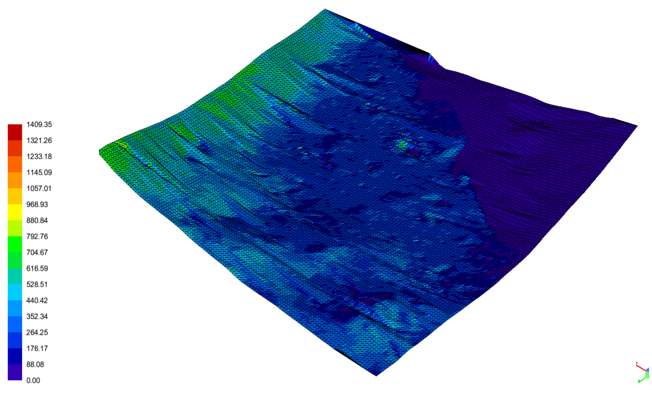
Topography Model – 30km x 30km

- Limited number of surface nodes with view factor to cube node
- Small dimensions of cube vs scale of topography



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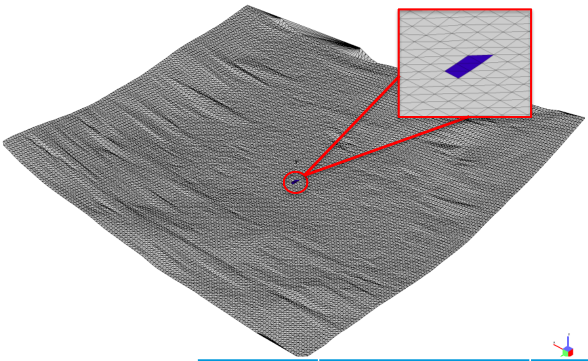
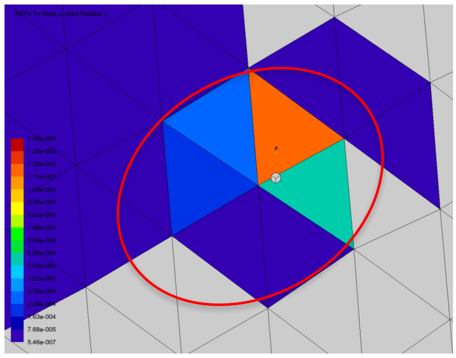
Topography Model – 30km x 30km

- 30m radius – comparable to disc model





Heat Load	Surface – Disc (30m radius)	Surface – Topography (1 km x 1 km)	Surface – Topography (30 km x 30 km)
Q_S	6.38 W	10.47 W	4.94 W
Q_{IR}	45.66 W	60.28 W	48.75 W

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Discussion

- Demonstrated feasibility of ESATAN-TMS for modelling lunar surface environment.
- Effect of mountains located 20-30km away negligible.
- 1km x 1km heat load presents highest heat loads; useful for specifying worst hot case conditions.
- All results specific for 82.7º S and 33.5º E.

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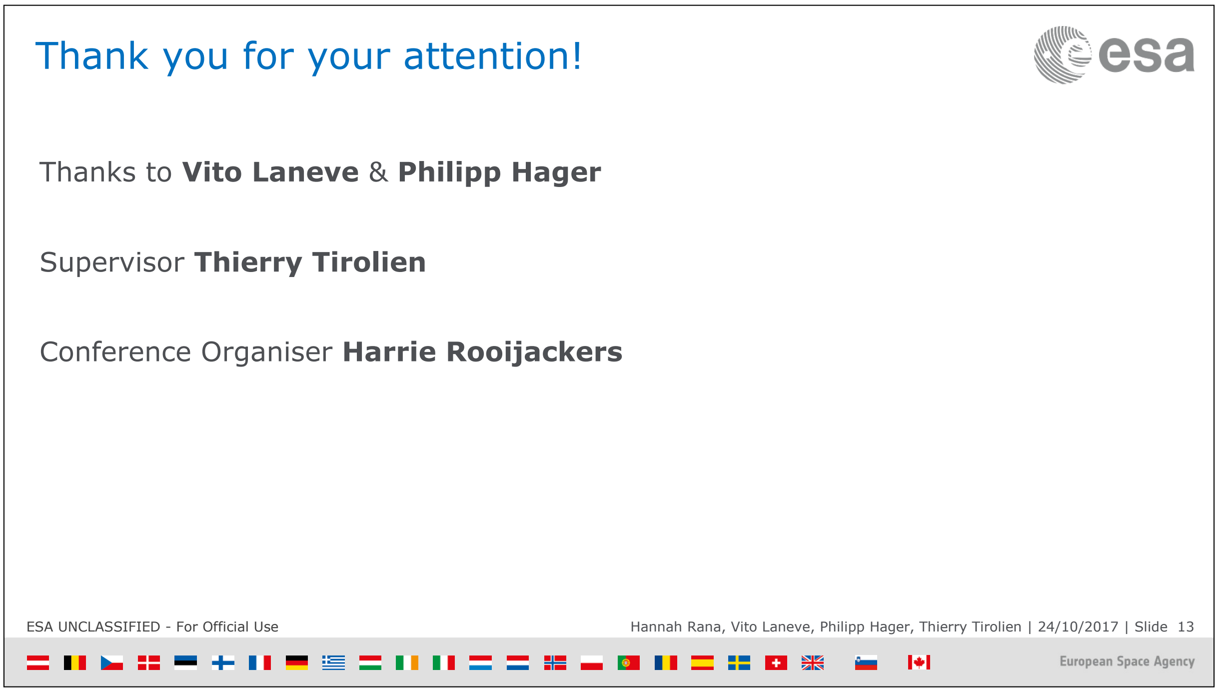
Thank you for your attention!
esa
Thanks to Vito Laneve & Philipp Hager
Supervisor Thierry Tirolien
Conference Organiser Harrie Rooijackers
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Appendix E

Construction of a reduced thermal model of a Traveling Wave Tube with a modal method

Martin Raynaud
(Thales Alenia Space, France)

Quentin Malartic   Frederic Joly   Alain Neveu
(Universite Evry Val Essone, France)

Abstract

This work presents the principle of the construction of a reduced thermal model using a modal method based on branches combination. The method is applied to a Traveling Wave Tube and shows that it is possible to obtain accurate enough results by using only 10 degrees of freedom instead of several hundred thousands degrees of freedom as required by Finite Elements or Finite Volume methods. The robustness, i.e., sensitivity to boundary conditions and heat sources, of the method is also studied.


ESA / ESTEC
October 24 & 25, 2017
Construction of a reduced thermal model of a Traveling Wave Tube with a modal method
Martin RAYNAUD – TAS-F
Quentin MALARTIC, Frederic JOLY & Alain NEVEU, LMME, UEVE, France
ThalesAlenia Space
a Thales / Leonardo company
1
2017-11-30
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Template : 83230347-DOC-TAS-EN-005
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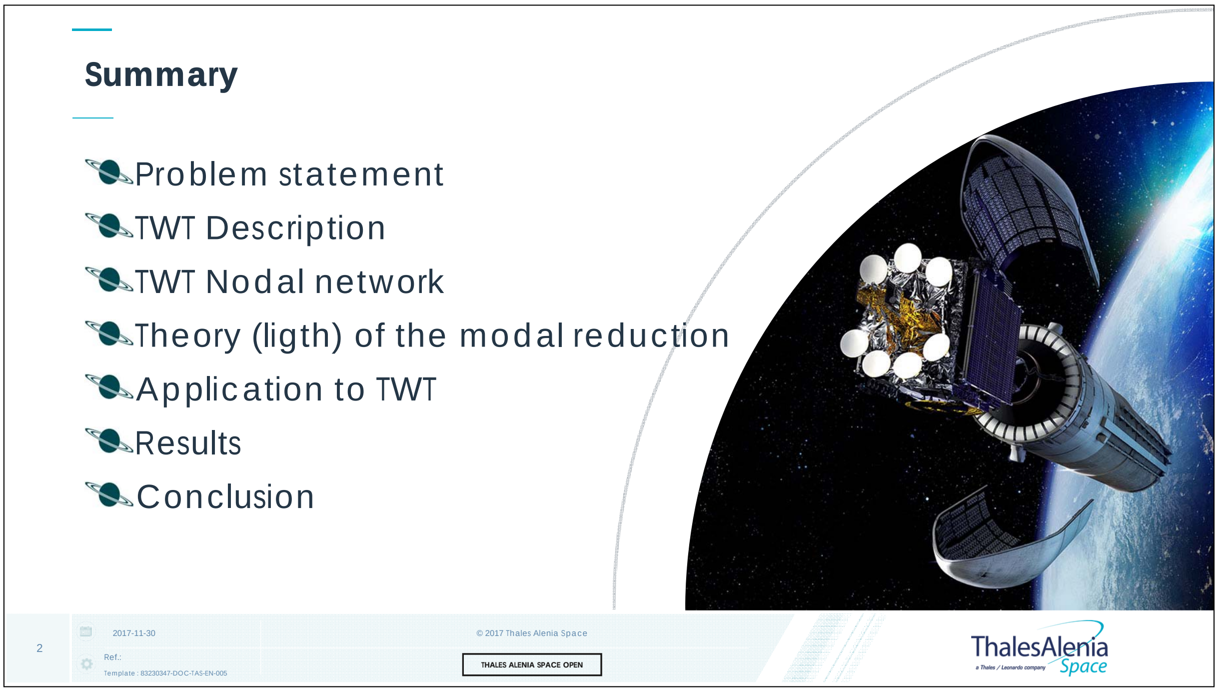
Summary
Problem statement
TWT Description
TWT Nodal network
Theory (ligth) of the modal reduction
Application to TWT
Results
Conclusion
2
2017-11-30
Ref.:
Template : 83230347-DOC-TAS-EN-005
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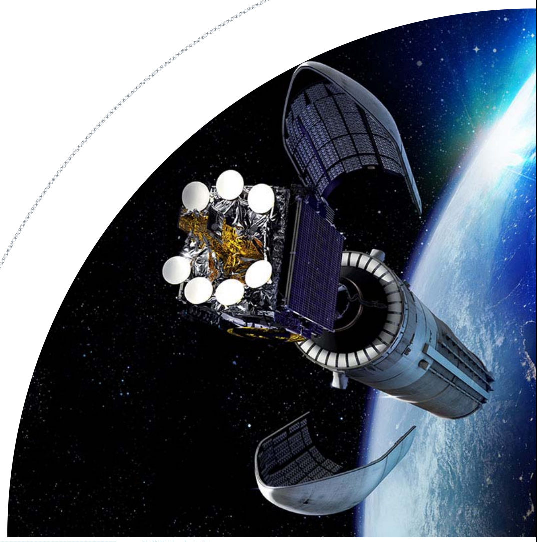
PH1

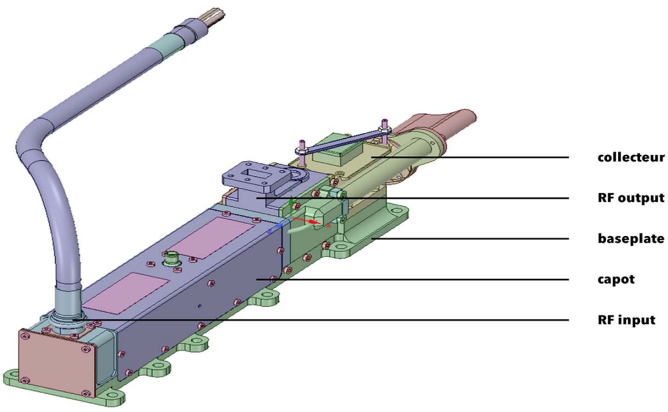
Problem statement

- Thermal Reduced model of equipments are mandatory as input for the SC thermal model
- Reduced model are given by the suppliers
- Difficulty to know the accuracy of the model
- Most often they are not robust to boundary conditions
- TAS want to improve the accuracy & robustness of reduced thermal model
- The objective of this work is to evaluate a method that is able to generate a model that could be coupled with e-Therm.



Conductive traveling Wave Tube (TWT) – Ka Band – 170 W

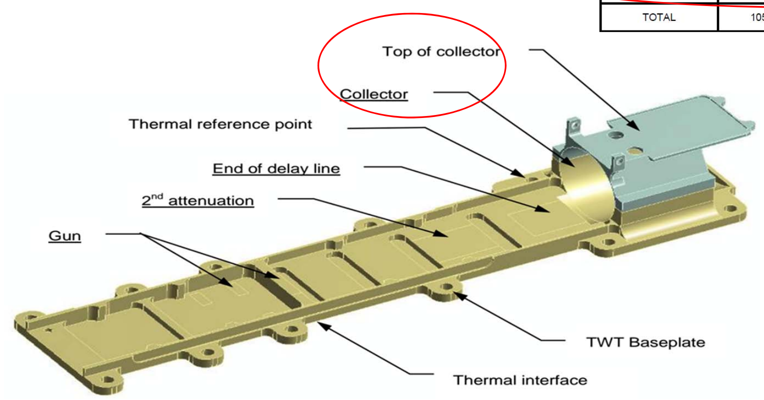
- External view (276 mm x 40 mm : baseplate area 130 cm²)



Thermal power Dissipation

- Total thermal power varies with mode : 100 W to 140 W

DISSIPATION AREA	ZERO DRIVE	SATURATION (*)	SMALL SIGNAL	3 dB OBO	OVERDRIVE @ +5 dB
Gun + RF input	4	4	4	4	4
End of the delay line	0	21.2	6.1	10.9	30.5
2^{nd} attenuator	0	0	0	0	8.7
Collector	101.0	84.8	114.9	107.1	94.8
TOTAL	105	110	125	122	138



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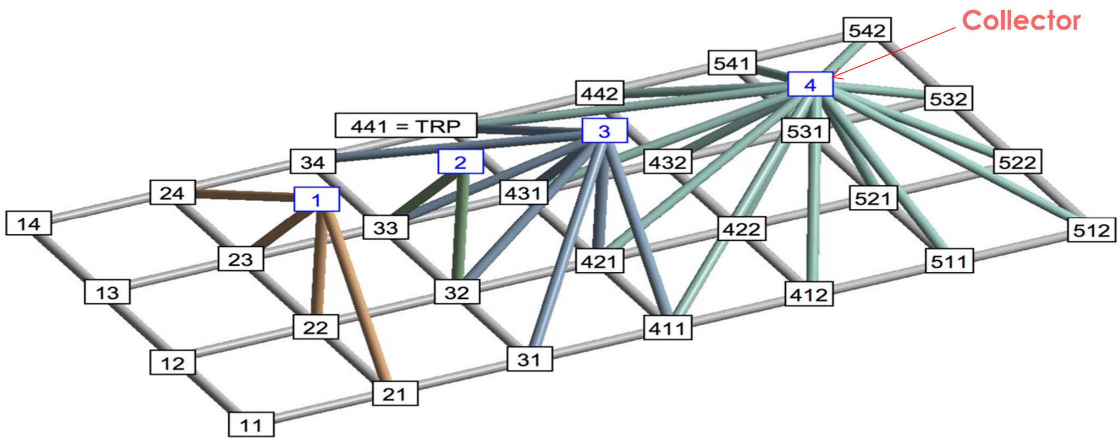
Nodal Network provided by the supplier

- 32 nodes with 28 nodes on the baseplate. Thermal Reference point is node 441



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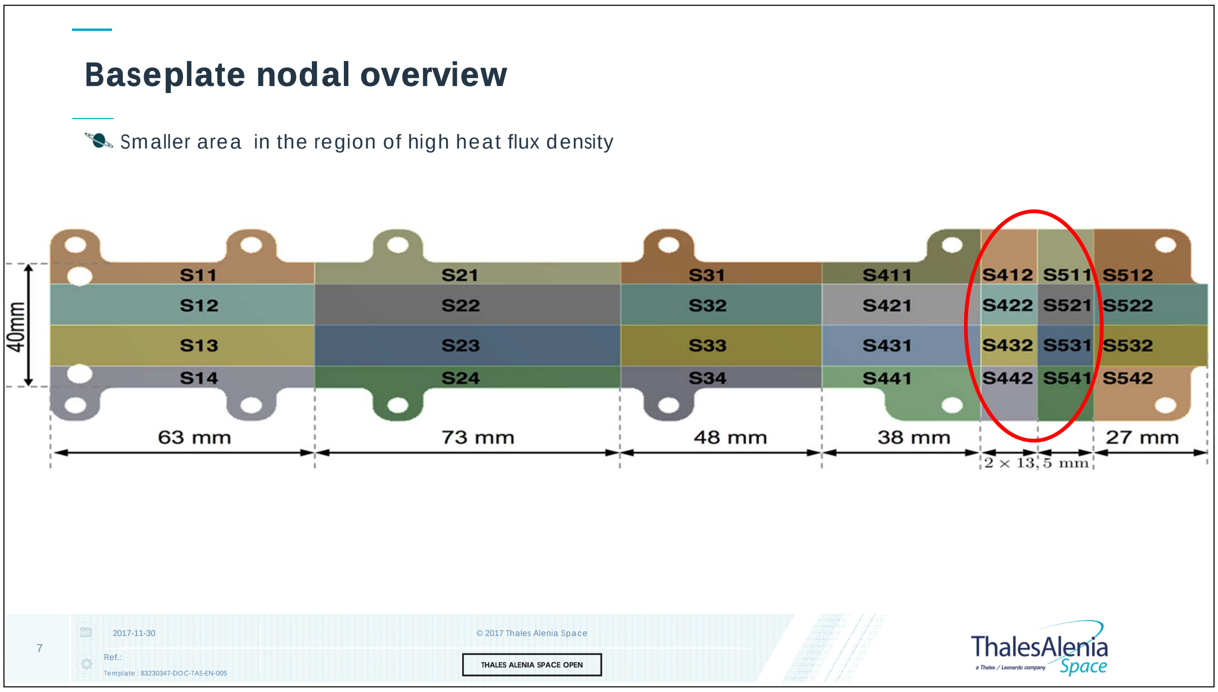
Baseplate nodal overview
Smaller area in the region of high heat flux density
S11
S12
S13
S14
S21
S22
S23
S24
S31
S32
S33
S34
S411
S421
S431
S441
S412
S422
S432
S442
S511
S521
S531
S541
S512
S522
S532
S542
40mm
63 mm
73 mm
48 mm
38 mm
2 × 13, 5 mm
27 mm
7
2017-11-30
Ref.:
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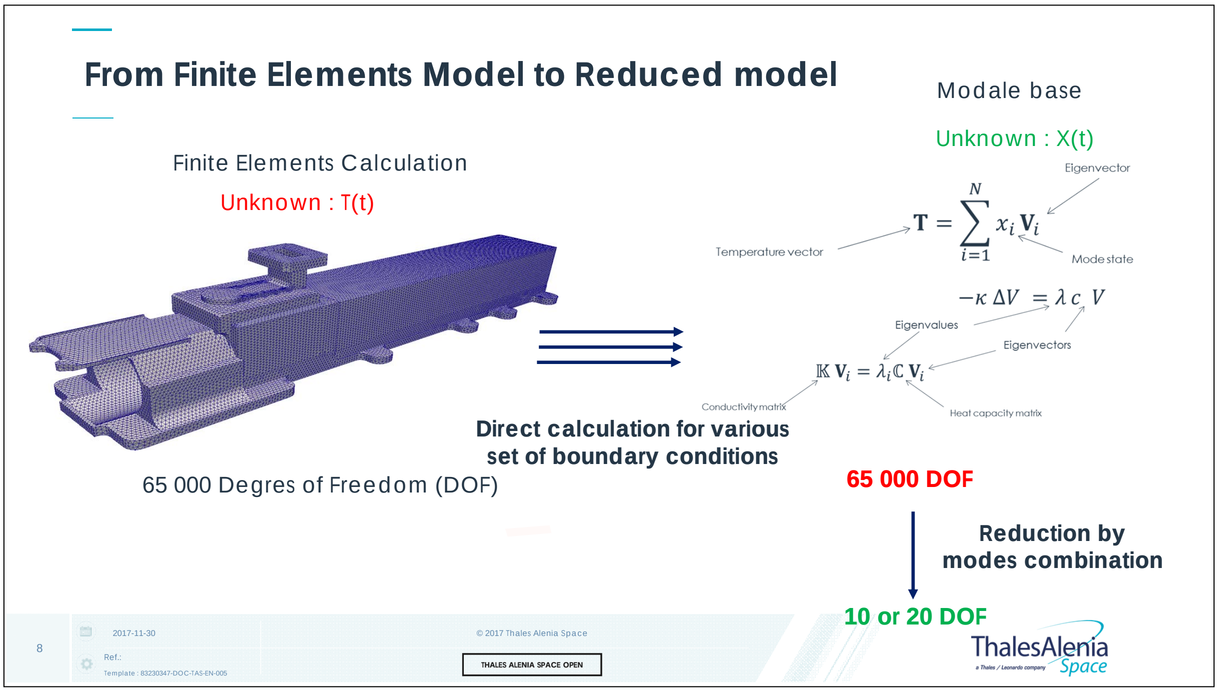
From Finite Elements Model to Reduced model
Finite Elements Calculation
Unknown : T(t)
65 000 Degres of Freedom (DOF)
Direct calculation for various set of boundary conditions
Modale base
Unknown : X(t)
Eigenvector
Temperature vector
$\mathbf{T} = \sum_{i=1}^{N} x_i \mathbf{V}_i$
Mode state
$-\kappa \, \Delta V = \lambda \, c \, V$
Eigenvalues
Eigenvectors
$\mathbb{K} \mathbf{V}_i = \lambda_i \mathbb{C} \mathbf{V}_i$
Conductivity matrix
Heat capacity matrix
65 000 DOF
Reduction by modes combination
10 or 20 DOF
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PH8

Various methods to obtain a reduced model

- Most usual → Neglect some modes based on various considerations (time, energy, mode sizes, …) :

$$\mathbf{T} = \sum_{i=1}^{\tilde{N}} x_i\,\mathbf{V}_i + \sum_{i=\tilde{N}+1}^{N} x_i\,\mathbf{V}_i$$

$$\tilde{N} \ll N$$

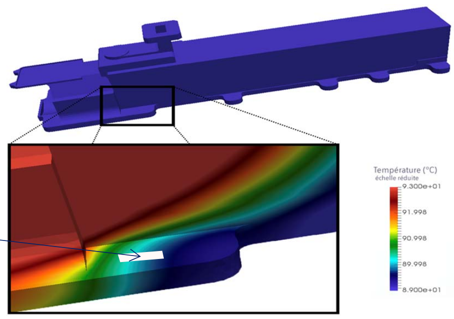
- The information contained in the mode that are neglected is lost → should be able to find a better process
- LMME has developed an original method based on mode combinations (quasi-automatic) that is very efficient … the combinations allows to reduce the total number of modes while minimizing the loss of information

PH9

Construction of the reduced thermal model (1/2)

- Import geometry from a step file
- Define thermal properties and boundary conditions
- Chose the number of "training" cases → very important as shown later
- Define the outputs that are desired → define the observation matrix

Exemple :
Temperature Reference Point



PH11

Construction of the reduced thermal model (2/2)

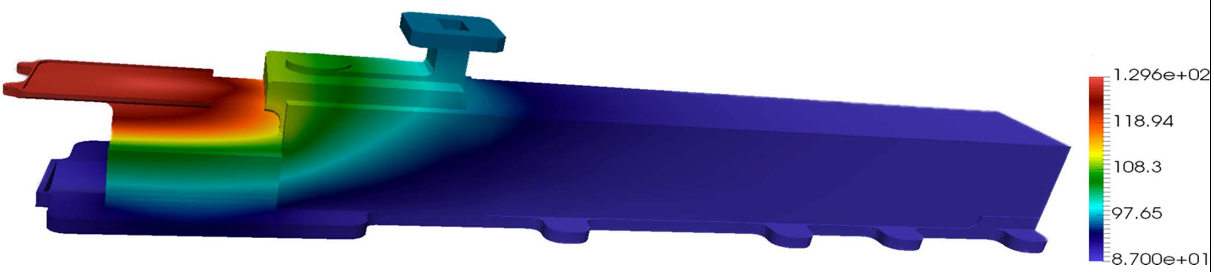
- Modes calculations for the following case :

Case	Conductance between baseplate and heat sink (W/(m²°C)	TWT mode	Convection
1	5000	no drive	no (Vacuum)
2	5000	saturation	no (Vacuum)
3	5000	3 dB OBO	no (Vacuum)
4	3000	no drive	no (Vacuum)
5	3000	saturation	no (Vacuum)
6	3000	3 dB OBO	no (Vacuum)
7	50	3 dB OBO	yes : h = 20 W/(m²°C)

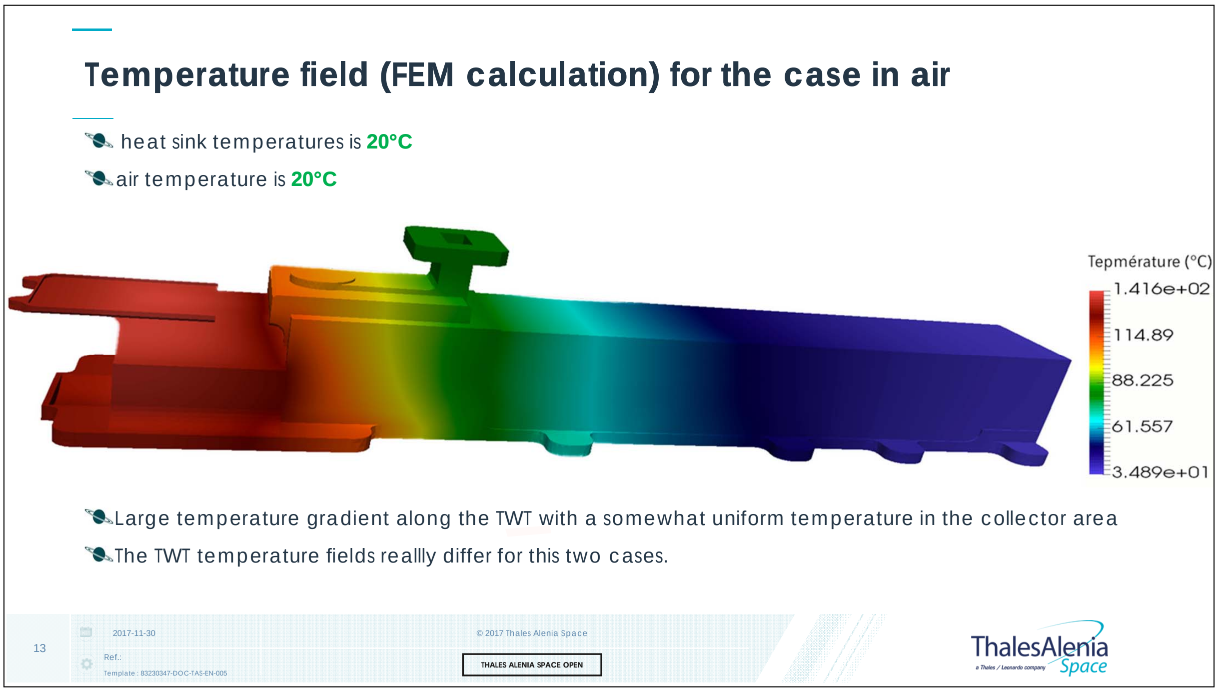
- Vacuum cases are preferred
- Compromise also to be find between transient and steady state → govern the time of study as shown later
- Decide the number of modes that will be kept for the reduced model → degree of freedom.

Temperature field (FEM calculation) for a vacuum case

- heat sink temperature is **87°C**



- large temperature gradient from top to bottom in the collector area


Temperature field (FEM calculation) for the case in air
heat sink temperatures is 20°C
air temperature is 20°C
Tepmérature (°C)
1.416e+02
114.89
88.225
61.557
3.489e+01
Large temperature gradient along the TWT with a somewhat uniform temperature in the collector area
The TWT temperature fields reallly differ for this two cases.
13
2017-11-30
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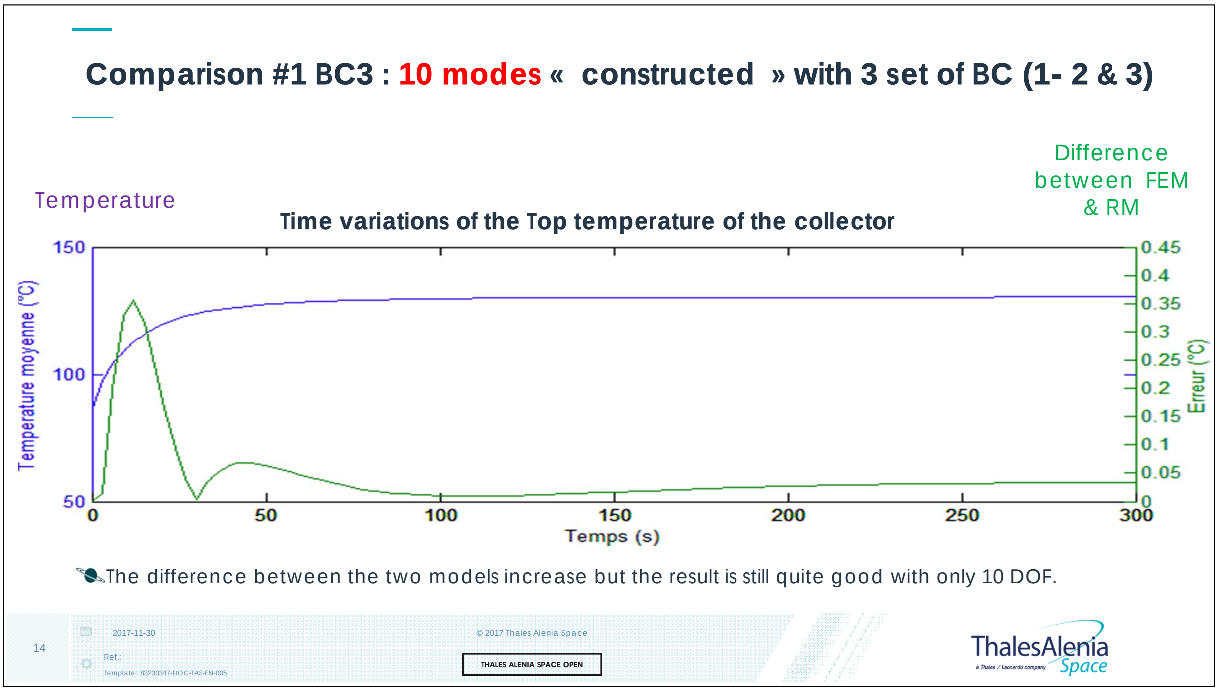
Comparison #1 BC3 : 10 modes « constructed » with 3 set of BC (1- 2 & 3)
Temperature
Time variations of the Top temperature of the collector
Difference between FEM & RM
Temperature moyenne (°C)
Erreur (°C)
Temps (s)
150
100
50
0
50
100
150
200
250
300
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
The difference between the two models increase but the result is still quite good with only 10 DOF.
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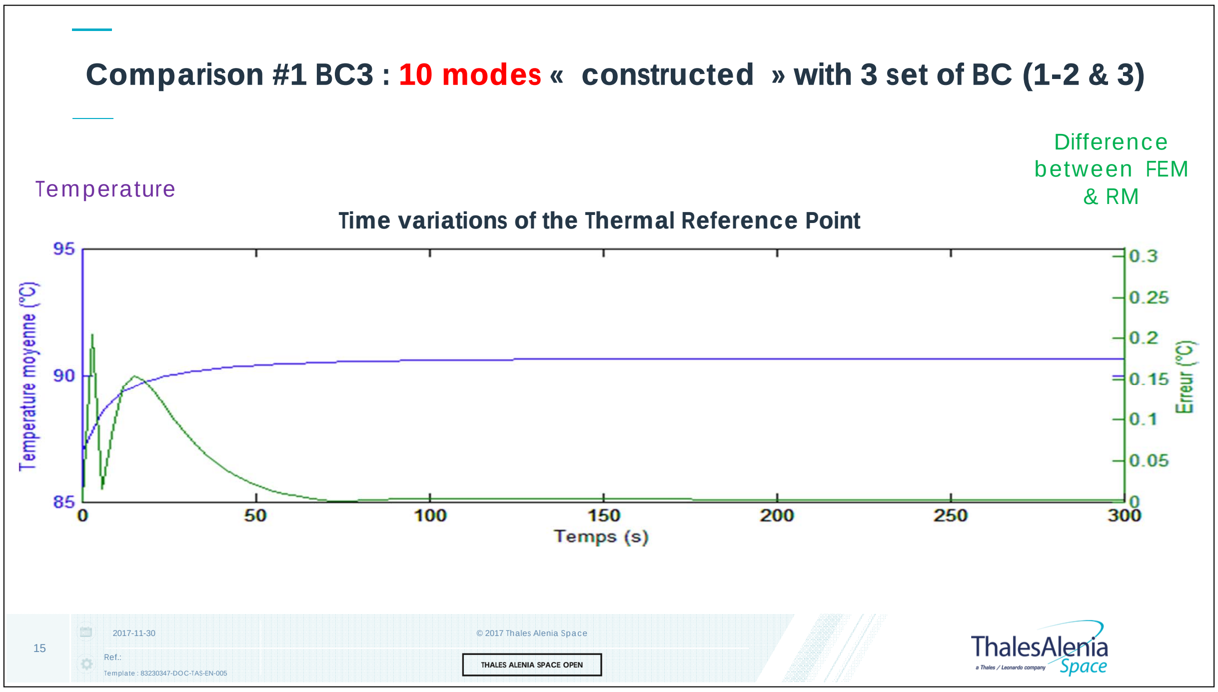
Comparison #1 BC3 : 10 modes « constructed » with 3 set of BC (1-2 & 3)
Temperature
Difference between FEM & RM
Time variations of the Thermal Reference Point
Temperature moyenne (°C)
95
90
85
0
50
100
150
200
250
300
Temps (s)
0.3
0.25
0.2
0.15
0.1
0.05
0
Erreur (°C)
15
2017-11-30
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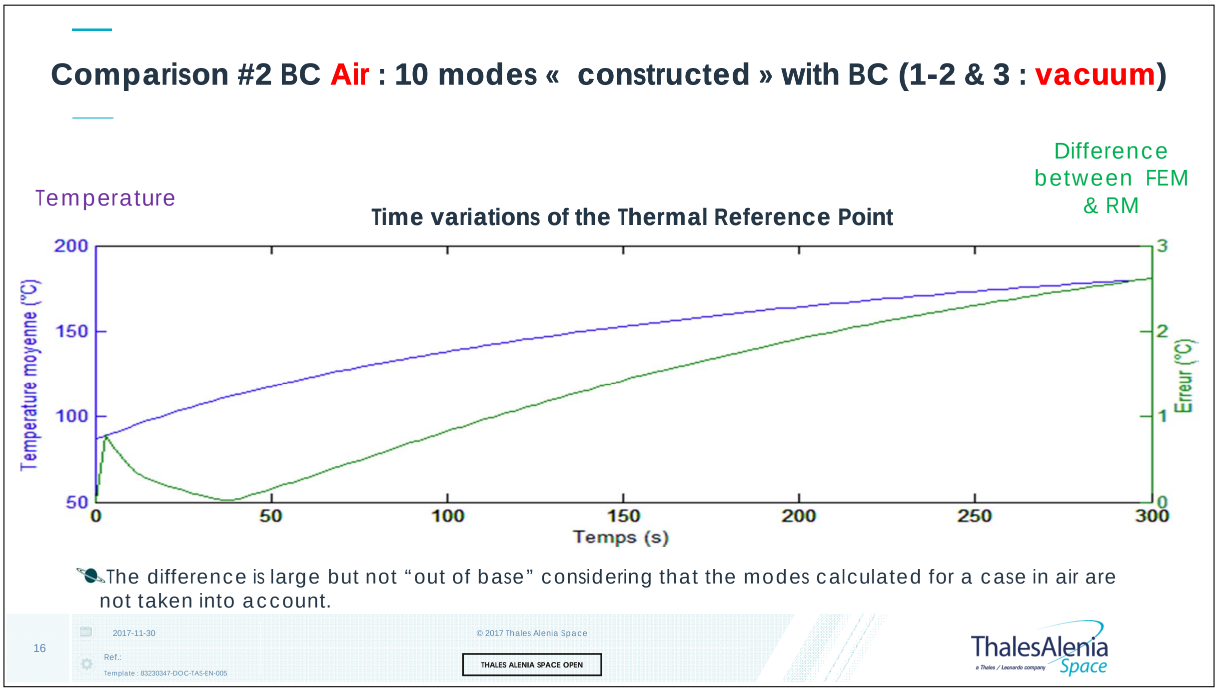
Comparison #2 BC Air : 10 modes « constructed » with BC (1-2 & 3 : vacuum)
Temperature
Difference between FEM & RM
Time variations of the Thermal Reference Point
Temperature moyenne (°C)
200
150
100
50
0
50
100
150
200
250
300
Temps (s)
3
2
1
0
Erreur (°C)
The difference is large but not "out of base" considering that the modes calculated for a case in air are not taken into account.
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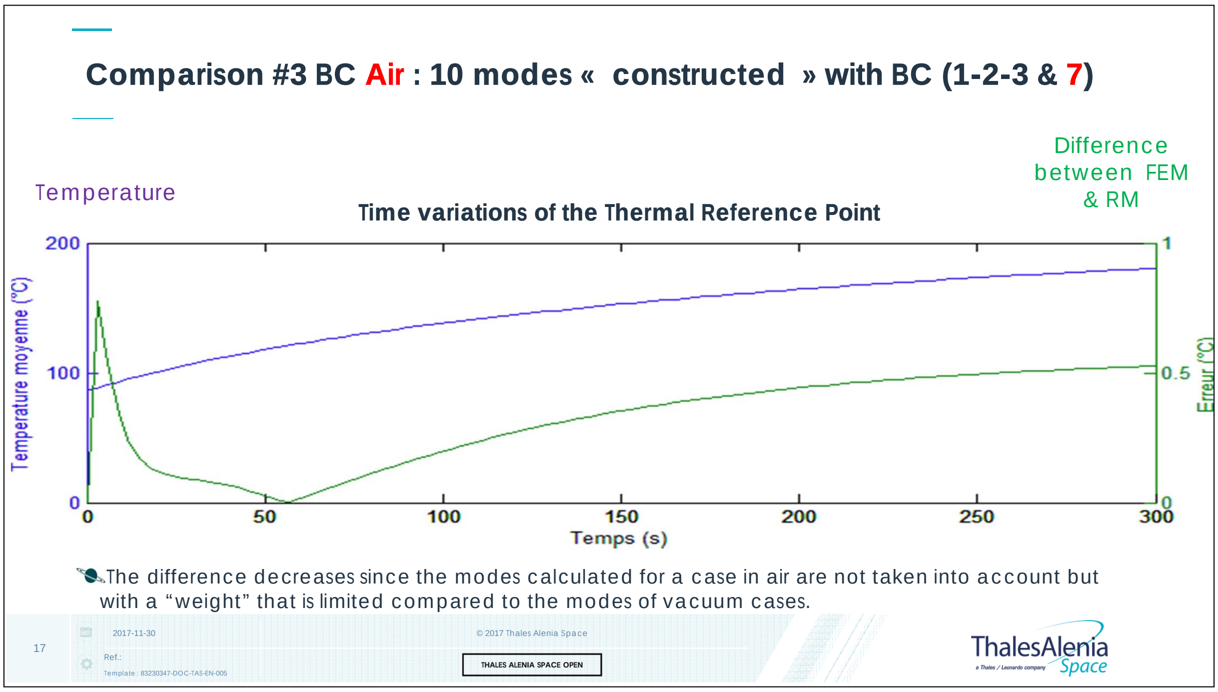
Comparison #3 BC Air : 10 modes « constructed » with BC (1-2-3 & 7)
Temperature
Time variations of the Thermal Reference Point
Difference between FEM & RM
Temperature moyenne (°C)
Erreur (°C)
Temps (s)
0
50
100
150
200
250
300
0
100
200
0
0.5
1
The difference decreases since the modes calculated for a case in air are not taken into account but with a "weight" that is limited compared to the modes of vacuum cases.
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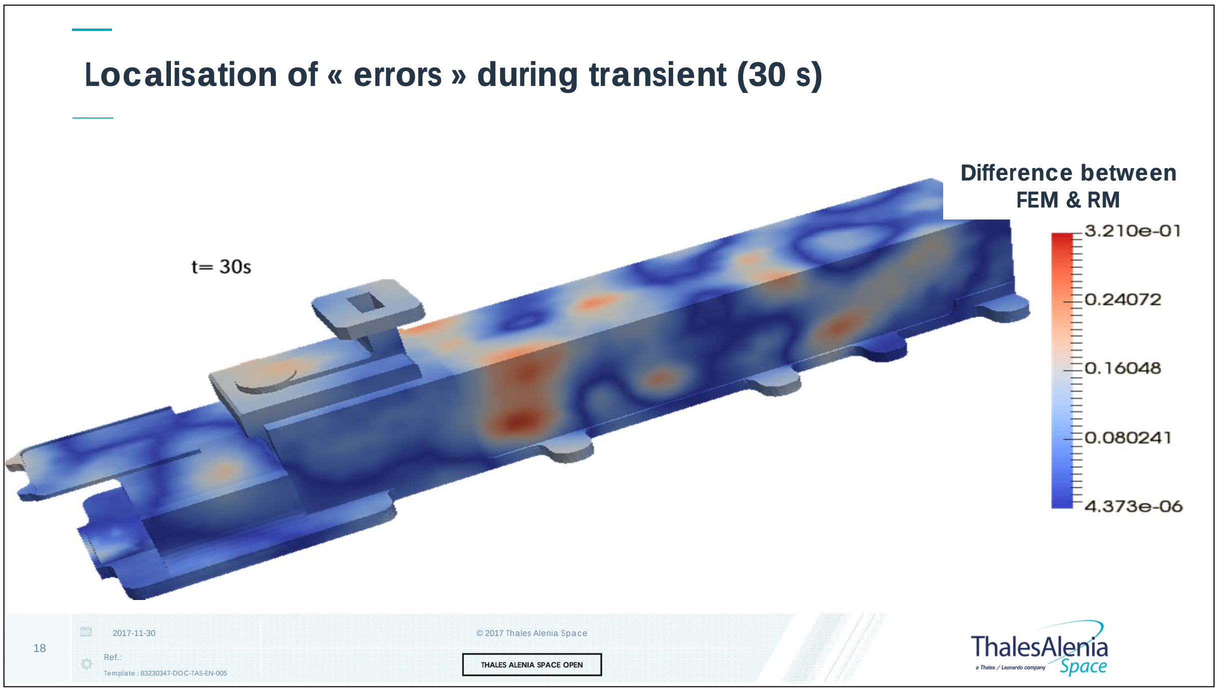
Localisation of « errors » during transient (30 s)
t= 30s
Difference between FEM & RM
3.210e-01
0.24072
0.16048
0.080241
4.373e-06
18
2017-11-30
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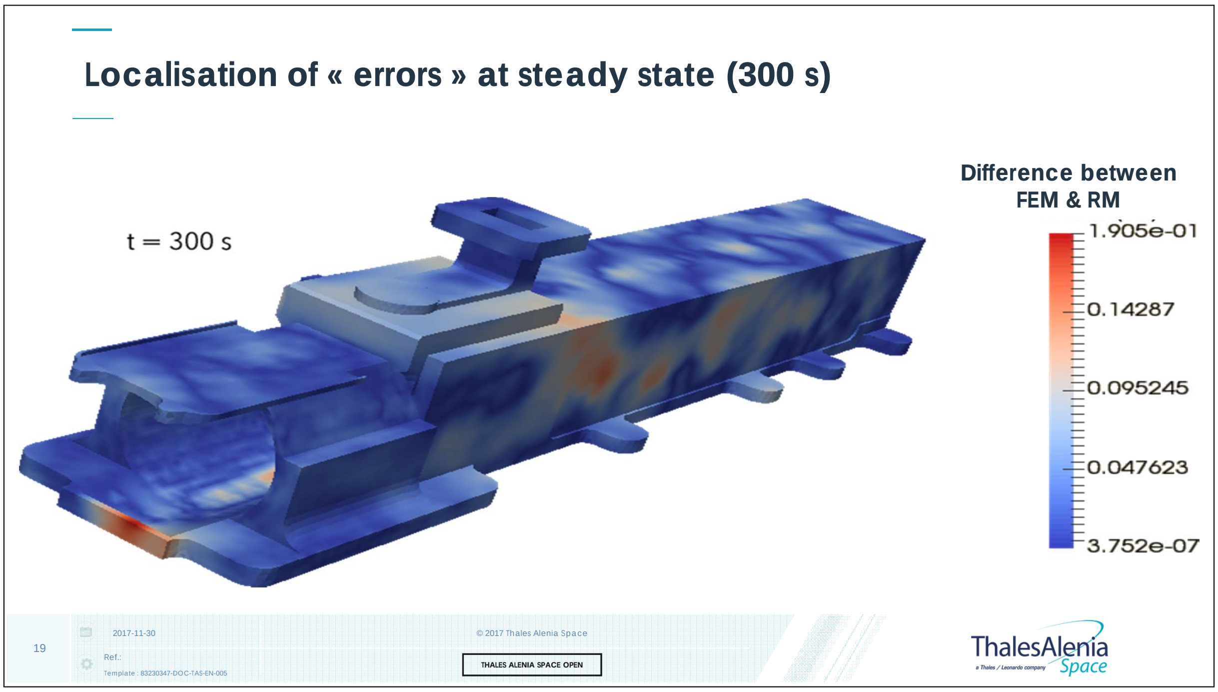
Localisation of « errors » at steady state (300 s)
t = 300 s
Difference between
FEM & RM
1.905e-01
0.14287
0.095245
0.047623
3.752e-07
19
2017-11-30
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Template : 83230347-DOC-TAS-EN-005
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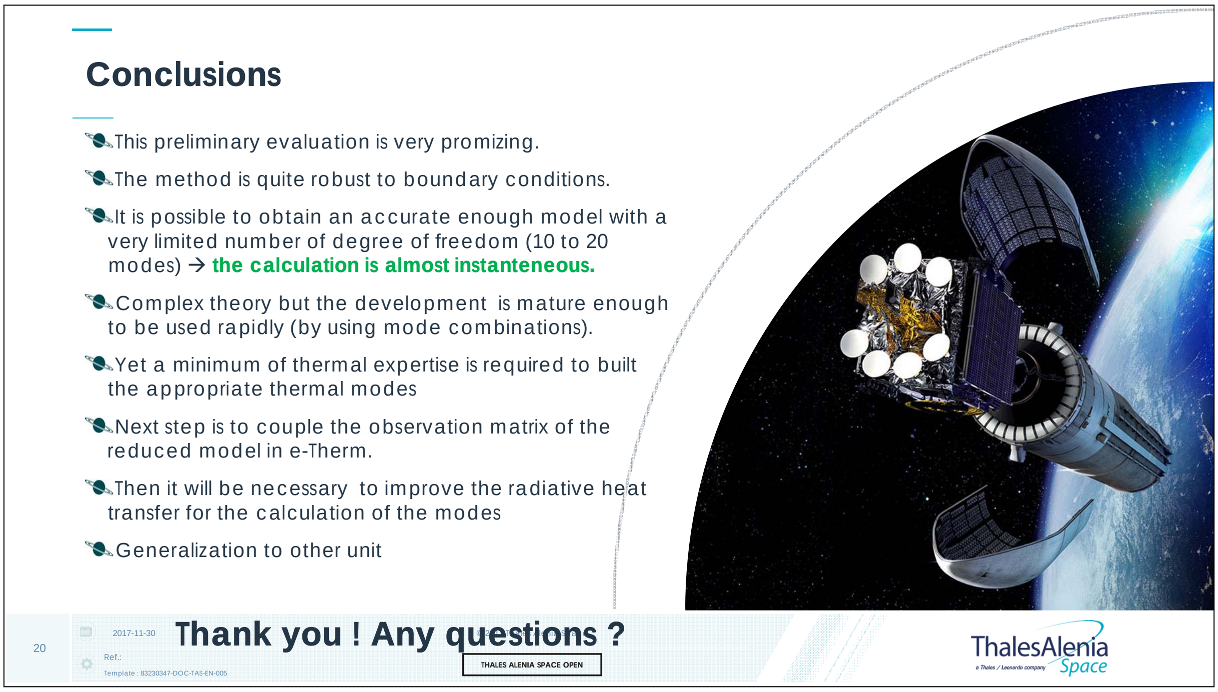
Conclusions
This preliminary evaluation is very promizing.
The method is quite robust to boundary conditions.
It is possible to obtain an accurate enough model with a very limited number of degree of freedom (10 to 20 modes) → the calculation is almost instanteneous.
Complex theory but the development is mature enough to be used rapidly (by using mode combinations).
Yet a minimum of thermal expertise is required to built the appropriate thermal modes
Next step is to couple the observation matrix of the reduced model in e-Therm.
Then it will be necessary to improve the radiative heat transfer for the calculation of the modes
Generalization to other unit
Thank you ! Any questions ?
20
2017-11-30
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Template : 83230347-DOC-TAS-EN-005
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Appendix F

Baseplate Pyramid Modelling of the Calibration Target for the MetOp-SG Microwave Sounder Instrument (MWS)

Katherine Ostojic
(RAL Space, United Kingdom)

Abstract

The Microwave Sounder instruments (MWS) are being built with Airbus Defence and Space (UK) as prime contractor. MWS, flying on the MetOp Second Generation A spacecraft, will make measurements from 23 to 229 GHz for operational meteorology. MWS will be calibrated pre-launch in a thermal vacuum using blackbody targets developed at STFC RAL Space, in Oxfordshire, UK. The variable temperature target, representing the Earth view of MWS, uses a liquid nitrogen / helium gas gap system to control the target temperature to between 80 K and 315 K. The baseplate of the 500 mm diameter target is required to be as isothermal as possible and, in order to approximate a blackbody, the aluminium target surface is machined to contain 2500 square pyramids, each 9 mm wide at base and 40 mm high. These are conformally covered by circa 1.5 mm of low thermal conductivity absorber. These pyramids have proven to be challenging to model using a finite difference method in ESATAN-TMS. A modelling method has been developed which uses the radiative aspects of ESATAN-TMS to determine the heat load on the surfaces of these pyramids. These outputs, in combination with a more detailed finite element ANSYS model of a single pyramid, better determine the temperature distribution through each pyramid for the calculation of physical and brightness temperatures. This talk will examine the lessons learned during the modelling process and the rationale behind the selection of the final analytical method.

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RAL Space

Baseplate Pyramid Modelling of the Calibration Target for the MetOp-SG Microwave Sounder Instrument (MWS)

Katherine Ostojic – RAL Space – 24/10/17

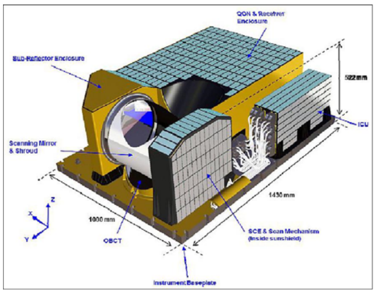
Microwave Sounder (MWS)

Science & Technology Facilities Council

RAL Space

- An instrument on MetOp-SG
- Provides atmospheric temperature and humidity profiles

MetOp-SG spacecraft
http://www.esa.int/spaceinimages/Images/2012/11/MetOp_Second_Generation

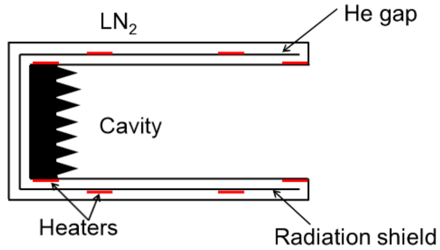


MWS instrument
http://alma-sistemi.com/?p=145

Calibration Target

- A microwave instrument calibration target for ground based testing
- RF engineered so that absorber is close to a perfect black body
- Very precisely controlled temperature
  - 80 K → 315 K
- Temperature control using a variable pressure Helium gas gap
  - Controls thermal conductance from absorber to the LN2 jacket

Diagram credit:
Nicole Melzack
Thermal Engineer
RAL Space



Microwave Absorber

- ~40 mm thick aluminium baseplate
- Covered in >2500 pyramids
  - ~9 mm wide at base and ~40 mm high
- Aluminium pyramids conformally coated in an iron powder / epoxy absorber (1.5 mm thick)

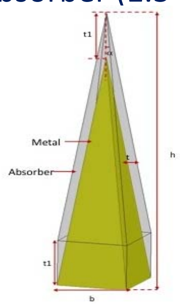


Diagram credit:
Manju Henry
RF Engineer
RAL Space

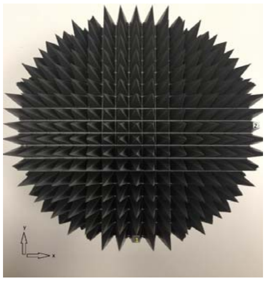
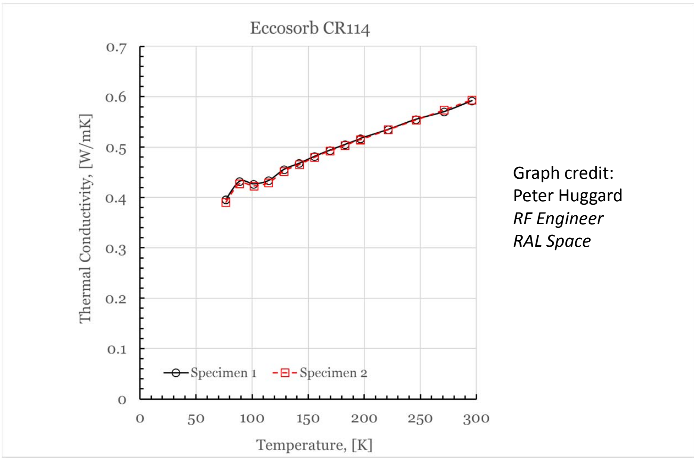


Photo credit:
Rosie Green
RF Engineer
RAL Space

Absorber Conductivity

- Measured at Southampton University
- Low thermal conductivity
  - Hence a high dT in the tip of the pyramid



Graph credit:
Peter Huggard
RF Engineer
RAL Space

Requirements and Challenges

- Need to characterise the temperature variation across the baseplate
  - Both across the width and up the pyramids
- Requirement of 0.1 K dT over the baseplate
  - Impossible due to the absorber → we have developed an alternative
- Verifying the design is tricky
  - Lots of SPRTs (standard platinum resistance thermometers), but mainly modelling

How It is Modelled

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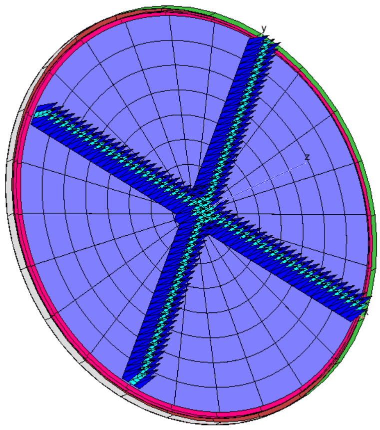
- Subset of pyramids modelled
  - Allows knowledge of variation across base
  - And keeps the radiative case fast
- Inner pyramids (teal) fully modelled
  - Manually generated conductive links
- Outer pyramids (dark blue) are purely radiative
  - Provide a representative radiative environment



Fully Modelled Pyramids

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- Manually added conductive links
  - Possible source of human error
- Low level of discretisation to save computational effort
  - BUT this underestimates the dT through the tip

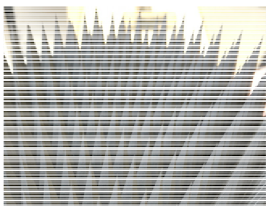
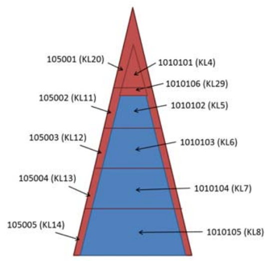


Photo credit:
Rosie Green
RF Engineer
RAL Space



ANSYS Use

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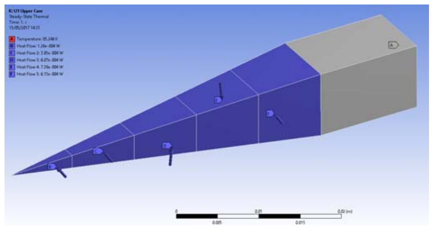
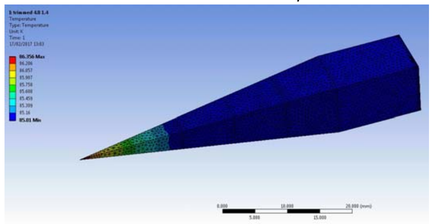
- Single pyramid modelled in FE
  - Higher discretisation
- Thermal boundary conditions taken from ESATAN-TMS model
  - Vary depending on pyramid position
- Results and node positions are used to generate brightness temperature
  - They are fed into a MATLAB code
- Constant relationship developed between the gradient and the ESATAN-TMS estimate



Modelling credit:
Joe Mann
Mechanical Engineer
RAL Space



FD vs. FE

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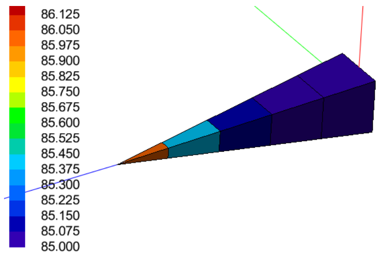
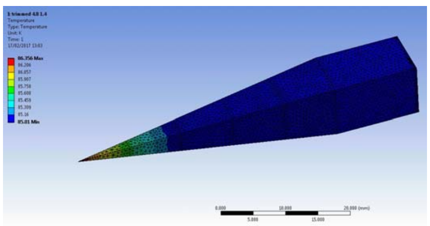
- ESATAN-TMS



- ANSYS



ESATAN-TMS vs. ANSYS

- ESATAN-TMS modelling is used for the overall system and to provide inputs to ANSYS
  - Calculates necessary heater power to achieve set points
  - Initial PID control variables
  - Inputs to ANSYS analysis
  - Checks how fast set point transitions are
  - Ensures that other gradients are acceptable

ESATAN-TMS vs. ANSYS

- ANSYS modelling is used to provide a more detailed pyramid analysis
  - Results used to generate a brightness temperature map of the baseplate for calibration
  - Effective variation in brightness temperature is below 0.1 K at 85K
  - Results have been used to generate a new requirement in terms of brightness temperature
    - Achievable whilst ensuring a good calibration

Lessons Learned

- Collaborating between disciplines has helped to solve the tricky modelling challenges
  - Thermal, mechanical and RF
- 2 years in
  - It’s been a steep learning curve taking on this complex model as my first project

What’s next?

- MWS Calibration Rig incorporating these blackbodies just passed CDR
- It will be manufactured in Q1/2 2018
- Verification testing will occur in Q2/3 2018

- MetOp-SG-A is due for launch in 2021

MetOp-SG Spacecraft
https://directory.eoportal.org/web/eoportal/satellite-missions/m/metop-sg


Thanks for listening
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RAL Space
Any questions?

Appendix G

Enhancement of Loop Heat Pipe module for thermal analysis

Ludovic Zurawski
(Airbus Toulouse, France)

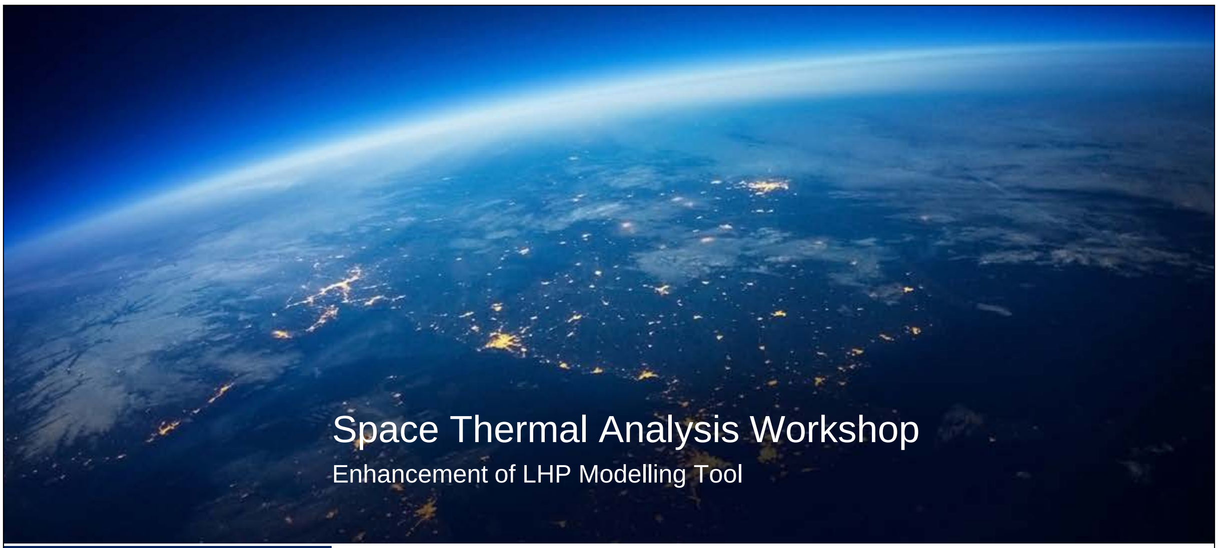
Patrick Hugonnot Paul Atinsounon
(Thales-Alenia Space, France)

James Etchells
(ESA/ESTEC, The Netherlands)

Abstract

This presentation reports on the Loop Heat Pipe (LHP) module enhancement aiming to provide to the European space community a software to model Loop Heat Pipes for system level thermal analyses in the scope of a collaboration between ESA & CNES Agencies, Airbus Defence and Space and Thales-Alenia Space.
LHPs are indeed more and more used in space for current & future applications, due to their performances (in terms of weight, design flexibility, thermal transport capacity and accommodation flexibility).
The previous LHP module version, developed in the frame of a R&T CNES activity is fully operational and has been used on a number of programs. However, it only addresses a limited number of LHP architectures and analytical scenarios. The objective of the "Enhancement of LHP Modelling tool" program is then to further develop the module to support the new identified needs consisting of complex architectures (e.g. regulation valves & multiple condensers) and also physical scenarios. In addition, from experience gained on the software by several users, the need of improving the module in terms of robustness, performance & ease of use is clearly identified.
The main topics to be addressed during the Workshop are presented hereafter:

- Program organization
- LHP Module overview (purposes, theoretical bases, ...)
- General improvements (solvers compatibility , man-machine interface, ...)
- Complex architectures modelling capabilities (recursive approach for multi-branches architecture)
- New functionalities implementation (regulating valve, capillary blocker) with validation test cases
- Black boxes (Thermisol , Esatan and e-Therm) presentation
- Way forward
  - gravity effect
  - transient phenomena (start-up, ...)



DEFENCE AND SPACE

L. Zurawski (ADS), P. Hugonnot (TAS), P. Atinsounon (TAS), J. Etchells (ESA)
24-25 October 2017

31st European Space Thermal Analysis Workshop – Enhancement of LHP Modelling Tool

Agenda

- Introduction (ESA/ADS)
- Improvements versus previous version (TAS/ADS)
- Validation cases (TAS/ADS)
- Black boxes versions (ADS)
- Way forward (ADS)
- Conclusion (ESA)

2 23 October, 2017 Enhancement of LHP Modelling Tool

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Introduction

- **General introduction (ESA)**
- **LHP Module Overview (ADS)**
- **Program organisation (ADS)**

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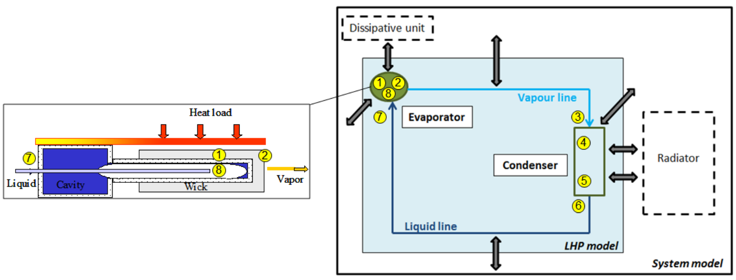
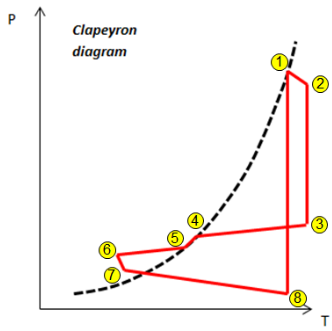
Introduction – LHP Module overview

- **LHP**
  - 2 phase flow heat transfer device using
    - *evaporation, condensation to transfer heat*
    - *capillary forces to circulate the fluid*
  - To transport large amounts of thermal fluxes on large distances (next generation of S/L)
  - One of the most promising fluid loop technologies (weight, flexibility, accommodation, …)





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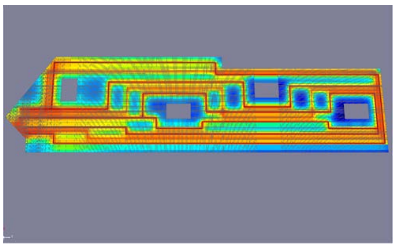
Introduction – LHP Module overview

- **LHP Module v2**
  - To model the behaviour of LHP at System level ➔ just-enough modelling
  - Compatible with Thermisol and Esatan solvers
  - Fully operational and used on a number of programs (EarthCare instrument, DPR, …)
- **New needs (not covered by v2)**
  - Complex architectures as multi-condensers or multi-branches configurations
  - New advanced components enabling to better control the loop performances
  - Gravity effect to better understand/correlate ground tests
  - Customer survey highlighted some improvements to be done
    - *Simplification of both input and output files*
    - *Increase flexibility for piping definition*
    - *To modify the converging mode to allow larger time steps in transient mode*

➔ Development of LHP Module v3

DPR at clean room

DPR thermal model



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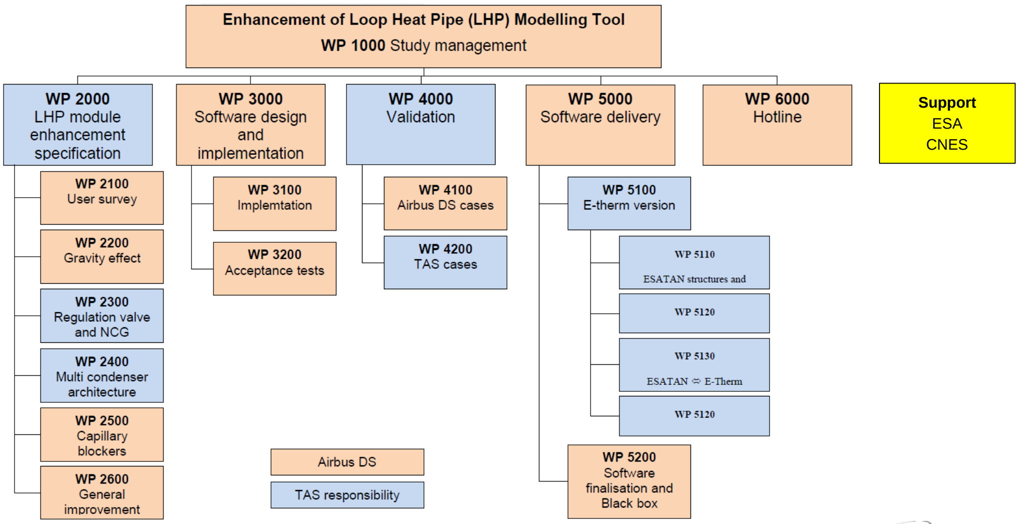
Introduction – Program organisation



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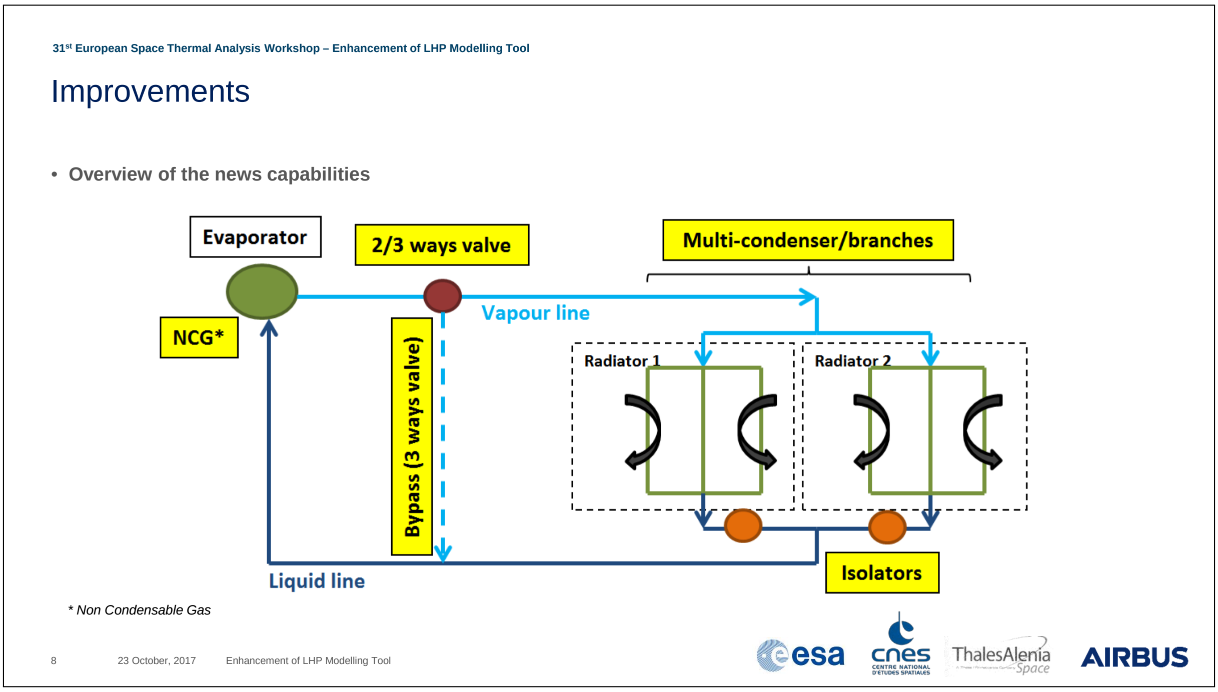
Improvements versus previous versions
• Overview (ADS)
• Complex architecture management (TAS)
• New functionalities (TAS)
• General improvements (ADS)
7
23 October, 2017
Presentation title runs here (go to Header and Footer to edit this text)
esa
cnes
ThalesAlenia Space
AIRBUS


31st European Space Thermal Analysis Workshop – Enhancement of LHP Modelling Tool
Improvements
• Overview of the news capabilities
Evaporator
2/3 ways valve
Multi-condenser/branches
NCG*
Vapour line
Bypass (3 ways valve)
Radiator 1
Radiator 2
Isolators
Liquid line
* Non Condensable Gas
8
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Enhancement of LHP Modelling Tool
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AIRBUS

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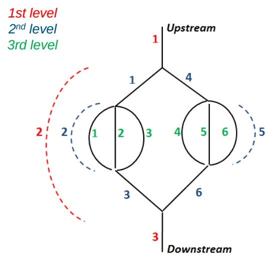
Improvements – Complex architecture management

Functions
To enable the user to model the condenser either in series or parallel configuration
At least two possible levels of parallel branches

- **Solution/implementation**
  - Recursion
  - Nota: current versions of solvers do not support recursion
    - *Bypassed by implementing pseudo recursion*
    - *Limited to 2 sublevels*
    - *Future versions of Thermisol will support recursion*

```
Recursive Subroutine process_section(isection)
For component = 1st component to last component
   If type = cell_line then process_cell_line
   If type = isolator then process_isolator
   If type = 2ways_valve then process_2ways_valve
   If type = 3ways_valve or simple_derivation then
      Process derivation inlet
         For each branch
            Call process_section(ibranch)
         EndFor
      Process derivation outlet
EndFor
Endroutine
```



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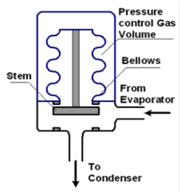
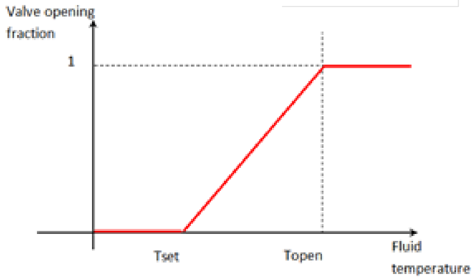
Improvements – New functionalities – 2 ways valve



Functions
To regulate the flow according to the temperature of the fluid
To block the mass flow to the condenser (LHP stop) when the fluid is below a specified temperature

- **Solution/implementation**
  - Add of pressure drop at evaporator outlet
  - Modelled with a transfer function depending on:
    - *The valve pressure drop factor E (provided by the manufacturer)*
    - *The fluid features (density, velocity)*
    - *The valve opening fraction OF*
    - *Characteristic temperatures (Tset and Topen)*



$$\mathrm{OF} = \frac{T - Tset}{Topen - Tset} \Rightarrow dP = \frac{E}{OF^3}\frac{\rho V^2}{2}$$

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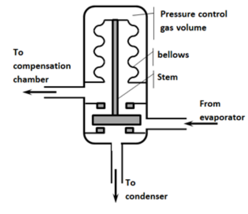
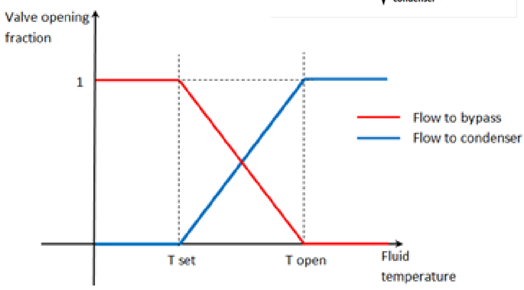
Improvements – New functionalities – 3 ways valve



Functions
To regulate the reservoir temperature splitting the flow between reservoir and condenser
To block the mass flow to the condenser (LHP stop) when the fluid is below a specified temperature

- **Solution/implementation**
  - Add of pressure drop at evaporator outlet
  - Modelled with a transfer function depending on:
    - *The valve pressure drop factors in both by-pass and condenser lines*
    - *The fluid features (density, velocity in both by-pass and condenser lines)*
    - *The valve opening fraction OF*
    - *Characteristic temperatures (Tset and Topen)*

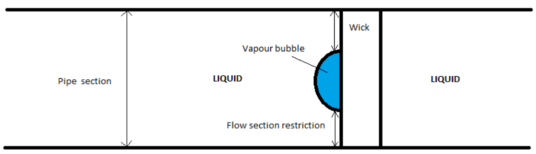


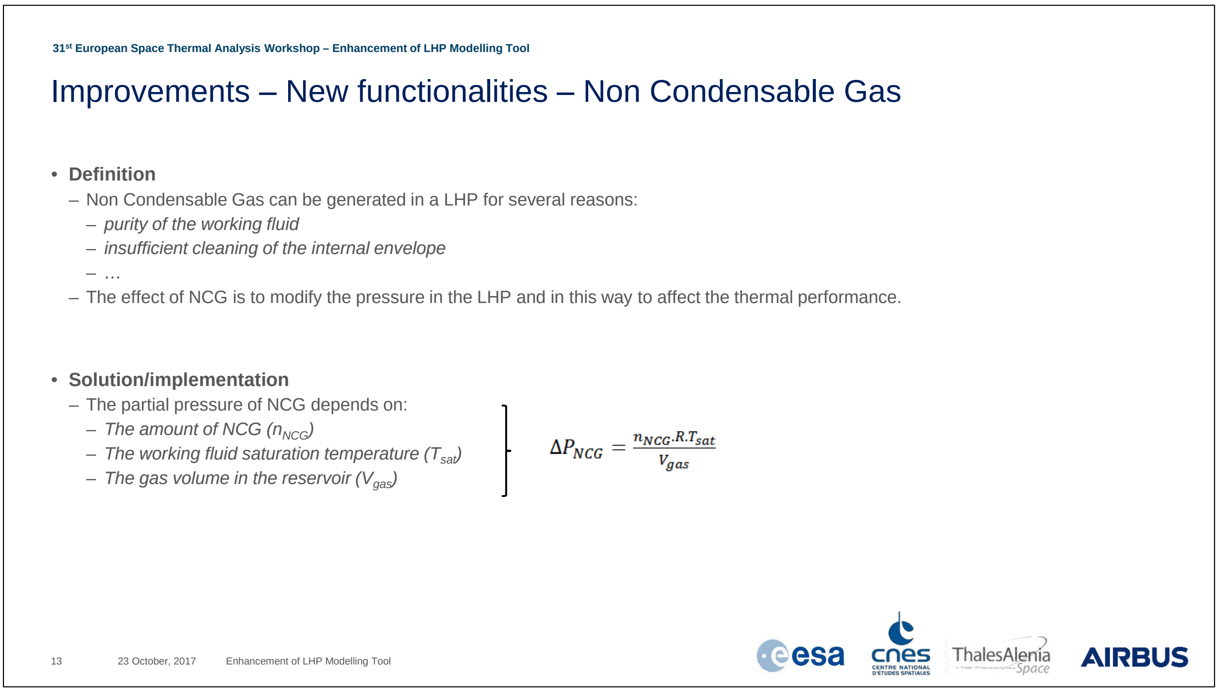
$$OF = \frac{T - Tset}{Topen - Tset} \Rightarrow \begin{cases} dP_{cond} = \frac{\varepsilon_{cond}}{OF^2}\,\frac{\rho V_{cond}{}^2}{2} \\ dP_{bypass} = \frac{\varepsilon_{bypass}}{(1-OF)^2}\,\frac{\rho V_{bypass}{}^2}{2} \end{cases}$$

Improvements – New functionalities – Capillary blocker

Functions
To block the vapour that could remain at the condenser outlet and perturb LHP operation
To balance the heat exchanges between the different branches in case of parallel condensers

- **Solution/implementation**
  - Add of capillary pressure drop at condenser outlet
  - The total pressure drop in the capillary blocker depends on:
    - *The Darcy pressure drop*
    - *The singular pressure drop (change of section)*
    - *The capillary pressure drop*
    - *The frictional pressure drops*
    - *Possibly the static pressure drop in case of functioning under gravity condition*

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Improvements – New functionalities – Non Condensable Gas
• Definition
– Non Condensable Gas can be generated in a LHP for several reasons:
– purity of the working fluid
– insufficient cleaning of the internal envelope
– …
– The effect of NCG is to modify the pressure in the LHP and in this way to affect the thermal performance.
• Solution/implementation
– The partial pressure of NCG depends on:
– The amount of NCG (n_{NCG})
– The working fluid saturation temperature (T_{sat})
– The gas volume in the reservoir (V_{gas})
$\Delta P_{NCG} = \frac{n_{NCG}.R.T_{sat}}{V_{gas}}$
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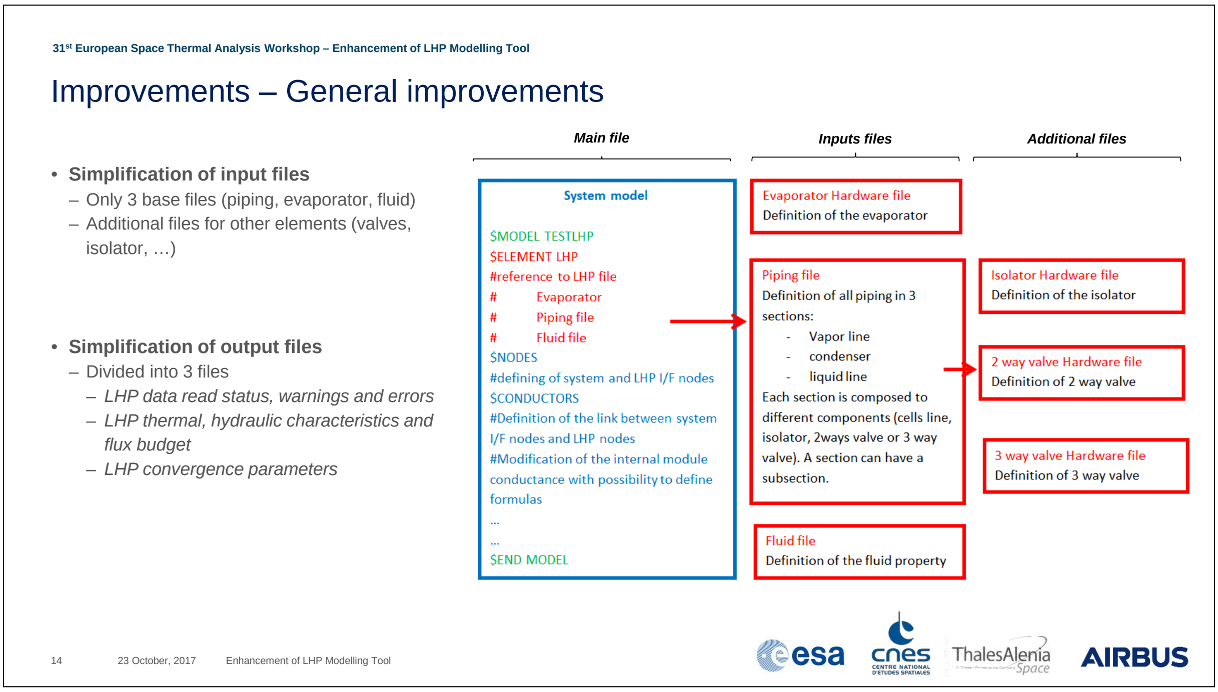
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Improvements – General improvements
• Simplification of input files
– Only 3 base files (piping, evaporator, fluid)
– Additional files for other elements (valves, isolator, …)
• Simplification of output files
– Divided into 3 files
– LHP data read status, warnings and errors
– LHP thermal, hydraulic characteristics and flux budget
– LHP convergence parameters
Main file
Inputs files
Additional files
System model
$MODEL TESTLHP
$ELEMENT LHP
#reference to LHP file
Evaporator
Piping file
Fluid file
$NODES
#defining of system and LHP I/F nodes
$CONDUCTORS
#Definition of the link between system I/F nodes and LHP nodes
#Modification of the internal module conductance with possibility to define formulas
...
...
$END MODEL
Evaporator Hardware file
Definition of the evaporator
Piping file
Definition of all piping in 3 sections:
- Vapor line
- condenser
- liquid line
Each section is composed to different components (cells line, isolator, 2ways valve or 3 way valve). A section can have a subsection.
Fluid file
Definition of the fluid property
Isolator Hardware file
Definition of the isolator
2 way valve Hardware file
Definition of 2 way valve
3 way valve Hardware file
Definition of 3 way valve
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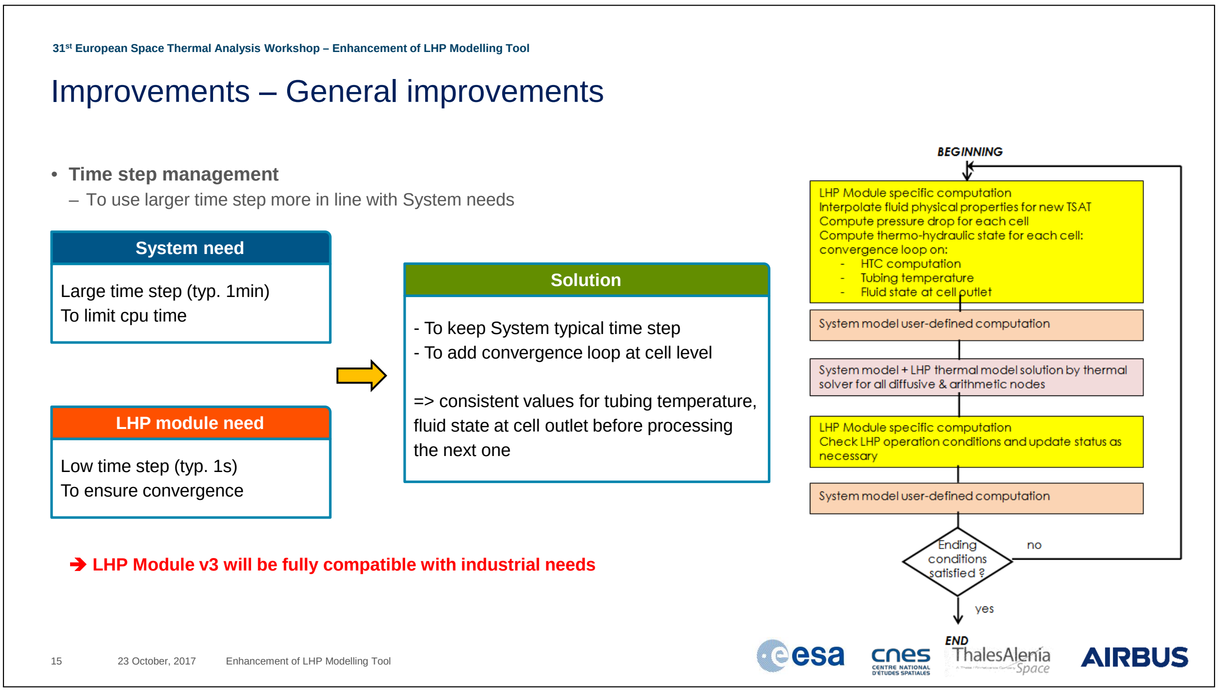
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Improvements – General improvements
• Time step management
– To use larger time step more in line with System needs
System need
Large time step (typ. 1min)
To limit cpu time
LHP module need
Low time step (typ. 1s)
To ensure convergence
Solution
- To keep System typical time step
- To add convergence loop at cell level
=> consistent values for tubing temperature, fluid state at cell outlet before processing the next one
BEGINNING
LHP Module specific computation
Interpolate fluid physical properties for new TSAT
Compute pressure drop for each cell
Compute thermo-hydraulic state for each cell:
convergence loop on:
- HTC computation
- Tubing temperature
- Fluid state at cell outlet
System model user-defined computation
System model + LHP thermal model solution by thermal solver for all diffusive & arithmetic nodes
LHP Module specific computation
Check LHP operation conditions and update status as necessary
System model user-defined computation
Ending conditions satisfied ?
no
yes
END
➔ LHP Module v3 will be fully compatible with industrial needs
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Validation cases
• Multi-condenser architecture (TAS)
• 2 ways valve (TAS/ADS)
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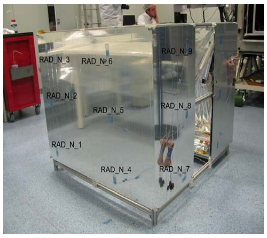
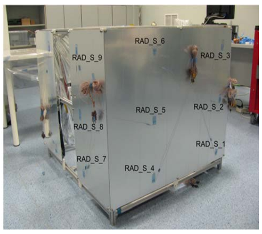
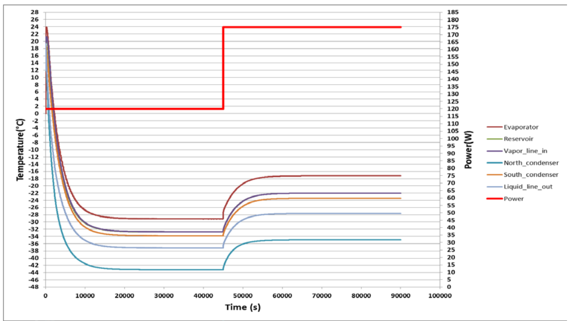
Validation cases

- **Multi-condenser / Multi-branches architecture (TAS)**
  - 2 parallel condensers each associated to North and South radiators (unit radiative area=1.1 m²)
  - Validation cases: 2 steady-state cases with fixed powers on the evaporator saddle (@120W / @175W)
  - Correlation criteria :+/- 5°C

		TEMPERATURES		
		Test (°C)	LHP Module (°C)	Delta test (°C)
CASE 1 @120W	Saddle	-25.6	-29.1	**-3.5**
	Compensation chamber	-28.3	-32.7	**-4.4**
	Vapour line inlet	-28.6	-32.7	**-4.1**
	North condenser	-46.3	-43.2	**3.1**
	South condenser	-33.1	-33.8	**-0.7**
	Liquid line outlet	-39.5	-37.2	**2.3**
CASE 2 @175W	Saddle	-12.7	-17.2	**-4.5**
	Compensation chamber	-18.7	-22.0	**-3.3**
	Vapour line inlet	-17.7	-22.0	**-4.3**
	North condenser	-31.4	-34.9	**-3.5**
	South condenser	-24.5	-23.4	**1.1**
	Liquid line outlet	-30.3	-27.6	**2.7**







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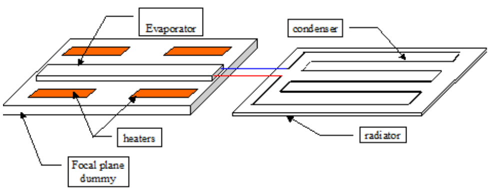
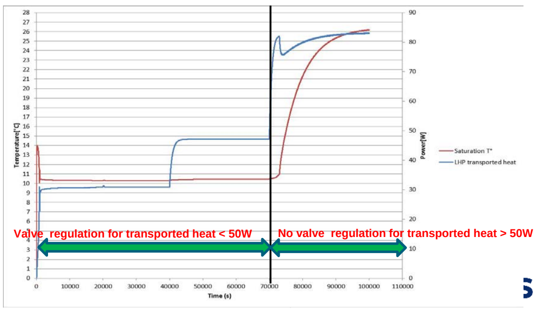
Validation cases

- **2 ways valve – Case 1 (TAS)**
  - Test configuration: focal plane dummy + 2 way-valve LHP + radiative plate
  - Tset valve = 10°C
  - Validation cases: 4 steady-state cases with 4 steps of power on the evaporator saddle (@29W, @30W, @ 47W, and @84W)
  - Correlation criteria :+/- 5°C and +/- 15% on Focal plane ATC consumption

		TEMPERATURES		
		Test (°C)	LHP Module TMM (°C)	Delta test (°C)
CASE 3 (@29W)	FP_TRP1	15.1	15.0	**-0.1**
	FP_TRP2	14.9	15.0	**0.1**
	Saddle	14.2	12.7	**-1.5**
	Compensation chamber	9.4	7.4	**-2.0**
	Vapour line inlet	10.8	10.3	**-0.5**
	Condenser	-35.3	-36.9	**-1.6**
CASE 3* (@30W)	FP_TRP1	15.5	15.0	**-0.5**
	FP_TRP2	15.0	15.0	**0.0**
	Saddle	14.4	12.7	**-1.7**
	Compensation chamber	9.6	7.4	**-2.2**
	Vapour line inlet	10.9	10.3	**-0.6**
	Condenser	-33.8	-34.0	**-0.2**
CASE 4 (@47W)	FP_TRP1	18.3	17.6	**-0.7**
	FP_TRP2	17.8	17.6	**-0.2**
	Saddle	16.8	14.1	**-2.7**
	Compensation chamber	10.0	7.6	**-2.4**
	Vapour line inlet	11.9	10.4	**-1.5**
	Condenser	-10.5	-11.5	**-1.0**
CASE 5 (@84W)	FP_TRP1	36.7	38.8	**2.1**
	FP_TRP2	36.0	38.8	**2.8**
	Saddle	34.0	32.7	**-1.3**
	Compensation chamber	24.4	26.0	**1.6**
	Vapour line inlet	26.6	26.2	**-0.4**
	Condenser	24.8	24.5	**-0.3**





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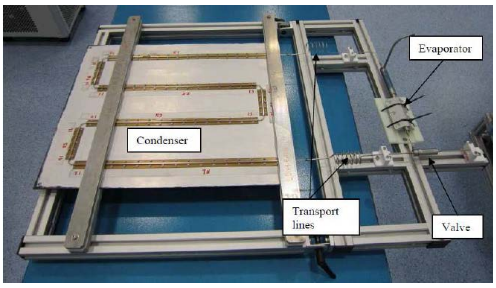
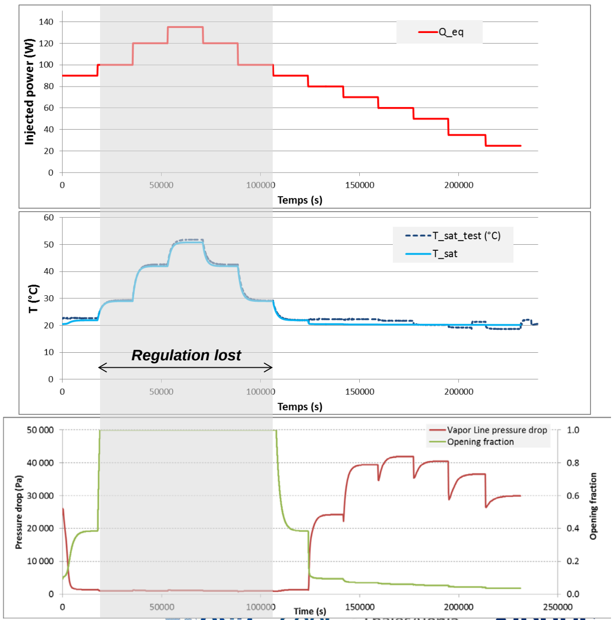
Validation cases

- **2 ways valve – Case 2 (ADS)**
  - Iberespacio LHP
  - Power stages from 20W to 140W





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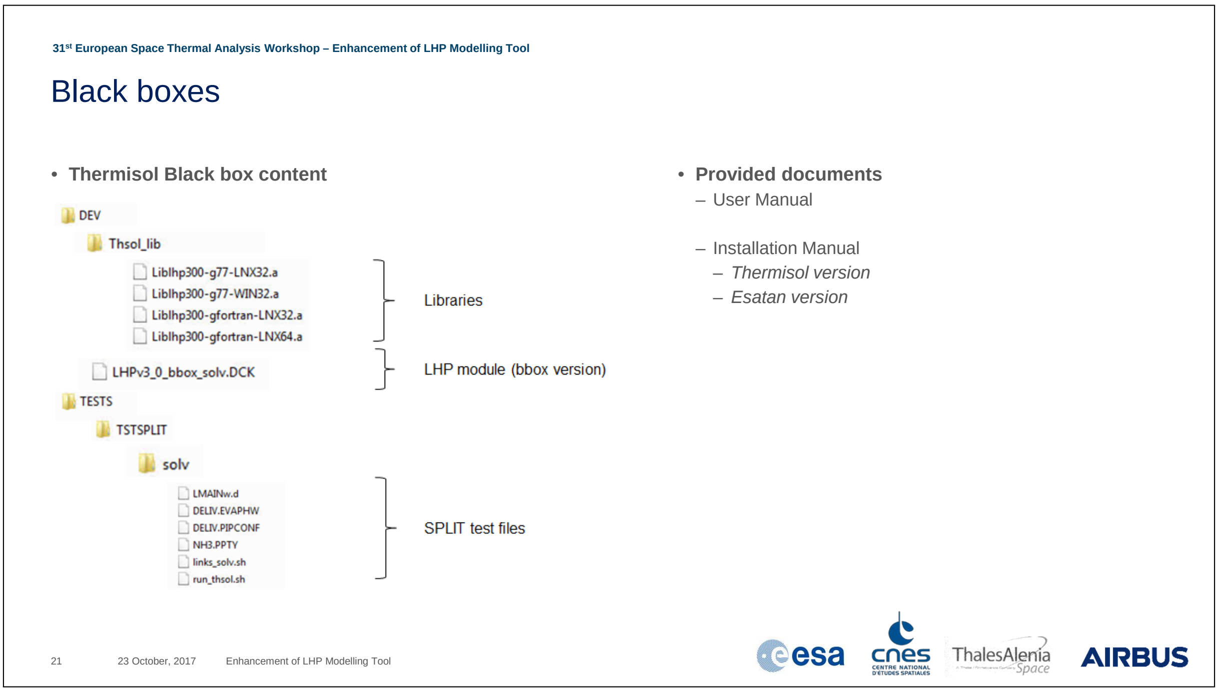
Black boxes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Black boxes
• Thermisol Black box content
DEV
Thsol_lib
Liblhp300-g77-LNX32.a
Liblhp300-g77-WIN32.a
Liblhp300-gfortran-LNX32.a
Liblhp300-gfortran-LNX64.a
Libraries
LHPv3_0_bbox_solv.DCK
LHP module (bbox version)
TESTS
TSTSPLIT
solv
LMAINw.d
DELIV.EVAPHW
DELIV.PIPCONF
NH3.PPTY
links_solv.sh
run_thsol.sh
SPLIT test files
• Provided documents
– User Manual
– Installation Manual
– Thermisol version
– Esatan version
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Way forward
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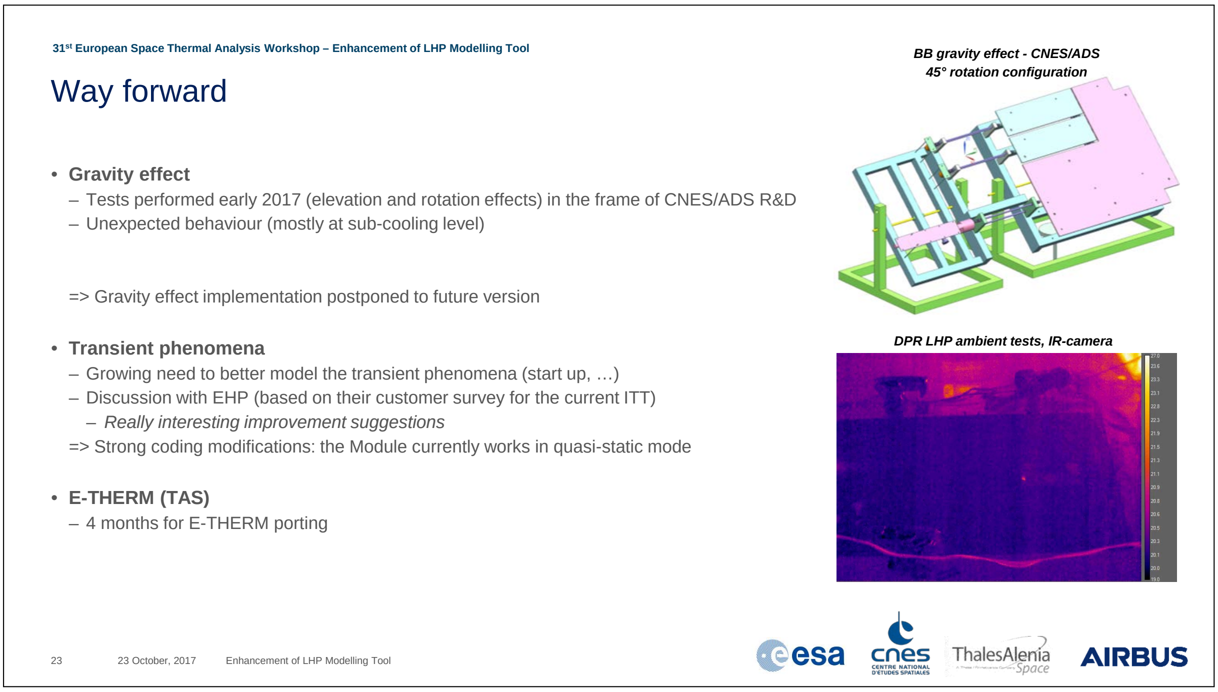
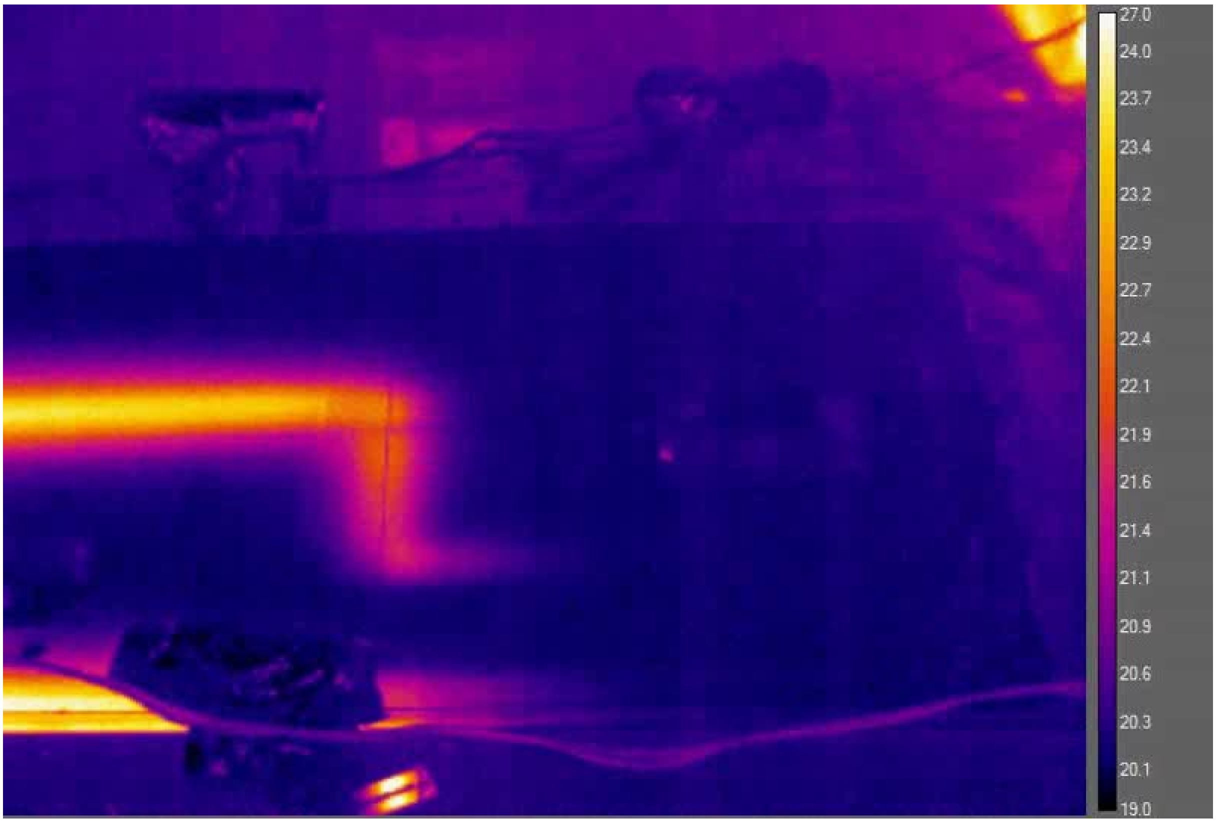
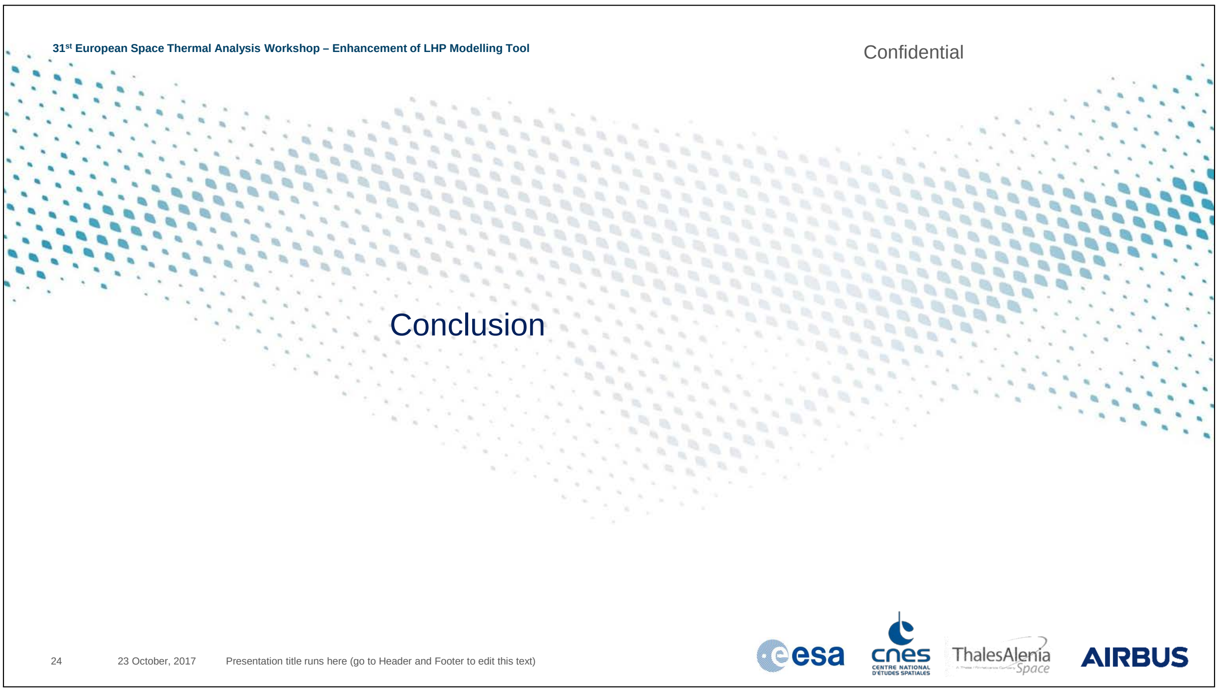




Save the attachment to disk or (double) click on the picture to run the movie.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Conclusion
24
23 October, 2017
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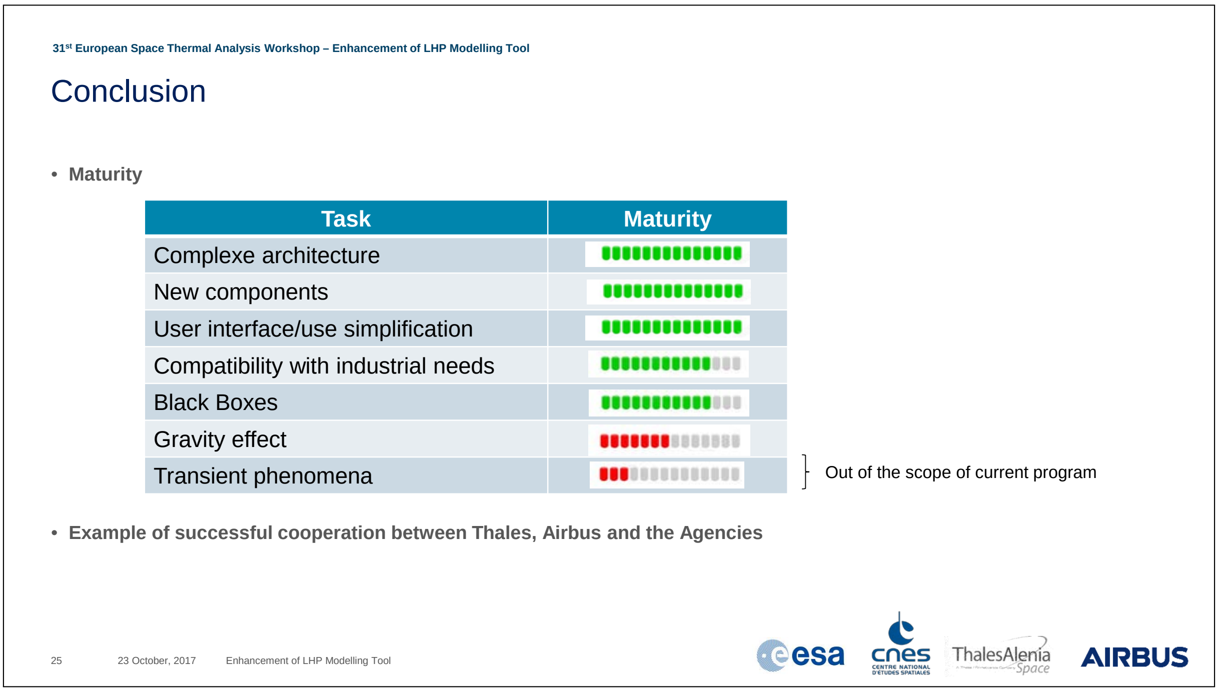
cnes
ThalesAlenia Space
AIRBUS


31st European Space Thermal Analysis Workshop – Enhancement of LHP Modelling Tool
Conclusion
• Maturity
Task
Maturity
Complexe architecture
New components
User interface/use simplification
Compatibility with industrial needs
Black Boxes
Gravity effect
Transient phenomena
Out of the scope of current program
• Example of successful cooperation between Thales, Airbus and the Agencies
25
23 October, 2017
Enhancement of LHP Modelling Tool
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cnes
ThalesAlenia Space
AIRBUS


Thank you
Copyright mention

Appendix H

Improved Integrated Way of Post-processing Thermal Model Data

Nicolas Bures
(ITP Engines UK, United Kingdom)

Abstract

Post-processing of the thermal results is a significant part of the overall thermal modelling process. Clear presentation of results not only helps towards the understanding of the thermal behaviour of the model, but also helps towards model validation. This presentation focuses on how ESATAN-TMS 2018 further helps the thermal engineer to work efficiently, eliminating repetitiveness by making the process fully automatic and integrated within a single interface.

ESATAN-TMS thermal modelling suite

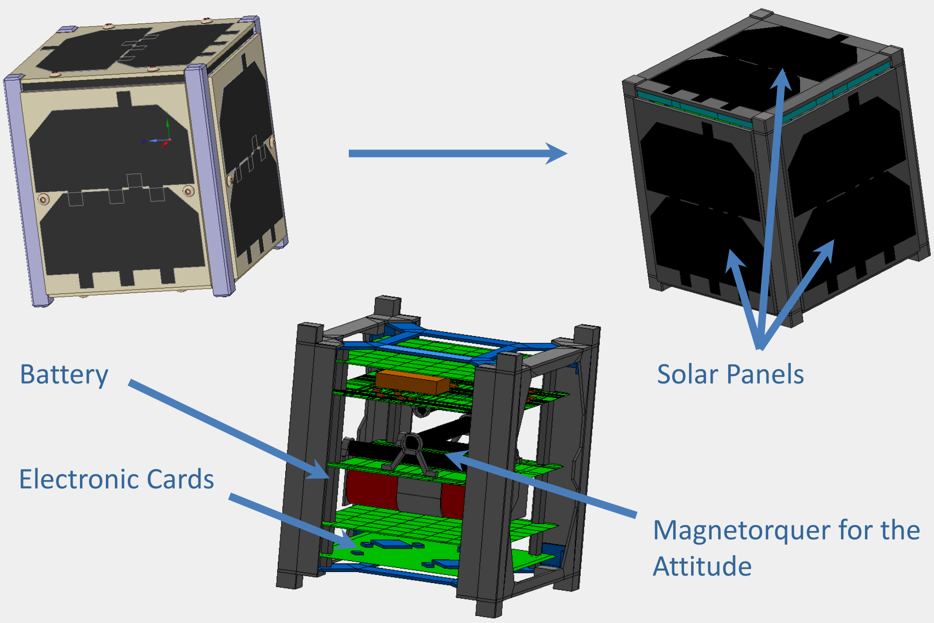
Summary of the Presentation

- Summary of the CubeSat provided by Melbourne University
  - Provided as a .stp file, converted using CADbench
- Presentation of the requirements
  - Temperature of different components will be plotted using charts for multiple cases
  - Cases will be compared to evaluate the temperature change and temperature evolution using a Delta Chart
  - Temperature requirements will be verified using a Limits Chart
- Demo
  - A typical post-processing example will be presented using the new version of ESATAN-TMS

ESATAN-TMS thermal modelling suite

Model Presentation

- Thermal design created in ESATAN-TMS, imported from CADbench



ESATAN-TMS thermal modelling suite

Thermal Requirements

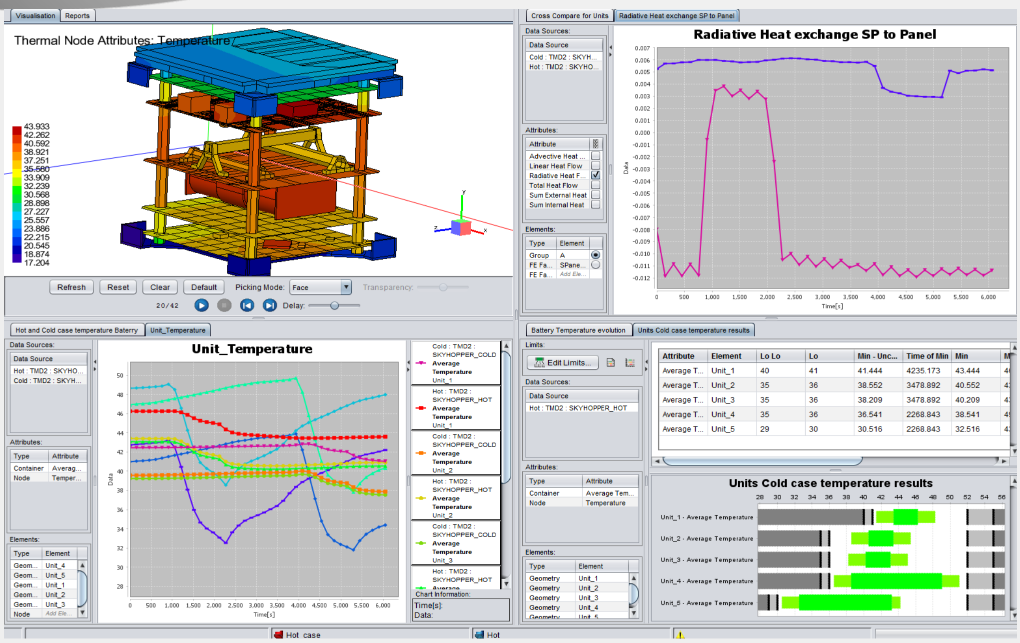
- Temperature requirements
  - Units 1 to 5 located on different electronic cards in the model are constrained by temperature requirements provided by the supplier
  - The battery temperature must strictly be between 35 and 50 degrees for both the hot and cold case
- Heat exchange requirements
  - The radiative heat exchange between Solar_Cell_10 and the Solar_Panel_6 structure must be negligible (less than 1W)
- The model shall be exported and provided as a text file to the customer

ESATAN-TMS
thermal modelling suite

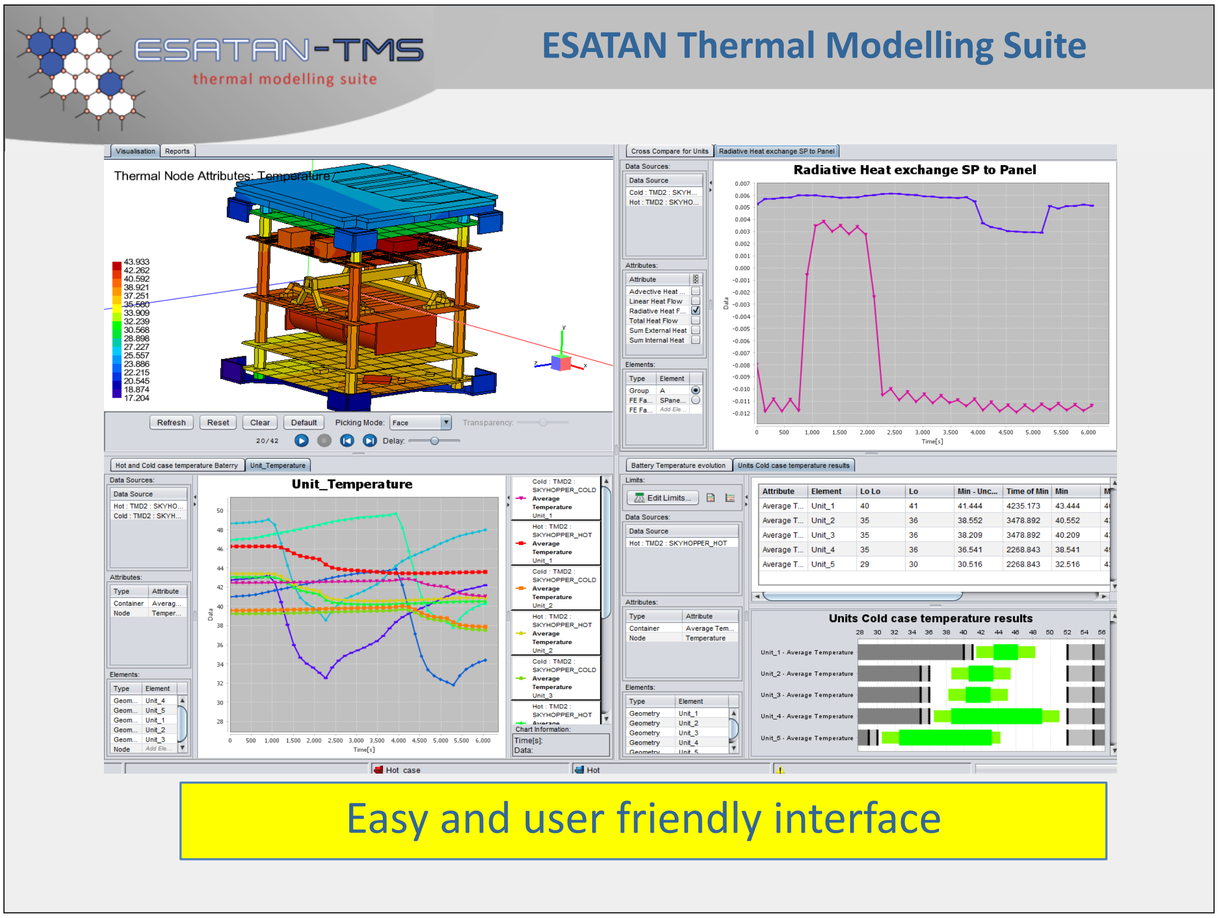
DEMO

ESATAN-TMS
thermal modelling suite

ESATAN Thermal Modelling Suite



Complete environment for thermal modelling


ESATAN-TMS
thermal modelling suite
ESATAN Thermal Modelling Suite
Thermal Node Attributes: Temperature
Radiative Heat exchange SP to Panel
Unit_Temperature
Units Cold case temperature results
Easy and user friendly interface


ESATAN-TMS
thermal modelling suite
www.esatan-tms.com

Appendix I

Thermal Analysis of Electrochromic Radiators on Sentinel 2

Oliver Kluge Alexander Zwiebler Dr. Tino Schmiel Prof. Dr. Martin Tajmar
(Dresden University of Technology, Germany)

Martin Altenburg
(Airbus Defence and Space, Germany)

Abstract

The potential of electrochromic thin film radiators with variable optical properties is more and more evaluated by spacecraft developers. The design of the Thermal Control System is driven by constraints that can appear in the form of a limited power budget, high thermal gradients, different thermal loads or a limited mass budget.

Electrochromic radiators with variable optical properties can repeal such a limitation by adjusting both emissivity (ε) and solar absorptivity (α). This capability may ease the design of a Thermal Control System itself, the design of the satellite and the Mission/Operation. Consequently such a radiator should have monetary advantages. This presentation contains the thermal and electrical analysis of the earth observation satellite Sentinel 2 equipped with a theoretical electrochromic radiator which is currently developed by TU-Dresden in cooperation within an industrial (Airbus Defence and Space GmbH) co-founded Graduate School. These electrochromic radiators are based on electrochemical cells and the intercalation of Li-Ions into transition-metal oxides.

The first results of our simulations show, that power savings (e.g. for payload heating) up to 100% are possible. A value of $\Delta\varepsilon$>=0,4 seems to be the threshold for using electrochromic surfaces efficiently in thermal engineering of spacecrafts. They also make clear that the control speed of radiators α/ε is not highly relevant for thermal design due to the high thermal masses in the spacecraft.

These advantages are limited caused by still necessary redundant systems to ensure the survival of the payloads and the electrical power for the electrochromic radiator itself. These results encourage to more detailed investigations on a thermal control system using electrochromic radiators. The results of the Sentinel 2 thermal analysis will be presented and the restrictions will be discussed.

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Faculty of Mechanical Science and Engineering, Institute of Aerospace Engineering, Chair of Space Systems

Thermal Analysis of Electrochromic Radiators on Sentinel 2

Oliver Kluge *)[1], Alexander Zwiebler[1], Martin Altenburg[2], Tino Schmiel[1], Martin Tajmar[1]

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[2]Airbus Defence & Space GmbH, Germany

Noordwijk, 24.10.2017

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Institute of Aerospace Engineering Dresden

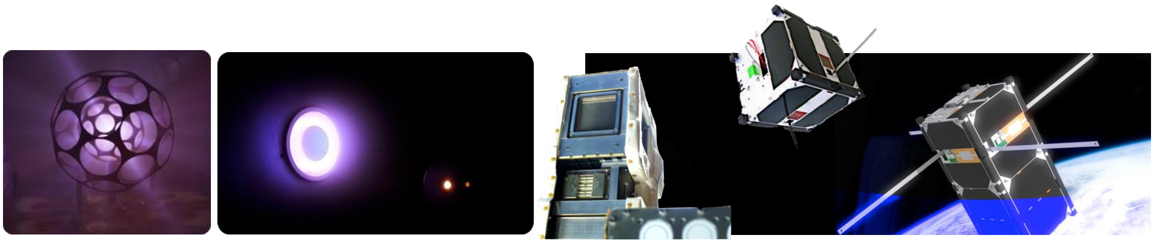
Institute of Aerospace Engineering

Director: Prof. Dr. Martin Tajmar

Aircraft Engineering	Space Systems
Prof. Dr. Klaus Wolf	Prof. Dr. Martin Tajmar

Research Groups

Space Propulsion & Future Concepts (Prof. Dr. Martin Tajmar)	Small Satellites & Spin-off Technologies (Dr.-Ing. Tino Schmiel)	Space Power Systems & Mobile Applications (Dr.-Ing. Tino Schmiel)



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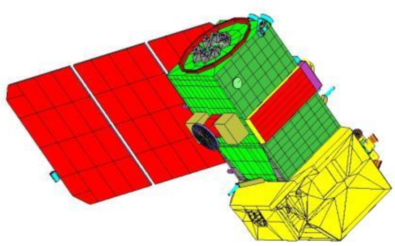
Content

- Variable Radiator: Need → Solution
- Description: Electrochromic Radiator
- Description: Thermal Analysis on Sentinel 2
- Heater Power savings (e.g. Battery, VCU, LCT)
- $\Delta\alpha/\Delta\varepsilon$ Requirements (e.g. Battery)
- $\Delta\alpha/\Delta\varepsilon$ control speed (e.g. Battery)
- Preliminary Hardware results
- Conclusion
- Contact Information



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Need → Solution

- **Intro**
  - Current Missions needs significant heater power
- **NEED / Problem**
  - Different thermal loads on space missions
  - Solararray + battery for heater
  - High temperature gradients on sensititve payloads
  - Missions canceled in Phase 0...B1 due to the small mass budgets
  - Heavy Louver (≈ 5 kg/m²…only ε)
- **SOLUTION: Adjustable radiators**
  - Scalable production for different requirements
  - ↓ temperature gradients ↓ thermal noise → Performance increase (e.g. LISA Pathfinder..sensors)
  - Savings: Heater Power (up to 100 %) → Solar Array → Harness → Mass
  - Simplification of Design justification

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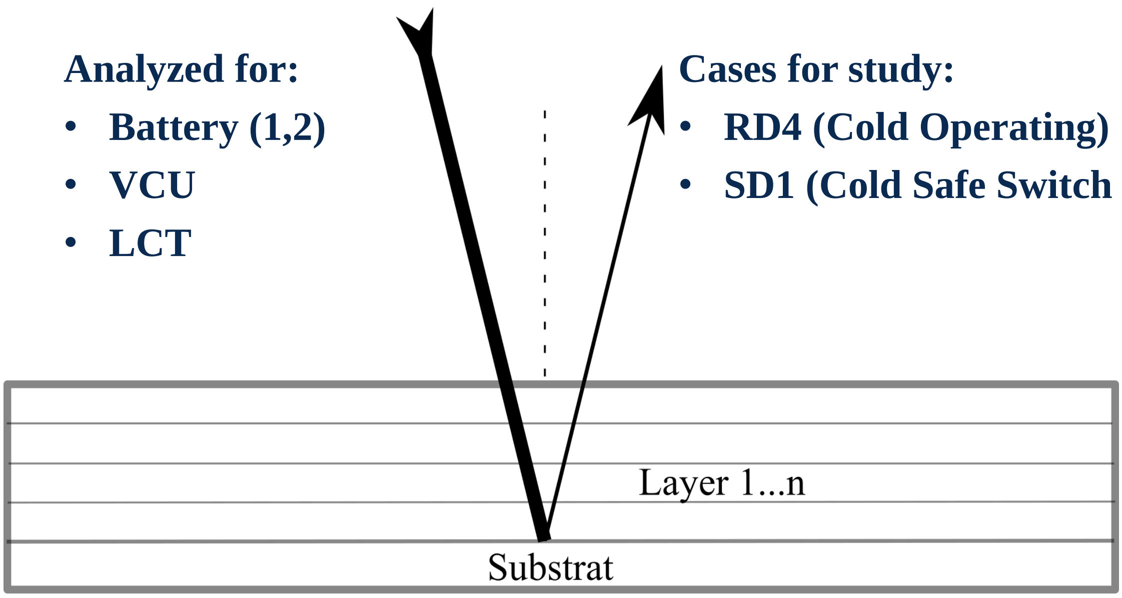
Electrochromic Radiator

Cold Case: ↑α ↓ε

Hot Case: ↓α ↑ε

Analyzed for:
- **Battery (1,2)**
- **VCU**
- **LCT**

Cases for study:
- **RD4 (Cold Operating)**
- **SD1 (Cold Safe Switch On)**



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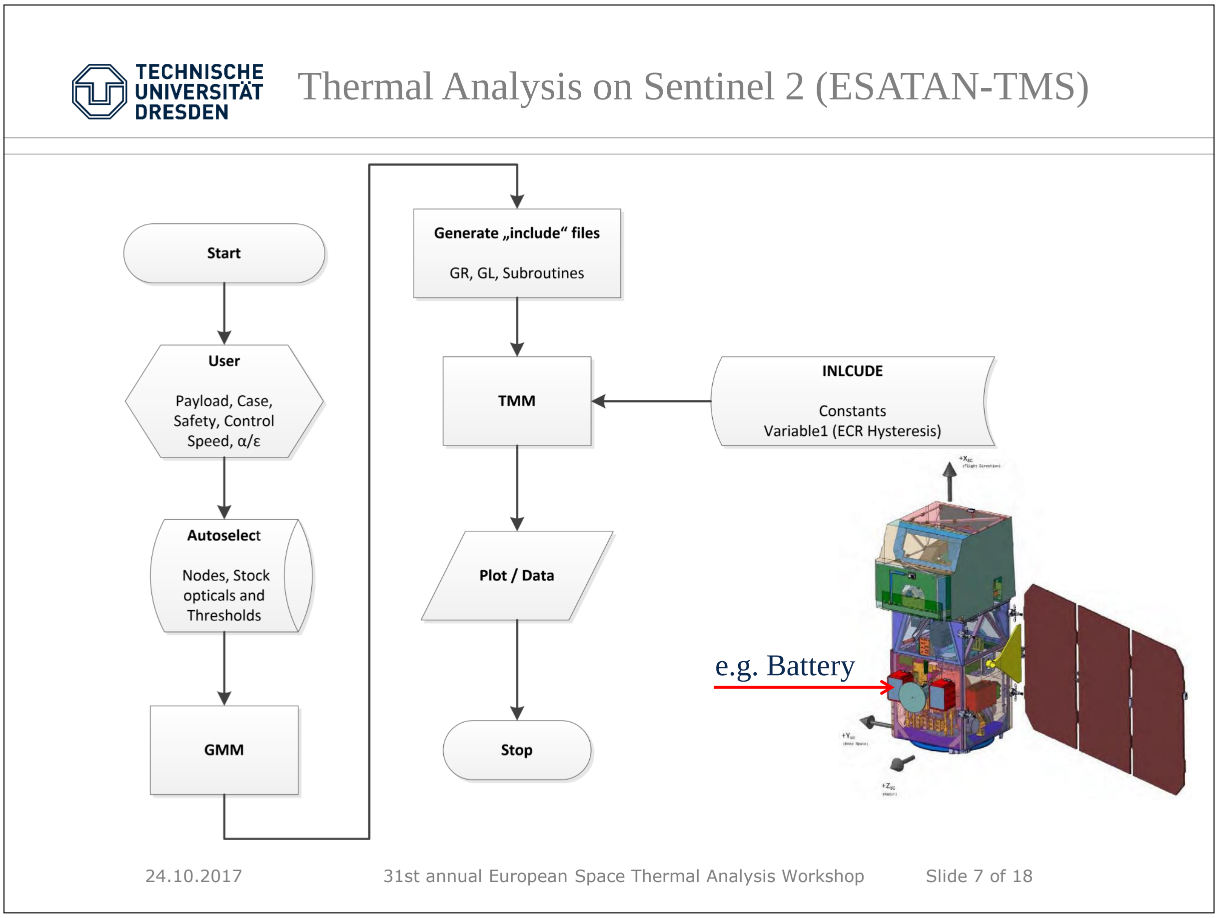
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Thermal Analysis on Sentinel 2 (ESATAN-TMS)
Start
User
Payload, Case, Safety, Control Speed, α/ε
Autoselect
Nodes, Stock opticals and Thresholds
GMM
Generate „include“ files
GR, GL, Subroutines
TMM
INLCUDE
Constants
Variable1 (ECR Hysteresis)
Plot / Data
Stop
e.g. Battery
24.10.2017
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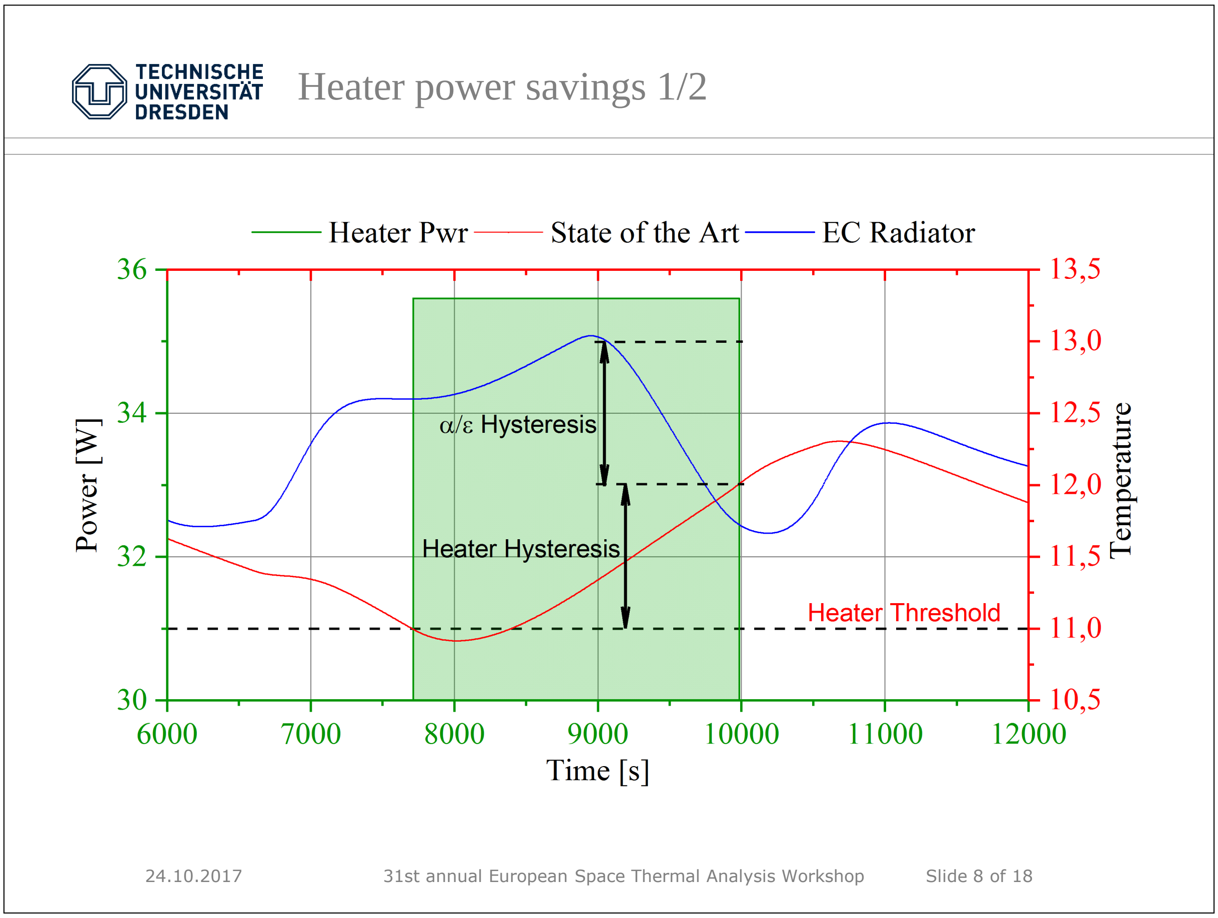
Slide 7 of 18


TECHNISCHE UNIVERSITÄT DRESDEN
Heater power savings 1/2
Heater Pwr
State of the Art
EC Radiator
α/ε Hysteresis
Heater Hysteresis
Heater Threshold
Power [W]
Temperature
Time [s]
30
32
34
36
10,5
11,0
11,5
12,0
12,5
13,0
13,5
6000
7000
8000
9000
10000
11000
12000
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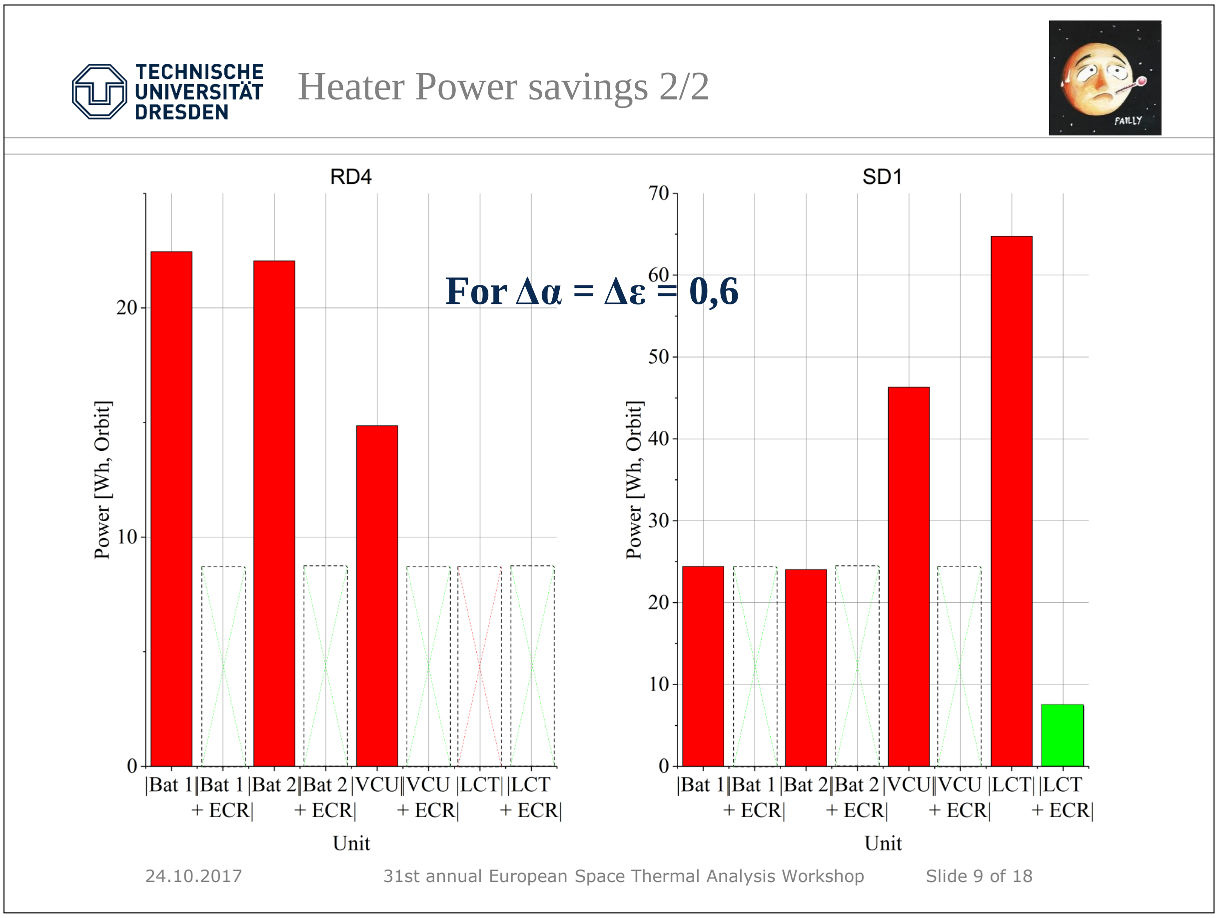
Slide 8 of 18


TECHNISCHE UNIVERSITÄT DRESDEN
Heater Power savings 2/2
RD4
SD1
For Δα = Δε = 0,6
Power [Wh, Orbit]
|Bat 1|Bat 1 |Bat 2|Bat 2 |VCU|VCU |LCT||LCT
+ ECR| + ECR| + ECR| + ECR|
Unit
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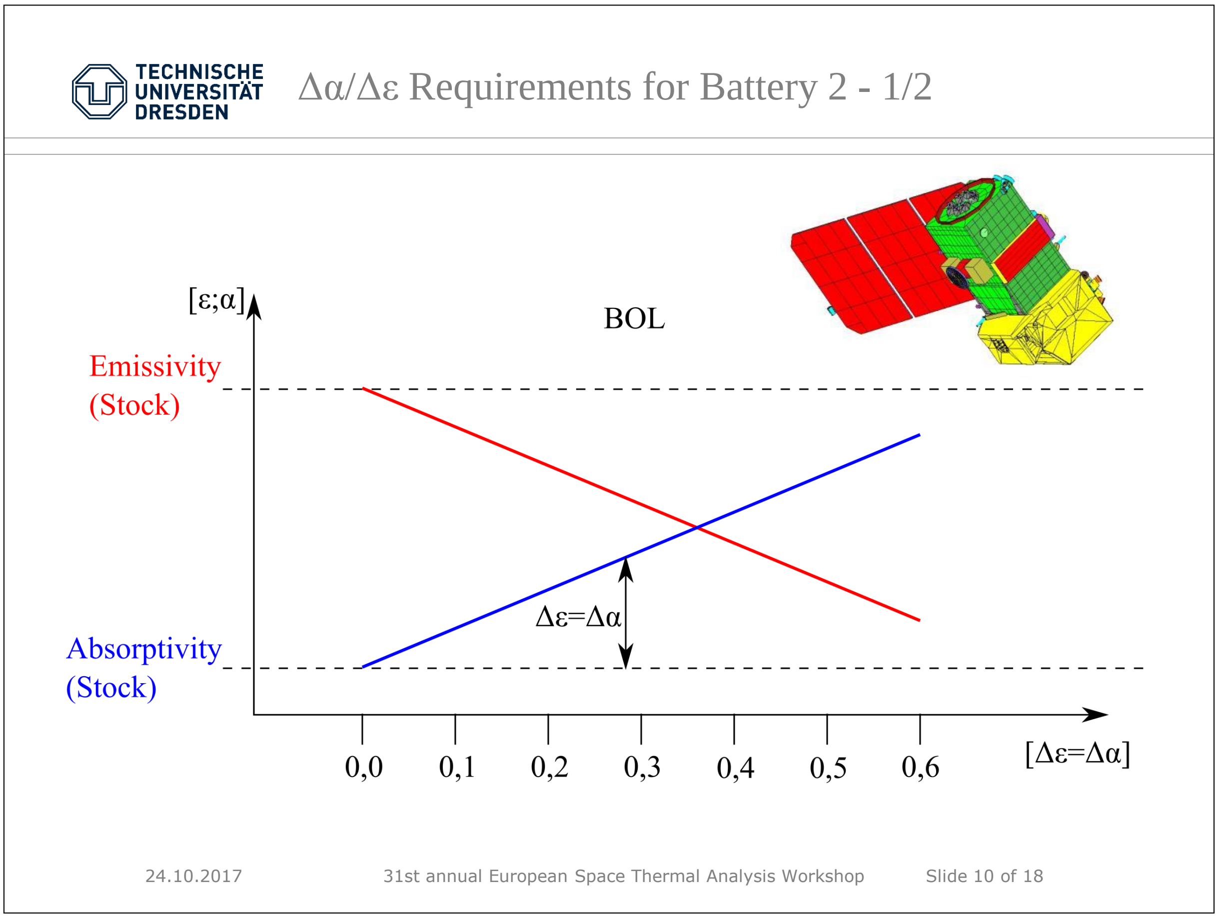
Slide 9 of 18


TECHNISCHE UNIVERSITÄT DRESDEN
Δα/Δε Requirements for Battery 2 - 1/2
[ε;α]
BOL
Emissivity
(Stock)
Absorptivity
(Stock)
Δε=Δα
0,0 0,1 0,2 0,3 0,4 0,5 0,6
[Δε=Δα]
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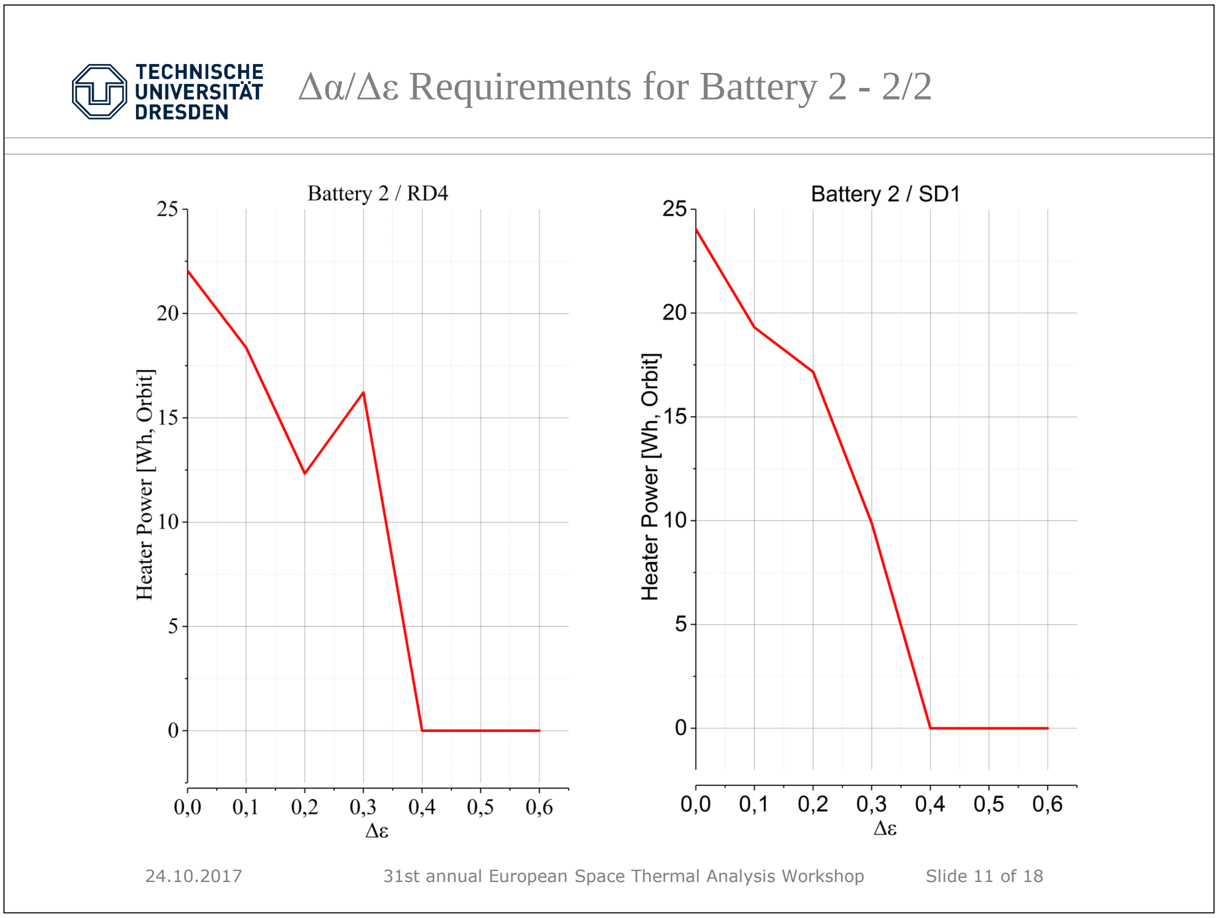
TECHNISCHE UNIVERSITÄT DRESDEN
Δα/Δε Requirements for Battery 2 - 2/2
Battery 2 / RD4
Battery 2 / SD1
Heater Power [Wh, Orbit]
Δε
0,0
0,1
0,2
0,3
0,4
0,5
0,6
0
5
10
15
20
25
24.10.2017
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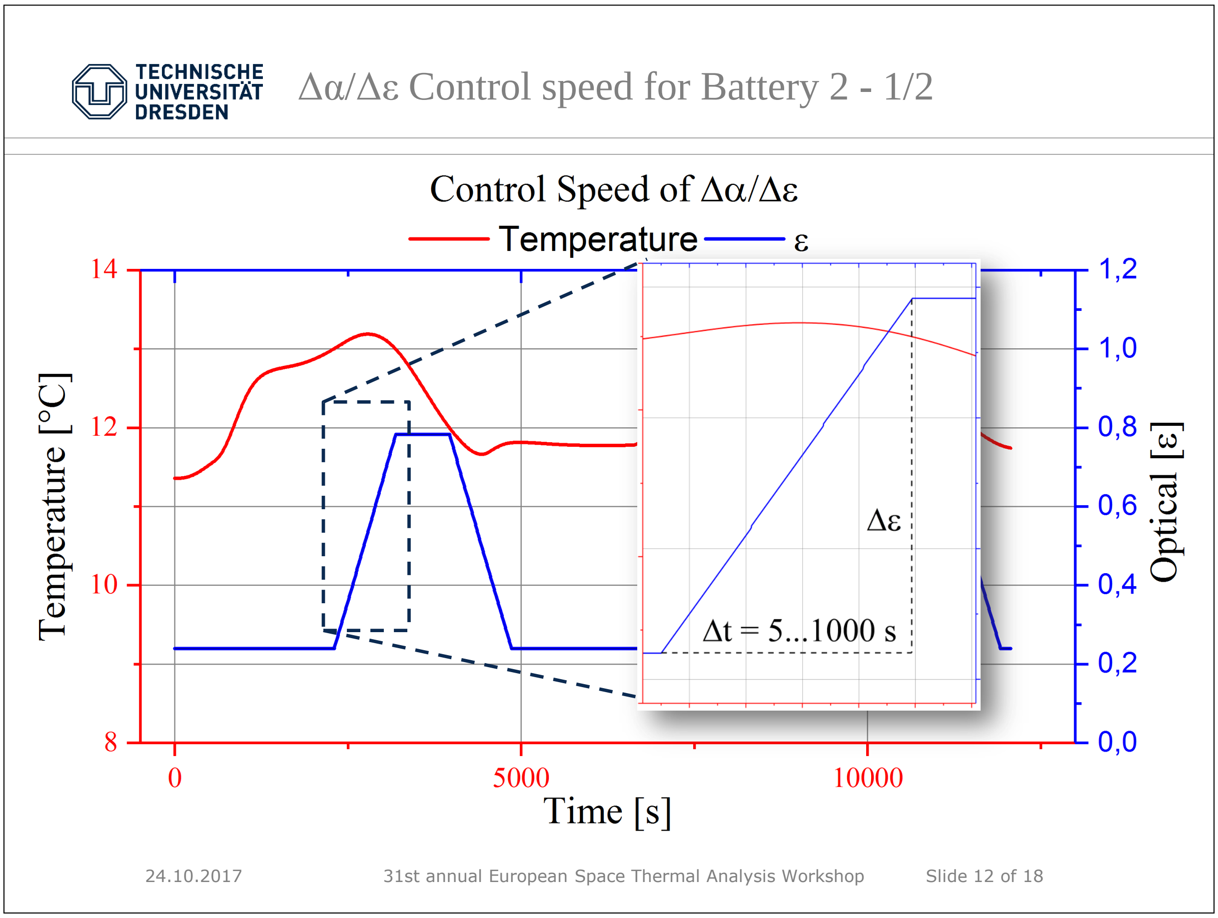
TECHNISCHE UNIVERSITÄT DRESDEN
Δα/Δε Control speed for Battery 2 - 1/2
Control Speed of Δα/Δε
Temperature
ε
Temperature [°C]
Optical [ε]
Time [s]
Δε
Δt = 5...1000 s
8
10
12
14
0
5000
10000
0,0
0,2
0,4
0,6
0,8
1,0
1,2
24.10.2017
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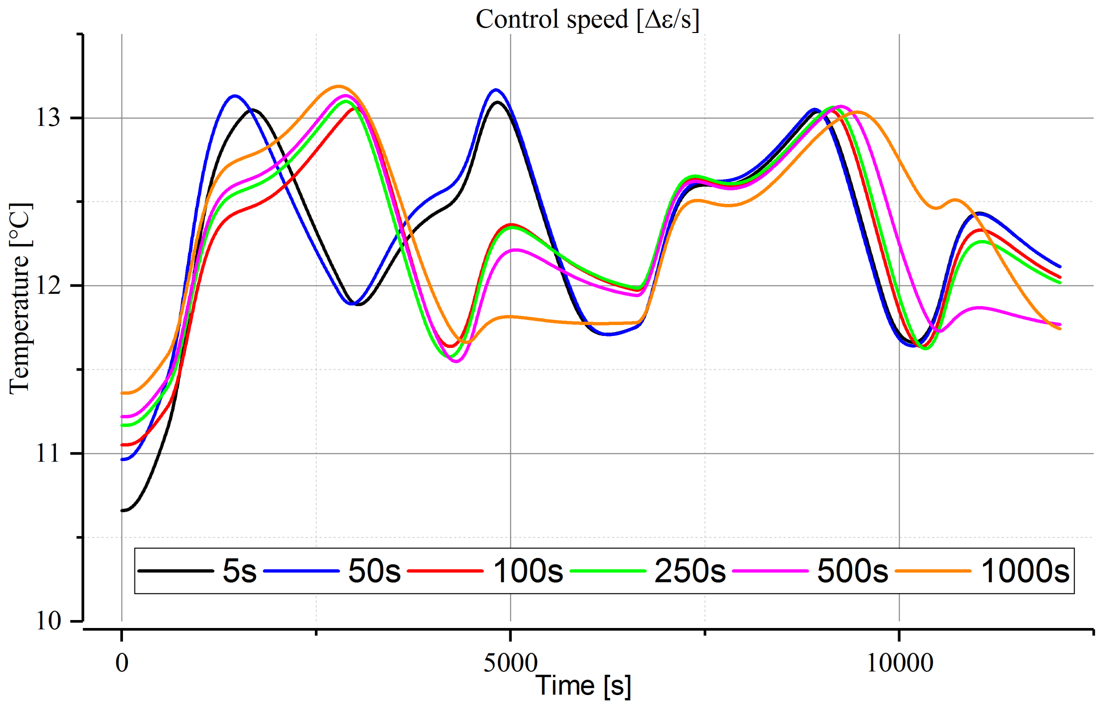
Δα/Δε Control speed for Battery 2 - 2/2



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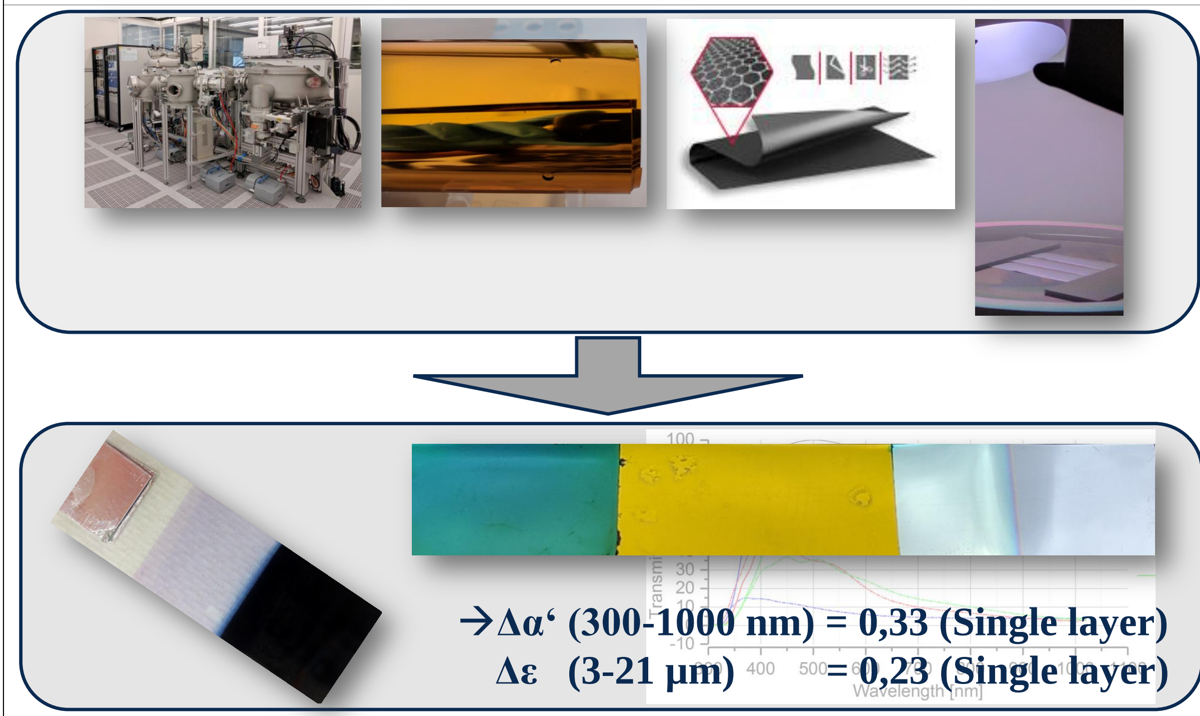
Preliminary Hardware results



→Δα‘ (300-1000 nm) = 0,33 (Single layer)

Δε (3-21 µm) = 0,23 (Single layer)

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Conclusion / Prospect

- Results
  - Heater power savings **up to 100%**
  - Threshold for emissivity control: **$\Delta\varepsilon \geq 0{,}4$**
  - Control **duration up to 1000s** simulated (Peak to Peak)
- Prospect
  - Safety analysis (radiator size, redundancy, additional heater…)
  - Analysis in “Systema”
  - Analysis of sensitive payloads (thermal gradients)?
  - Results not for “Electrochromic” radiators only?

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Contact Information

Thanks to Airbus Defence & Space GmbH (Martin Altenburg, TSOTM13) for providing the Sentinel 2 Thermal Model.

ilr

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Faculty of Mechanical Science and Engineering, Institute of Aerospace Engineering, Chair of Space Systems

Thermal Analysis of Electrochromic Radiators on Sentinel 2

Oliver Kluge *)[1], Alexander Zwiebler[1], Martin Altenburg[2], Tino Schmiel[1], Martin Tajmar[1]

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[2]Airbus Defence & Space GmbH, Germany

Noordwijk, 24.10.2017

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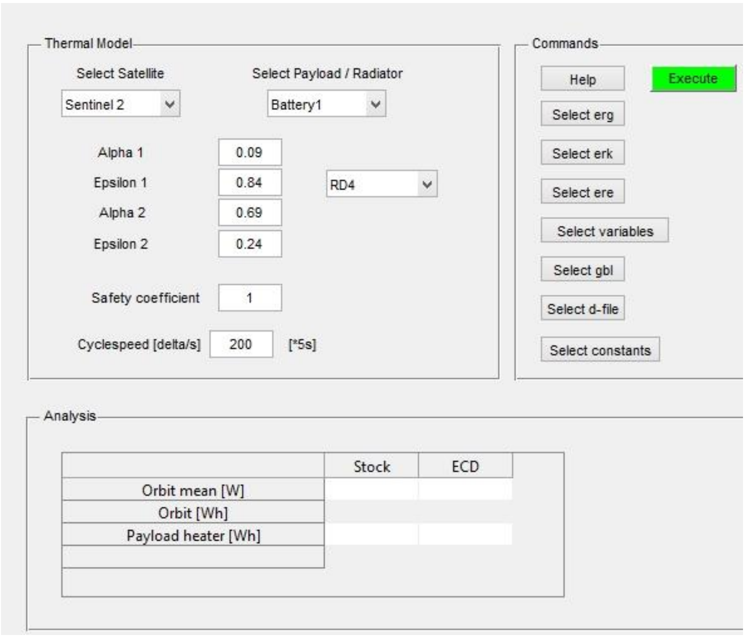
Appendix



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Appendix J

Thermal analysis approach for finding Bepi Colombo MTM SA wing generated PV power

Niels van der Pas
(Airbus Defence and Space, The Netherlands)

Abstract

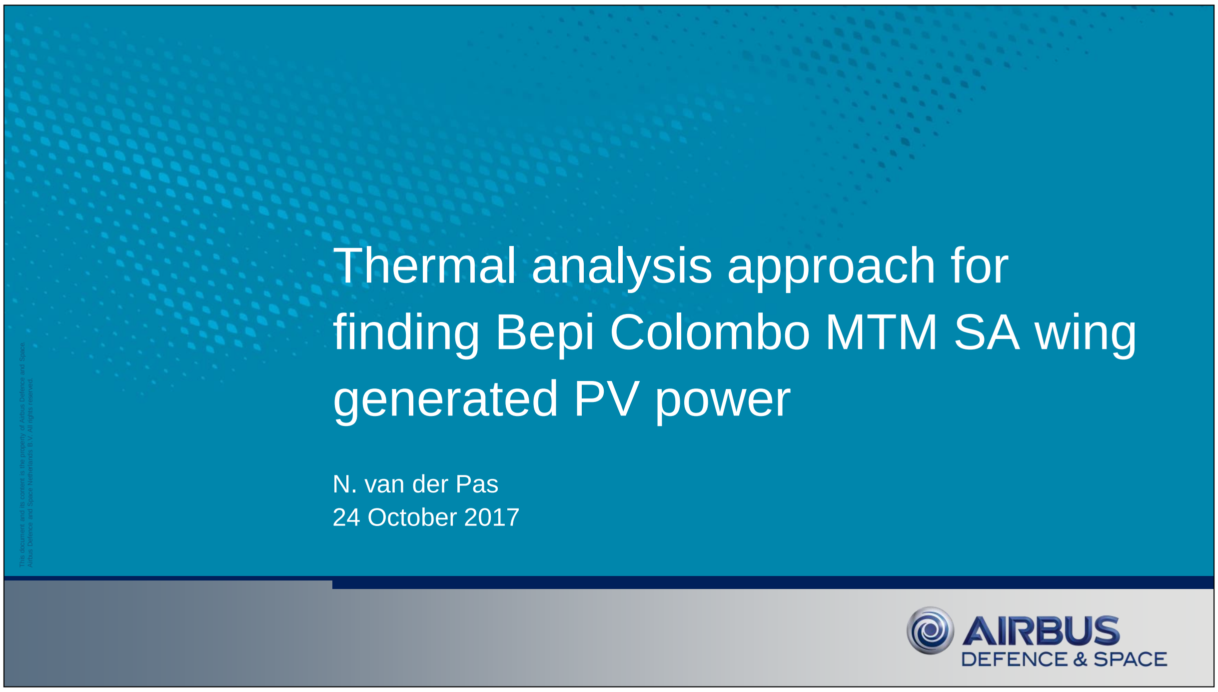
A thermal analysis was performed in support of the power analysis for the MTM wing of the Bepi Colombo mission. At 14 points in the mission the power and maximum incidence angle were requested. The temperature of the MTM solar array wing of the Bepi Colombo mission is highly dependent on the angle of incidence, especially when the space craft is close to the sun. As a result, small deformations due to thermal warping and production will have an effect on the temperature of the solar panels. These need to be accounted for in the analysis.

In a traditional approach these angles would be reflected directly into the ESATAN model. This would drastically increase the modelling effort and would in addition also require an extensive amount of manual iterations to find the worst case scenario with respect to the temperatures of the panels.

In order to save both time and to create flexibility a tool was constructed to find the maximum temperature per panel at these points in the mission for all solar array pointing and deformation angles without having to perform a new thermal analysis or remodelling.

Four different pointing parameters were considered. These different parameters were combined in a single equivalent solar aspect angle of the solar panel.

115 thermal cases were run in total. This resulted in a maximum temperature for all panels that could be interpolated as a function of the equivalent solar aspect angle.


Thermal analysis approach for finding Bepi Colombo MTM SA wing generated PV power
N. van der Pas
24 October 2017
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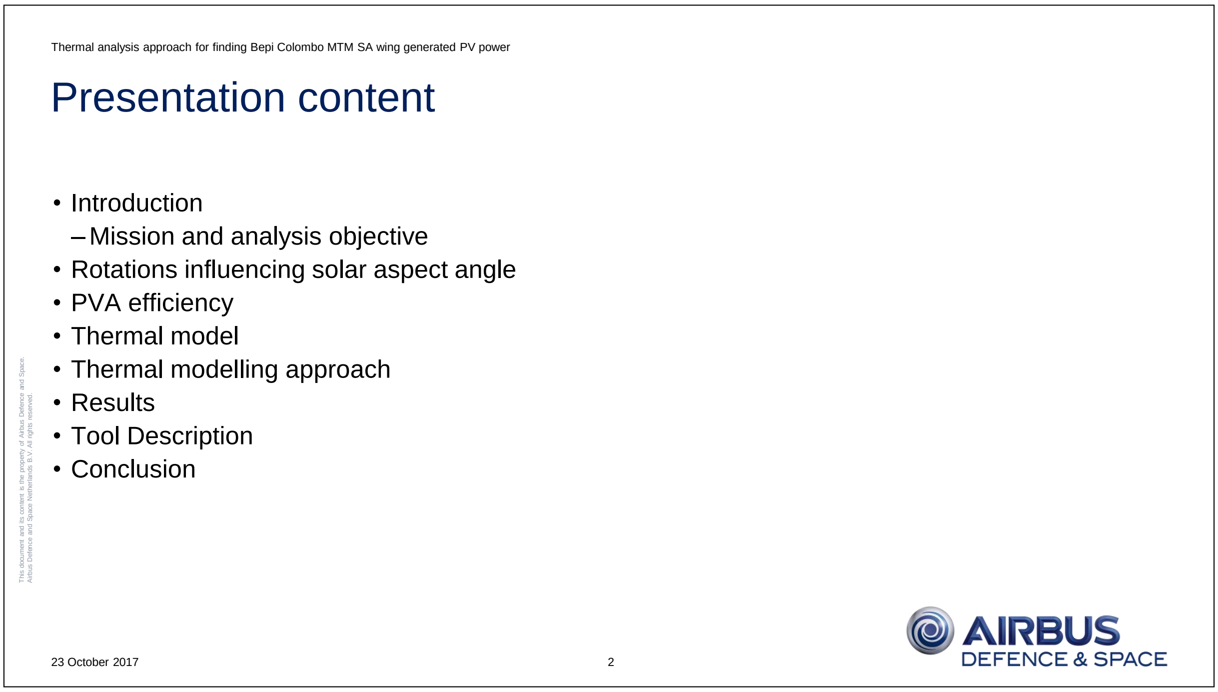
Thermal analysis approach for finding Bepi Colombo MTM SA wing generated PV power
Presentation content
• Introduction
– Mission and analysis objective
• Rotations influencing solar aspect angle
• PVA efficiency
• Thermal model
• Thermal modelling approach
• Results
• Tool Description
• Conclusion
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2
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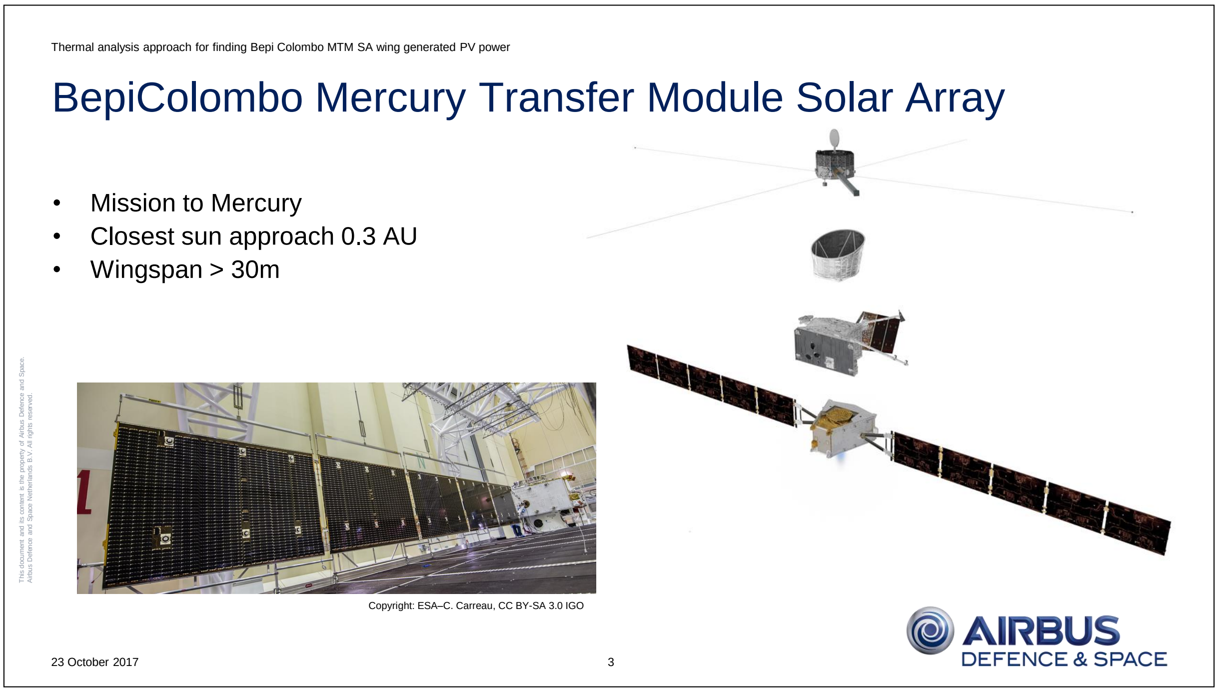
Thermal analysis approach for finding Bepi Colombo MTM SA wing generated PV power
BepiColombo Mercury Transfer Module Solar Array
• Mission to Mercury
• Closest sun approach 0.3 AU
• Wingspan > 30m
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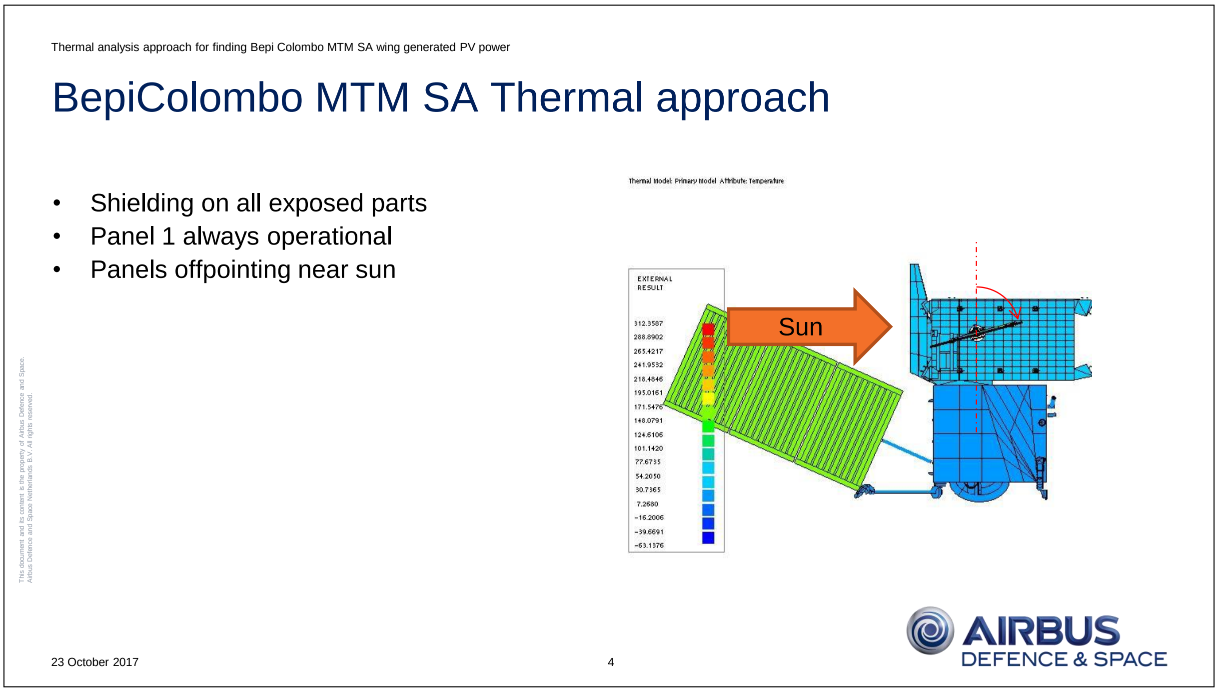
Thermal analysis approach for finding Bepi Colombo MTM SA wing generated PV power
BepiColombo MTM SA Thermal approach
• Shielding on all exposed parts
• Panel 1 always operational
• Panels offpointing near sun
Thermal Model: Primary Model Attribute: Temperature
EXTERNAL
RESULT
312.3587
288.8902
265.4217
241.9532
218.4846
195.0161
171.5476
148.0791
124.6106
101.1420
77.6735
54.2050
30.7365
7.2680
-16.2006
-39.6691
-63.1376
Sun
23 October 2017
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Analysis Objective

Client side request:

- Determine:
    - Loaded PVA hotspot temperature
    - Unloaded PVA hotspot temperature
    - Allowable limit pointing angle (in unloaded conditions)
- For 14 power cases
- Taking into account misallignements

Case	Day	ESH [hrs]	Sun Distance [AU]
1	277.2	6046	1.1946
2	345.5	7218	1.1286
3	477.2	10400	0.8836
4	832.5	18249	0.7500
5	855.9	19583	0.6429
6	1224.0	26877	0.3946
7	1367.6	30345	0.3072
8	1519.1	33114	0.5412
9	1650.3	38085	0.6100
10	1780.6	42061	0.5955
11	1901.6	45494	0.5829
12	2408.3	63819	0.3842
13	2516.1	68174	0.3136
14	2553.2	70683	0.4621

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Analysis Objective

Problem:
- Possibility of future changes
- Large amount of cases (for every possible angle)

Solution: Develop a tool and approach based on beta angle

Advantages:
- Robust for future requests
- Applicable to multiple situations (e.g. power or thermal calculations)
- Easy optimisation of pointing angle

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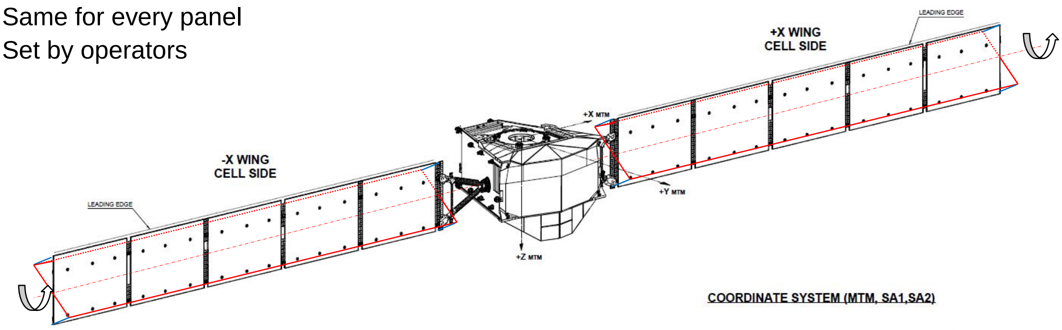
Rotations influencing the Solar Aspect Angle

SA Pointing angle:

- X-axis rotation
- Same for every panel
- Set by operators



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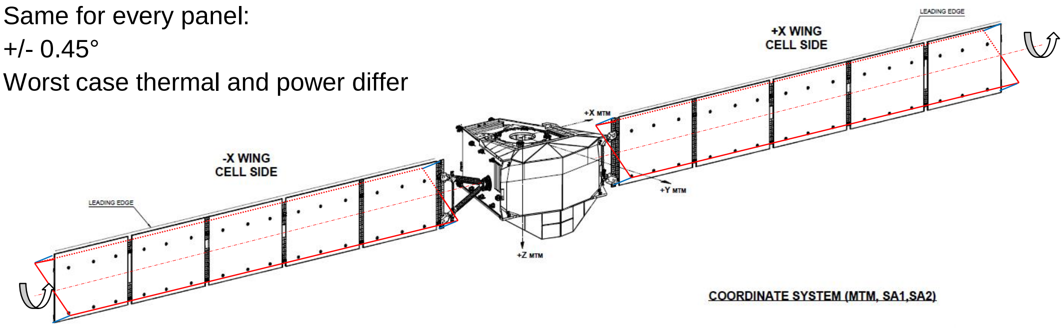
Thermal analysis approach for finding Bepi Colombo MTM SA wing generated PV power

Rotations influencing the Solar Aspect Angle

SA Pointing uncertainty:

- X-axis rotation
- Same for every panel:
- +/- 0.45°
- Worst case thermal and power differ



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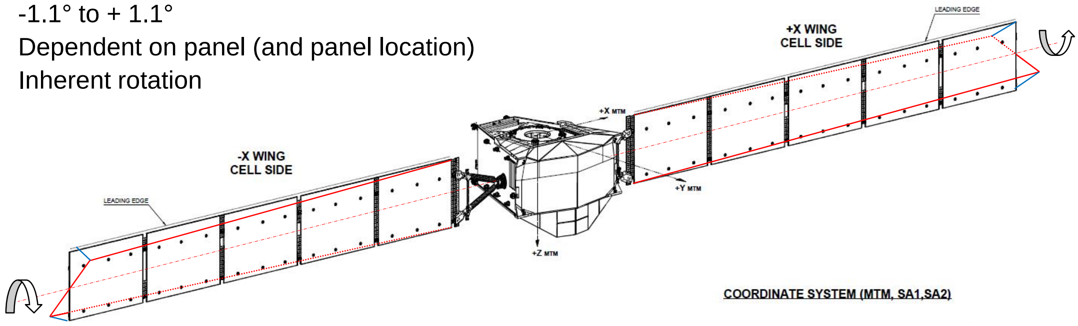
Rotations influencing the Solar Aspect Angle

Panel warp due to manufacturing:

- X-axis rotation
- -1.1° to + 1.1°
- Dependent on panel (and panel location)
- Inherent rotation



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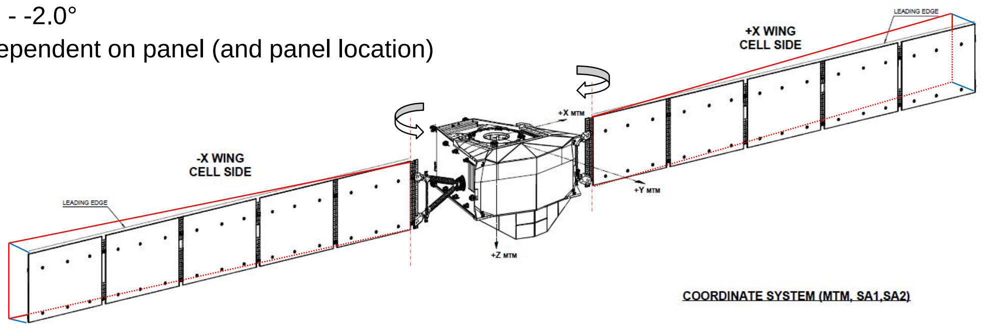
Thermal analysis approach for finding Bepi Colombo MTM SA wing generated PV power

Rotations influencing the Solar Aspect Angle

Thermal deformation due to temperature gradient:

- Y/Z-axis rotation
- 0° - -2.0°
- Dependent on panel (and panel location)



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Rotations influencing the Solar Aspect Angle

Rotations included in thermal model:

- SA pointing angle

Rotations not included in thermal model:

- SA pionting uncertainty
- Panel warp
- Thermal deformation

Beta angle:

$$\beta = \text{acos}\{\cos(SAA_{nom} + SAA_{uncertainty} + warp) \cdot \cos(deform_{thermal})\}$$

PVA efficiency

PVA efficiency dependent on:

- Mission time (cell degredation)
- Panel temperature (T)
- Solar flux (I)

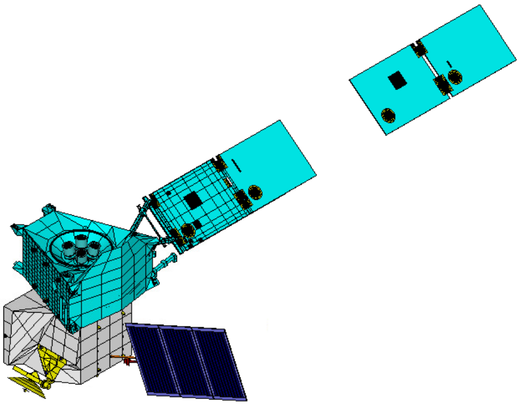
$$\eta_{PVA} = (c_{IdT} \cdot I + c_{TdT}) \cdot T + (c_I \cdot I + c_T)$$

Where c_{IdT}, c_{TdT}, c_I and c_T are coefficients determined for every power case based on client data.

Thermal Model

- Esatan-tms r5
- Adapted from thermal analysis model
- Single pointing axis

- Contains:
  - 1 (of 2) wings
  - 4 (of 5) panels
  - Details for hotspots:
    - Diodes
    - Harness clusters
    - Hold down structure



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Thermal modelling approach Solar Distance > 0.62 AU

Approach:
1. Predict the hotspot temperature for every power case for panel 1, 2 and 5 with SAA 0.0°
2. Predict hotspot temperature for all panels.

Assumption:
- At SAA 0.0°C small rotations have a negligible effect.

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Thermal modelling approach Solar Distance < 0.62 AU

Approach:

1. Predict the hotspot temperature for every power case for panel 1, 2 and 5 at min. 10 different SAA around a nominal estimate of the limit SAA.
2. Predict the temperature response of all panels, as function of the SAA angle.
3. Calculate the limit nominal pointing angle for every panel quadrant based on warp, panel deformation and SA pointing uncertainty.

Assumptions:

- Wing 1 and 2 have similar temperature and temperature response (conservative)
- Hot spot temperatures panels 3 and 4 can be interpolated.

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Thermal analysis approach for finding Bepi Colombo MTM SA wing generated PV power

Temperature fit

Every solar panel element can be fitted to:

$$T_{hotspot} = A \cdot \cos(\beta) + B$$

Where:

- A,B are determined by fitting analysis results
- $\beta = \mathrm{acos}\{\cos(SAA_{nom} + SAA_{uncertainty} + warp) \cdot \cos(deform_{thermal})\}$

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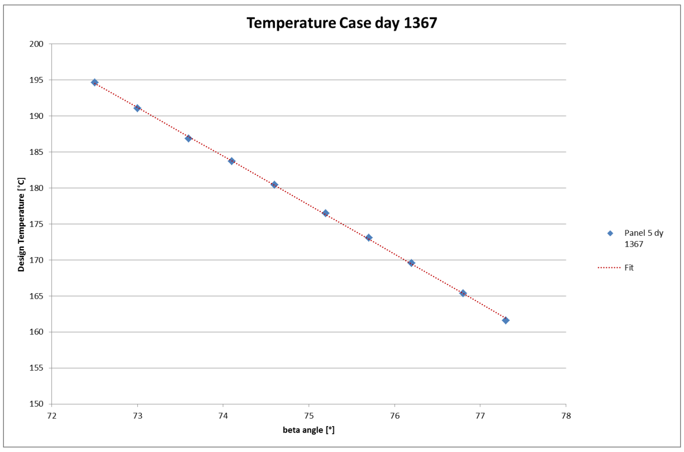
Analysis results



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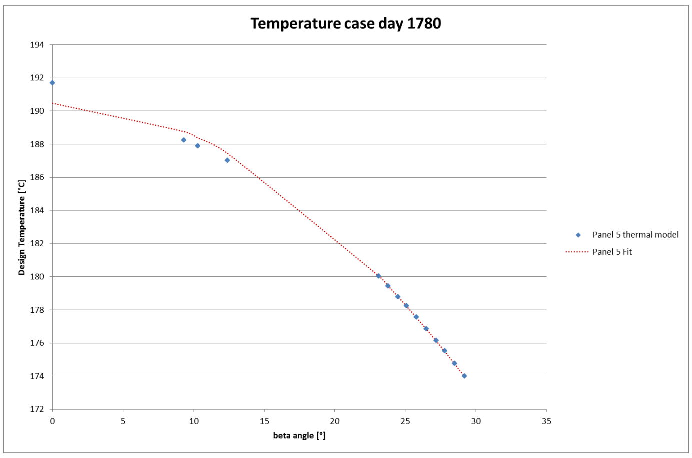
Thermal analysis approach for finding Bepi Colombo MTM SA wing generated PV power

Analysis results



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Tool

- Excel based
- Uses analysis results as basis
- Robust
- Flexible for future client requests

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Thermal analysis approach for finding Bepi Colombo MTM SA wing generated PV power

Tool
Temperature calculations

Nominal pointing

Pointing error

Deformation angles

Temperature results per case per panel

Temperature of PVA (only panel 1 loaded)

Input

Parameter	Value	Unit
Nominal Solar Incidence Angle	Per Case→	degrees
pointing error	-0.45	degrees

Day	277.2	345.4	477.2	832.5	855.9	1224.0	1367.6	1519.1	1650.3	1780.6	1901.6	2408.3	2516.1	2553.2
	0.0	0.0	0.0	0.0	0.0	65.2	74.8	38.5	4.6	17.9	24.1	66.5	74.1	55.3

Output

Expected PVA design temperature in degrees Celsius (Maximum temperature bolded)
Design temperature includes uncertainty

Wing	Panel	Warp Angle (Center) [degrees]	Thermal Gradient bend (Center) [degrees]	Day 277.2	345.4	477.2	832.5	855.9	1224.0	1367.6	1519.1	1650.3	1780.6	1901.6	2408.3	2516.1	2553.2
-X		-0.098	0.2	44.6	53.5	96.7	130.9	166.0	184.3	188.1	183.8	181.7	183.0	183.6	185.3	188.9	184.8
-X		-0.372	0.6	53.3	62.8	107.6	141.1	175.4	**189.7**	188.6	**189.8**	**189.9**	**190.0**	**189.9**	**189.7**	**189.5**	**189.6**
-X		-0.585	1.0	51.4	61.0	105.8	139.3	173.7	188.8	188.9	188.4	188.1	188.3	188.4	188.9	189.5	188.5
-X		-0.790	1.4	49.5	59.2	104.0	137.5	171.9	**187.9**	**188.9**	187.0	186.4	186.7	186.8	188.0	189.2	187.3
-X		-0.996	1.8	47.7	57.3	102.2	135.8	170.2	187.0	188.7	185.5	184.6	185.1	185.2	187.1	188.7	186.1
+X		0.122	0.2	44.6	53.5	96.7	130.9	166.0	183.3	186.3	183.5	181.7	182.9	183.4	184.1	187.2	184.1
+X		0.210	0.6	53.3	62.8	107.6	141.1	175.4	186.9	183.8	188.8	189.8	189.6	189.4	186.7	184.7	187.9
+X		0.368	1.0	51.4	61.0	105.8	139.3	173.7	184.2	181.5	186.8	188.0	187.7	187.5	183.9	182.1	185.6
+X		0.735	1.4	49.5	59.2	104.0	137.5	171.9	180.5	177.8	184.5	186.1	185.7	185.4	180.1	178.1	182.6
+X		1.027	1.8	47.7	57.3	102.2	135.8	170.2	177.1	175.0	182.2	184.3	183.7	183.4	176.6	175.0	179.9
			Distance [AU]	1.1946	1.1286	0.8836	0.7500	0.6429	0.3946	0.3072	0.5412	0.6100	0.5955	0.5829	0.3842	0.3136	0.4621

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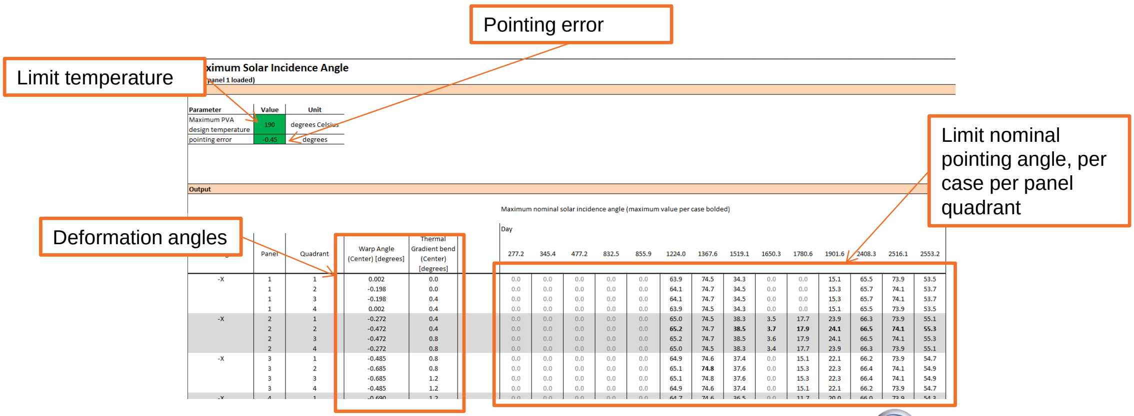
Tool
pointing calculations



ximum Solar Incidence Angle
panel 1 loaded)

Parameter	Value	Unit
Maximum PVA design temperature	190	degrees Celsius
pointing error	-0.45	degrees

Output

Maximum nominal solar incidence angle (maximum value per case bolded)

	Panel	Quadrant	Warp Angle (Center) [degrees]	Thermal Gradient bend (Center) [degrees]	Day 277.2	345.4	477.2	832.5	855.9	1224.0	1367.6	1519.1	1650.3	1780.6	1901.6	2408.3	2516.1	2553.2
-X	1	1	0.002	0.0	0.0	0.0	0.0	0.0	0.0	63.9	74.5	34.3	0.0	0.0	15.1	65.5	73.9	53.5
	1	2	-0.198	0.0	0.0	0.0	0.0	0.0	0.0	64.1	74.7	34.5	0.0	0.0	15.3	65.7	74.1	53.7
	1	3	-0.198	0.4	0.0	0.0	0.0	0.0	0.0	64.1	74.7	34.5	0.0	0.0	15.3	65.7	74.1	53.7
	1	4	0.002	0.4	0.0	0.0	0.0	0.0	0.0	63.9	74.5	34.3	0.0	0.0	15.1	65.5	73.9	53.5
-X	2	1	-0.272	0.4	0.0	0.0	0.0	0.0	0.0	65.0	74.5	38.3	3.5	17.7	23.9	66.3	73.9	55.1
	2	2	-0.472	0.4	0.0	0.0	0.0	0.0	0.0	**65.2**	74.7	**38.5**	**3.7**	**17.9**	**24.1**	**66.5**	**74.1**	**55.3**
	2	3	-0.472	0.8	0.0	0.0	0.0	0.0	0.0	65.2	74.7	38.5	3.6	17.9	24.1	66.5	74.1	55.3
	2	4	-0.272	0.8	0.0	0.0	0.0	0.0	0.0	65.0	74.5	38.3	3.4	17.7	23.9	66.3	73.9	55.1
-X	3	1	-0.485	0.8	0.0	0.0	0.0	0.0	0.0	64.9	74.6	37.4	0.0	15.1	22.1	66.2	73.9	54.7
	3	2	-0.685	0.8	0.0	0.0	0.0	0.0	0.0	65.1	**74.8**	37.6	0.0	15.3	22.3	66.4	74.1	54.9
	3	3	-0.685	1.2	0.0	0.0	0.0	0.0	0.0	65.1	74.8	37.6	0.0	15.3	22.3	66.4	74.1	54.9
	3	4	-0.485	1.2	0.0	0.0	0.0	0.0	0.0	64.9	74.6	37.4	0.0	15.1	22.1	66.2	73.9	54.7
-X	4	1	-0.690	1.2	0.0	0.0	0.0	0.0	0.0	64.7	74.6	36.5	0.0	11.7	20.0	66.0	73.9	54.3

Conclusion

- An extensive thermal analysis was performed to find PVA temperatures
- A tool was developed to summarize result

Appendix K

Time-Varying Thermal Dynamics Modeling of the Prototype of the REMS Wind Sensor

Maria-Teresa Atienza Lukasz Kowalski Sergi Gorreta Vicente Jiménez
Manuel Domínguez-Pumar
(Universitat Politecnica d'Catalunya, Spain)

Abstract

The objective of this work is to show the results from the analysis of the thermal dynamics of a prototype of the REMS 3D wind anemometer using the tools of Diffusive Representation (DR). DR is a mathematical tool that allows the description of physical phenomena based on diffusion using state-space models of arbitrary order in the frequency domain. From open-loop experimental measurements, where a current signal with a wide frequency spectrum is injected in the heaters, time-varying dynamical thermal models are extracted for different wind velocities. This models provide the temperature evolution of the parts of the system under study as a function of the power delivered to the heat sources.

The prototype of the wind sensor used in the experimental setup is based on thermal anemometry, which is the method that has been used in multiple occasions for the challenging task of wind sensing in Mars. It is based on the detection of the wind velocity by measuring the power dissipated of a heated element due to forced convection. This technique was employed in the wind sensor of REMS (Remote Environmental Monitor System) sensor suite, on board Curiosity rover since 2012. In 2018, it is expected to be launched the InSight (Interior Exploration using Seismic Investigation, Geodesy and Heat Transport) mission to Mars. It will include the TWINS instrument (Temperature and Wind sensors for InSight mission) which is an heritage from REMS. The prototype used in the experiments, is composed of three PCBs (Printed Circuit Board) placed on a cylindrical supporting structure (boom) at 120° from each other. Each PCB contains four Silicon dice set with Platinum resistors that are used as heating elements. The thermal dynamical characterization of one of the dice and its cross-heating with the boom is going to be presented.

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TIME-VARYING THERMAL DYNAMICS MODELING OF THE PROTOTYPE OF THE REMS WIND SENSOR

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31th European Space Thermal Analysis Workshop 24-25 October 2017, ESTEC

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- EXPERIMENTAL SETUP
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  - CROSS-HEATING MODEL OF THE BOOM
  - CLOSED-LOOP PREDICTION
- CONCLUSIONS

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OBJECTIVES

OBJECTIVES

- Time-varying thermal dynamics modeling of a 3D thermal anemometer for Mars.
- Modeling of self and cross-heating effects taking into account long term drifts due to thermal coupling.
- Black-box state-space modeling for prediction under arbitrary excitations.

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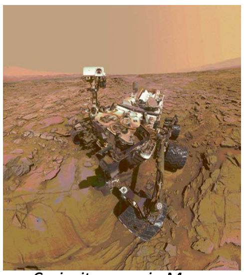
WIND SENSING IN MARS

WIND SENSING IN MARS

- Wind sensing in Mars is a challeging task
  - CO_2 atmosphere
  - Pressure ≈ [6 - 12]mBar
  - Temperature ≈ [150 - 300]K
- Curiosity rover included the REMS sensor suite:
  - Humidity
  - Pressure
  - Temperature
  - Radiation
  - **Wind velocity**



Curiosity rover in Mars.

- The prototype used in the experimental setup is the engineering model of the REMS wind sensor, developed in 2008, similar in size and concept to the flight model.
- This wind sensor is based on thermal anemometry.
- Same device sensor concept (with significant changes) is scheduled to flight in InSight mission (2018) and in Mars2020 rover (2020).

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PROTOTYPE DESCRIPTION

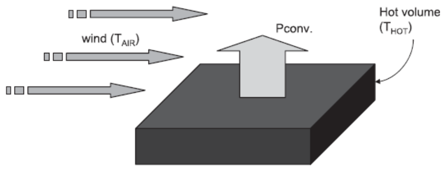
REMS PROTOTYPE DESCRIPTION

THERMAL ANEMOMETRY

Detects the wind velocity by measuring the power dissipated of a heated element due to forced convection

CONSTANT TEMPERATURE ANEMOMETRY (CTA)

The power required to maintain constant the temperature in the heating elements is the sensor output.

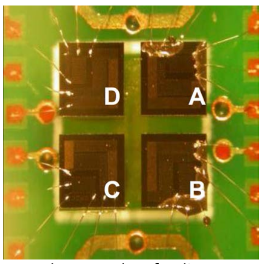


CTA concept

When the wind incides, the device is cooled, and more power is needed to keep constant the temperature

PROTOTYPE DESCRIPTION

REMS PROTOTYPE DESCRIPTION



Photography of a dice-set.

- Wind velocity and direction detection.
- Tangential wind components are measured at three points of a cylindrical structure (boom).
  - Dice-set composed of four Silicon dice (A, B, C and D) in coplanar plane (2D sensitivity)
  - Three dice-set 120º to each other (3D sensitivity)
- Each die contains Platinum (Pt) resistors for heating and sensing temperature.
- Inside boom, Pt100 resistor measures its temperature

Boom prototype used in the experiments.

OPEN-LOOP CHARACTERIZATION

OPEN-LOOP CHARACTERIZATION

- Time-varying thermal models are extracted from open-loop experiments using Diffusive Representation.
- These models provide the temperature dynamics of the components of the system under study as a function of the power delivered to the heat sources.
- Pseudo Random Binary Sequences (PRBS) of current are injected into the heat sources, while the temperature of different components of the system is sensed.
- During the experiment, different wind velocities are applied.
- The obtained thermal models follow the experimental data.

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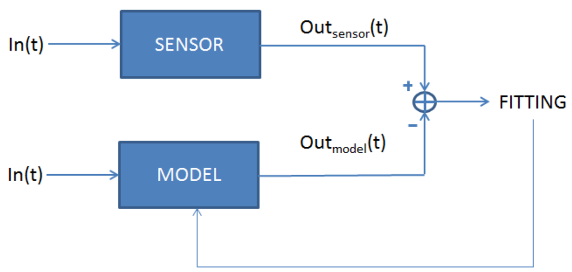
THEORETICAL GROUNDS

TOOLS: DIFFUSIVE REPRESENTATION (DR)



Description of thermal systems using models of arbitrary order.

- ζ_k is the frequency mesh
- $\Psi_k(t)$ contains the state of the system under actuation $In(t)$
- $\eta_k(t)$ represents how the system behaves

$$\frac{d\Psi_k(t)}{dt} = -\zeta_k \Psi_k(t) + \eta_k(t) In(t), \qquad \Psi_k(0) = 0$$

$$Out_{model}(t) = \sum_{k=1}^{K} \Psi_k(t)$$

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THEORETICAL GROUNDS

SELF AND CROSS-HEATING EFFECTS

SELF - HEATING

Injection of power into the own device's heat sources.

CROSS - HEATING

Injection of power into heat sources in parts of the structure different from the one in which temperature is sensed.

$$\frac{d\Psi_k^X(t)}{dt} = -\zeta_k \Psi_k^X(t) + \eta_k^{XX} P_X \qquad \Psi_k^X(0) = 0 \qquad k = 1 \dots K$$

$$K \neq J \qquad \{\zeta_k\} \neq \{\upsilon_j\}$$

$$\frac{d\Phi_j^Y(t)}{dt} = -\upsilon_j \Phi_j^Y(t) + \eta_j^{XY} P_Y \qquad \Phi_j^Y(0) = 0 \qquad j = 1 \dots J$$

$\boldsymbol{\eta_k^{XX}}$ represents thermal behaviour of device X as a function of power injected into itself.

Temperature in device *X*

$$\hat{T}_X(t) = \underbrace{\sum_{k=1}^{K} \Psi_k^X(t)}_{\text{Self-Heating contribution!}} + \underbrace{\sum_{j=1}^{J} \Phi_j^Y(t)}_{\text{Cross-Heating contribution!}}$$

$\boldsymbol{\eta_k^{XY}}$ represents thermal behaviour of device X as a function of power injected into device Y.

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EXPERIMENTAL SETUP

WIND TUNNEL DESCRIPTION

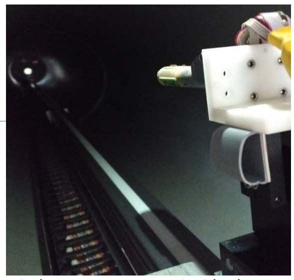
- Air atmosphere
- Pressure ≈ 240mBar
- Temperature = 298K
- Velocity range: [6 - 30]m/min

Mars equivalent wind velocities

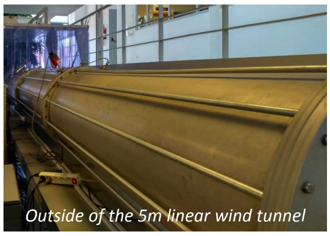
- CO_2 atmosphere
- Temperature = 223K
- Pressure = 7mBar
- same Reynolds number

[2 – 10]m/s

- Five meter linear wind tunnel (rail inside)
- Pan and tilt system



Wind sensor prototype inside the tunnel.



Outside of the 5m linear wind tunnel

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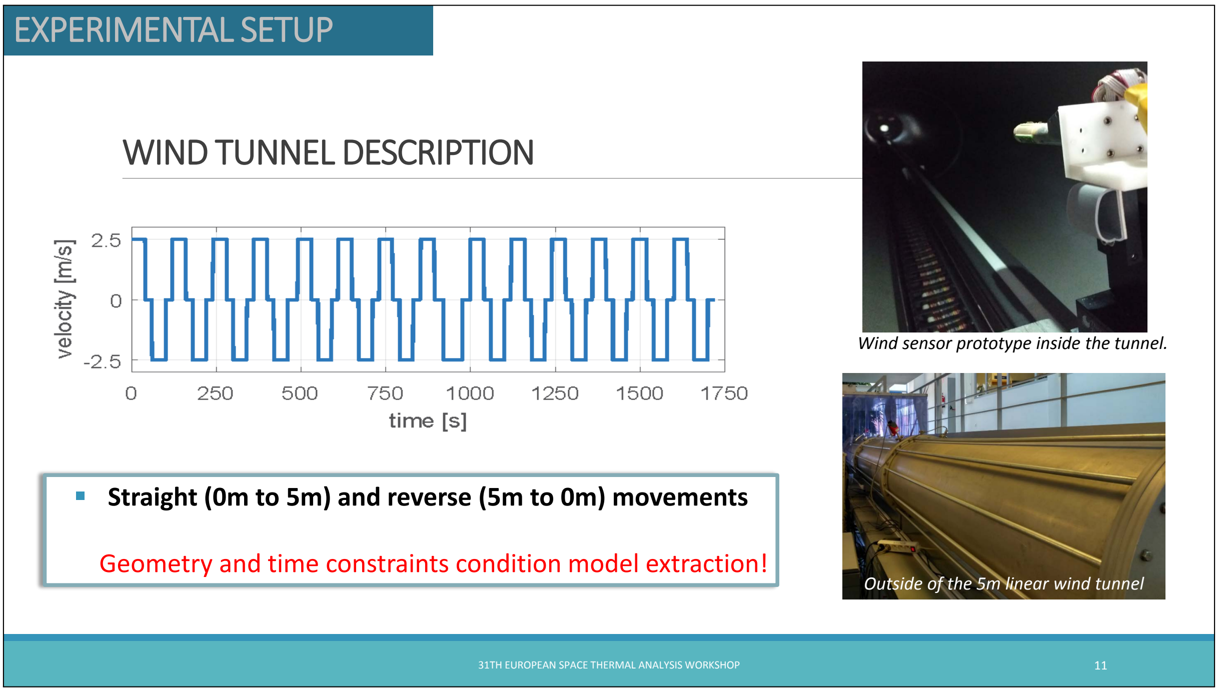
EXPERIMENTAL SETUP
WIND TUNNEL DESCRIPTION
velocity [m/s]
2.5
0
-2.5
0 250 500 750 1000 1250 1500 1750
time [s]
Straight (0m to 5m) and reverse (5m to 0m) movements
Geometry and time constraints condition model extraction!
Wind sensor prototype inside the tunnel.
Outside of the 5m linear wind tunnel
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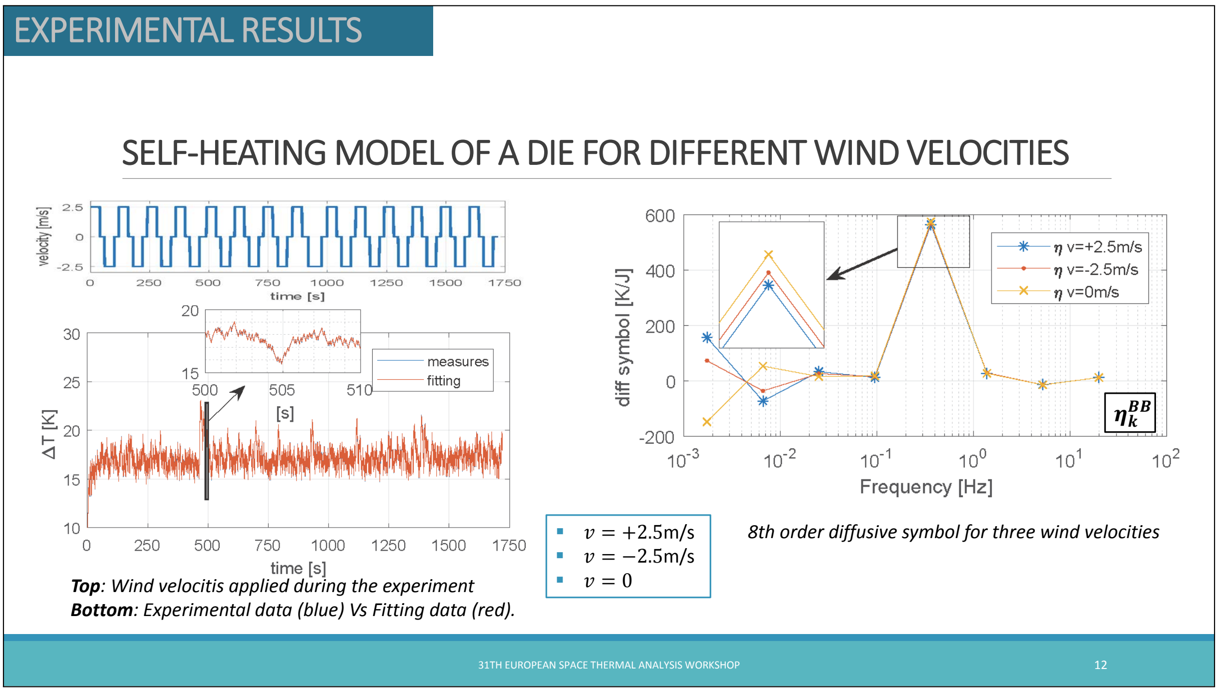
EXPERIMENTAL RESULTS
SELF-HEATING MODEL OF A DIE FOR DIFFERENT WIND VELOCITIES
velocity [m/s]
time [s]
ΔT [K]
measures
fitting
time [s]
Top: Wind velocitis applied during the experiment
Bottom: Experimental data (blue) Vs Fitting data (red).
v = +2.5m/s
v = −2.5m/s
v = 0
diff symbol [K/J]
η v=+2.5m/s
η v=-2.5m/s
η v=0m/s
Frequency [Hz]
8th order diffusive symbol for three wind velocities
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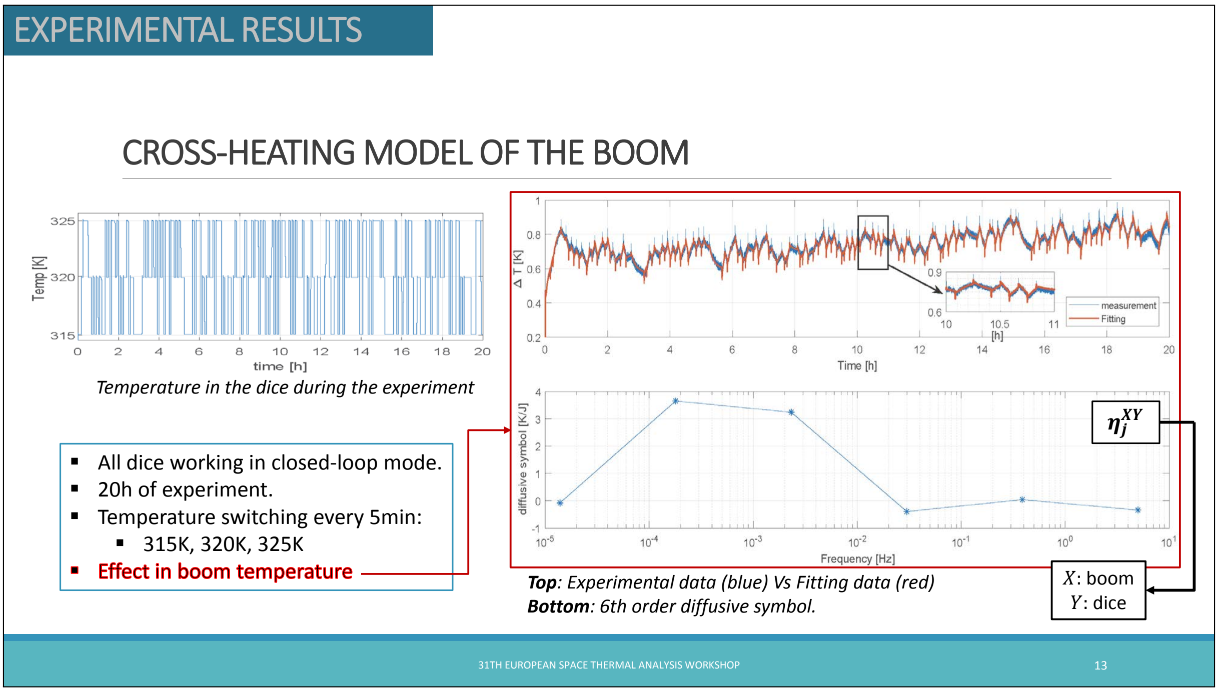
EXPERIMENTAL RESULTS
CROSS-HEATING MODEL OF THE BOOM
Temp [K]
time [h]
Temperature in the dice during the experiment
All dice working in closed-loop mode.
20h of experiment.
Temperature switching every 5min:
315K, 320K, 325K
Effect in boom temperature
Δ T [K]
Time [h]
measurement
Fitting
diffusive symbol [K/J]
Frequency [Hz]
η_j^{XY}
X: boom
Y: dice
Top: Experimental data (blue) Vs Fitting data (red)
Bottom: 6th order diffusive symbol.
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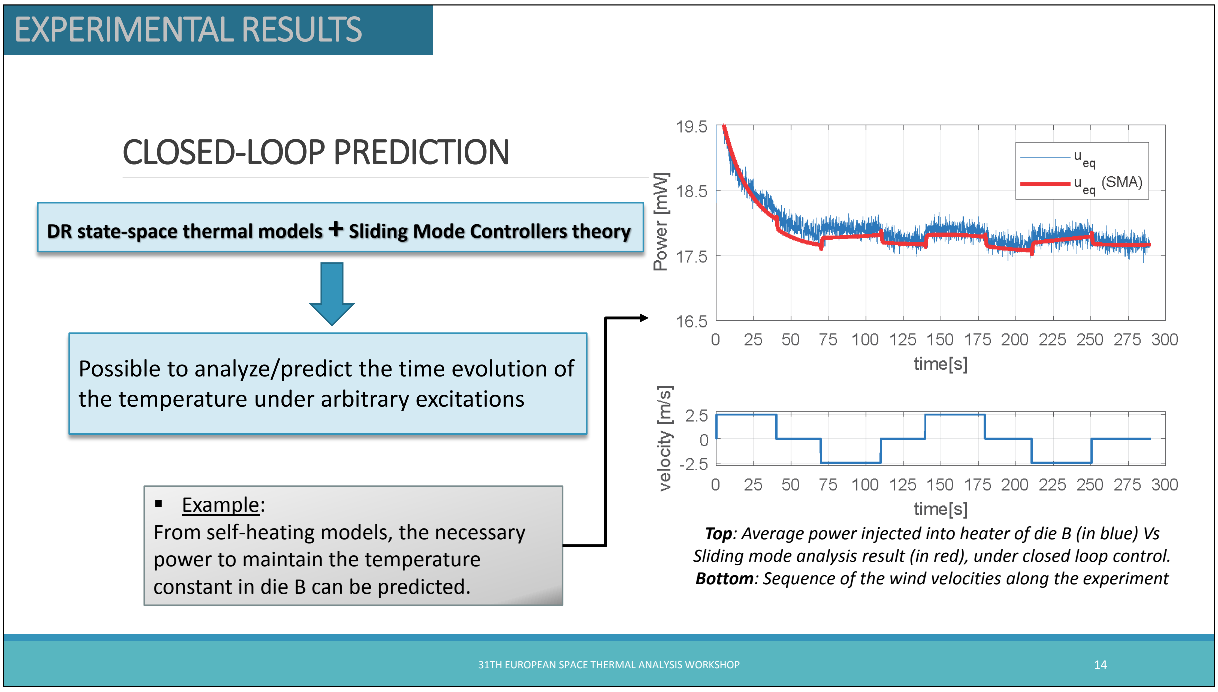
EXPERIMENTAL RESULTS
CLOSED-LOOP PREDICTION
DR state-space thermal models + Sliding Mode Controllers theory
Possible to analyze/predict the time evolution of the temperature under arbitrary excitations
Example:
From self-heating models, the necessary power to maintain the temperature constant in die B can be predicted.
Power [mW]
u eq
u eq (SMA)
time[s]
velocity [m/s]
time[s]
Top: Average power injected into heater of die B (in blue) Vs Sliding mode analysis result (in red), under closed loop control.
Bottom: Sequence of the wind velocities along the experiment
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CONCLUSIONS

CONCLUSIONS

- Time-varying thermal models of a prototype of the REMS wind sensor have been obtained for different wind velocities.
- Self and cross heating effects have been modeled.
- Obtained models help to understand the long term effects and drifts in the system.
- These state-space models may predict outputs for arbitrary excitations.

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THANK YOU!

31TH EUROPEAN SPACE THERMAL ANALYSIS WORKSHOP 16

Appendix L

A MLI model based on transient model correlation

Jan Klement Lena Bötsch Jonas Klose Christian Walker
(Tesat-Spacecom GmbH, Germany)

Abstract

Measuring and predicting the thermal heat flux trough a MLI is a challenging task. A modelling approach is presented based on sectioning the MLI into different areas (Flat surface, corners and edges with and without seam). The parameters for this model are obtained using an inverse problem approach. Transient testing and model correlation is used instead of the typical steady state approach.

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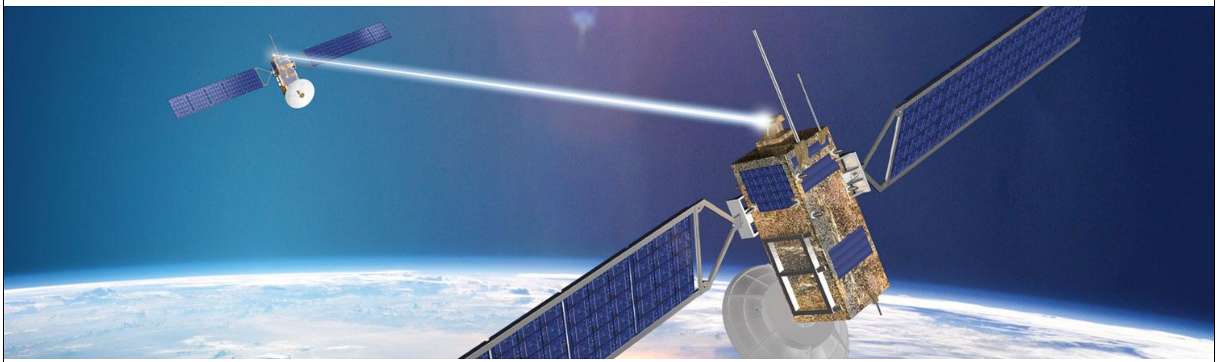
PIONEERING WITH PASSION



A MLI model based on transient correlation

Jan Klement, Lena Bötsch,
Jonas Klose, Christian Walker

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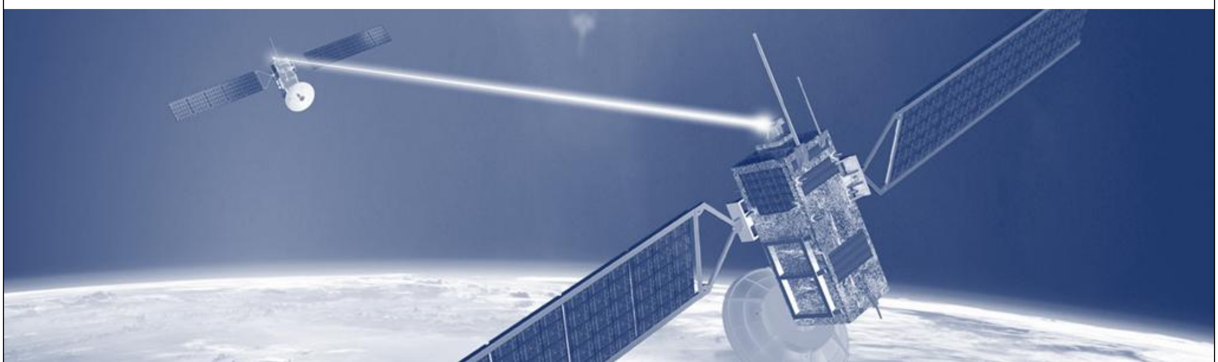

Introduction: the current status of MLI models

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THE THEORETICAL EFFECTIVE EMISSIVITY OF AN IDEAL MLI

A theoretical ideal MLI has the thermal heat flux described by an effective emissivity between the inner an the outer layers

$$\varepsilon_{theory} = \frac{1}{\dfrac{2}{\varepsilon_{Al}} - 1} * \frac{1}{N+1}$$

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THEORETICAL EFFECTIVE EMISSIVITY OF MLI

In reality this value is never reached.
There is also a huge scatter

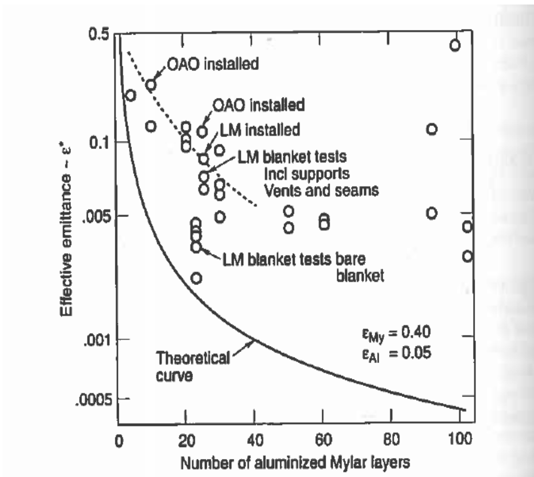

Fig. 5.3. Effective emittance vs. number of single aluminized layers.

Source: David G. Gilmore, „Spacecraft Thermal Control Handbook Volume I 2nd ed“, The Aerospace Press, 2002

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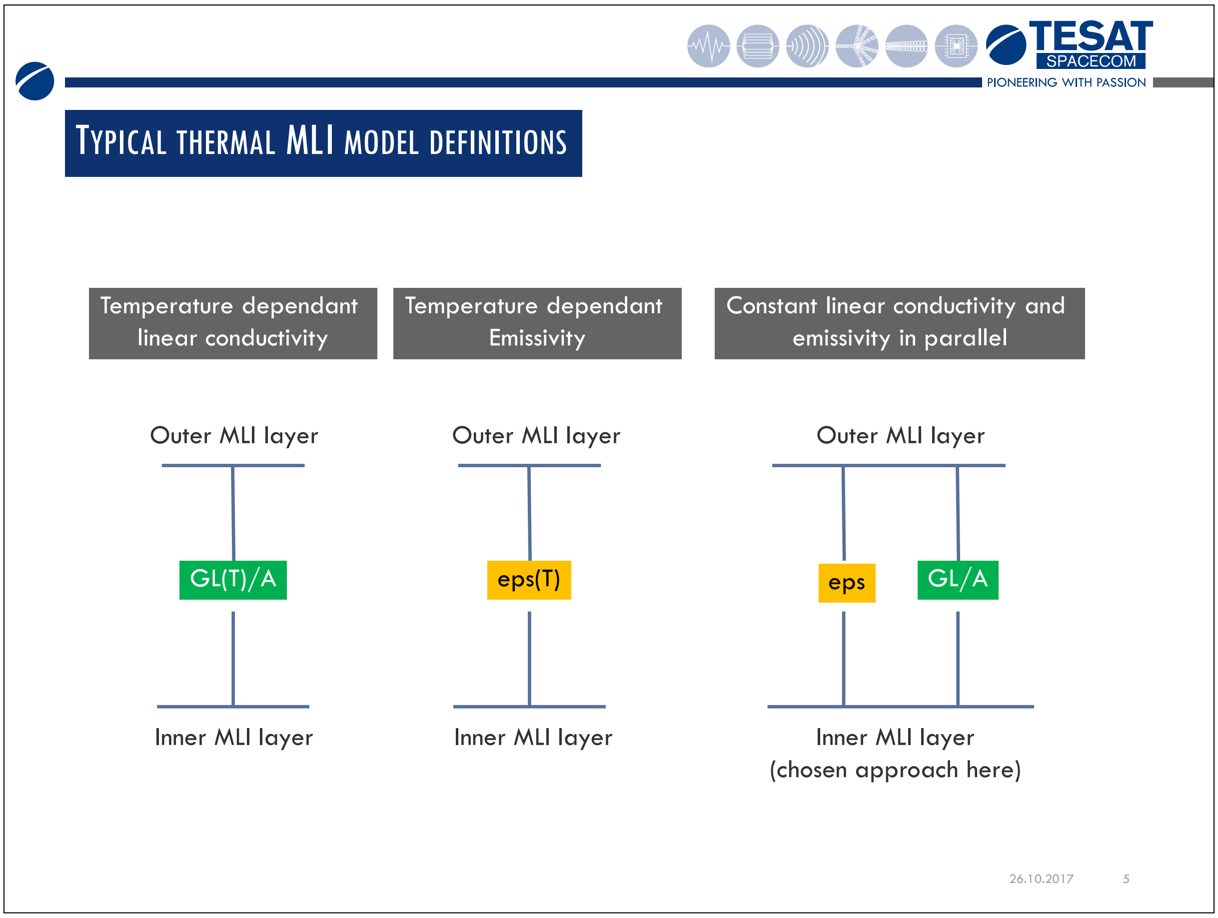
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PIONEERING WITH PASSION
TYPICAL THERMAL MLI MODEL DEFINITIONS
Temperature dependant linear conductivity
Temperature dependant Emissivity
Constant linear conductivity and emissivity in parallel
Outer MLI layer
GL(T)/A
Inner MLI layer
Outer MLI layer
eps(T)
Inner MLI layer
Outer MLI layer
eps
GL/A
Inner MLI layer
(chosen approach here)
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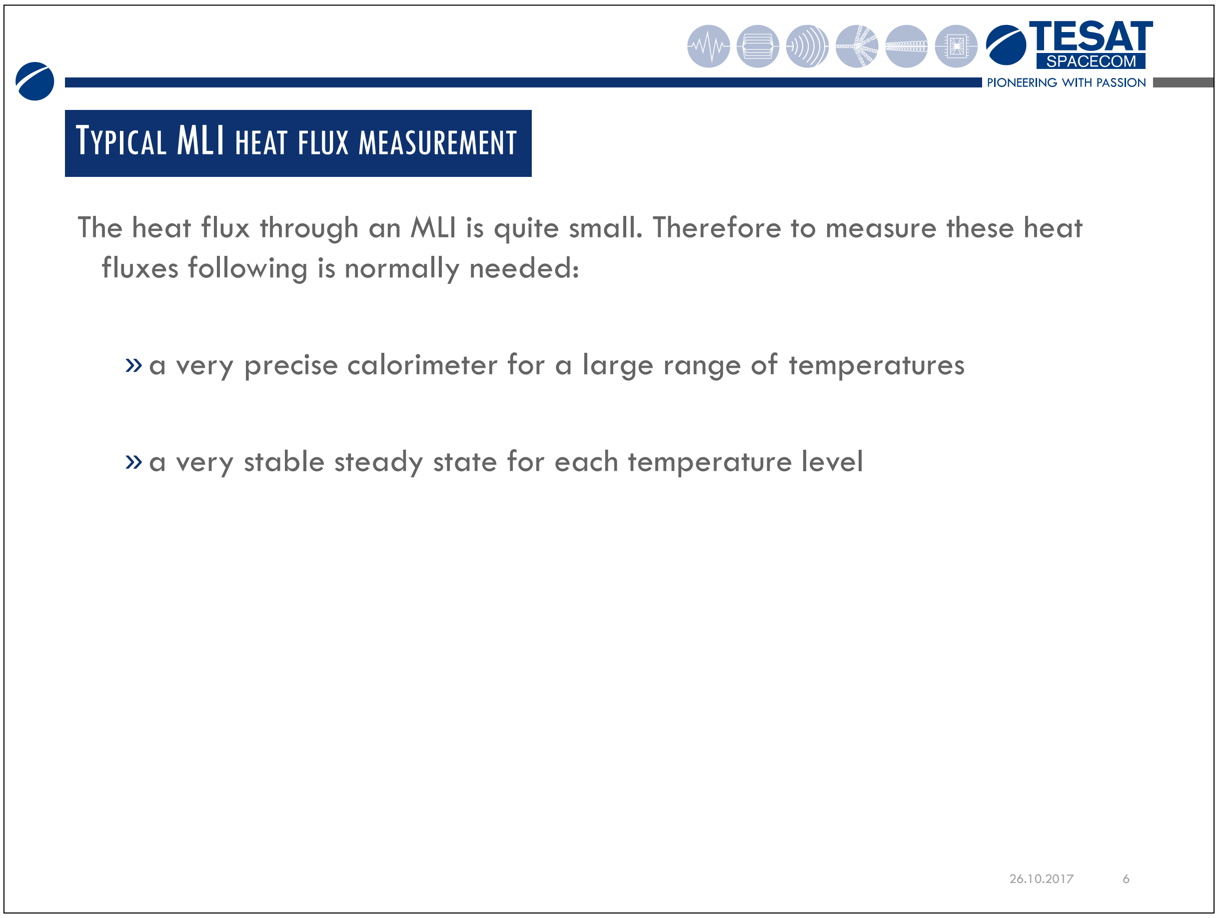
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TYPICAL MLI HEAT FLUX MEASUREMENT
The heat flux through an MLI is quite small. Therefore to measure these heat fluxes following is normally needed:
» a very precise calorimeter for a large range of temperatures
» a very stable steady state for each temperature level
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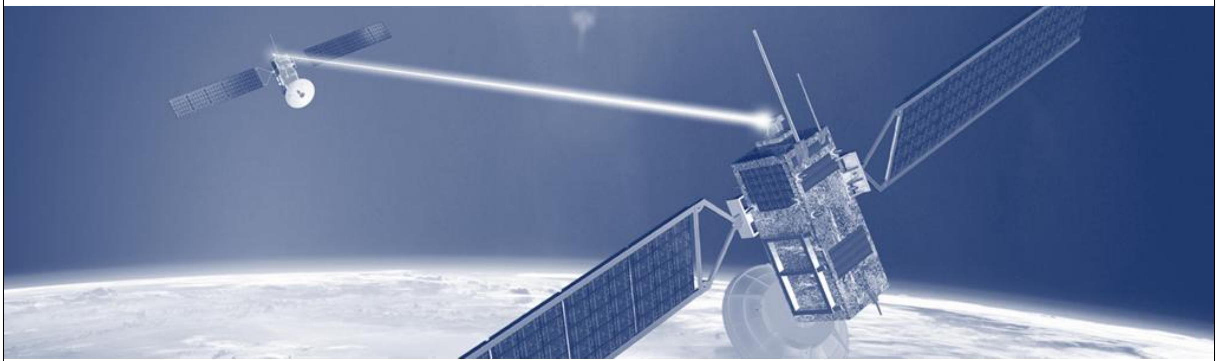

The new model approach

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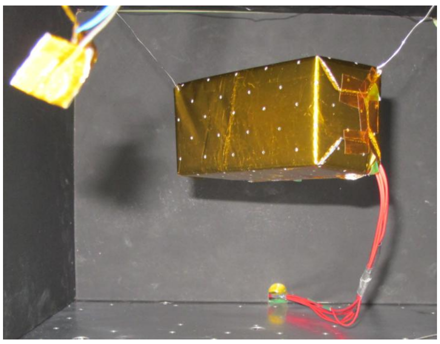
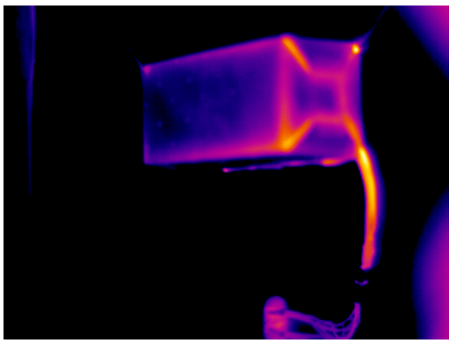
Visualizing the heatloss

Test body packed in MLI inside TV chamber



(This MLI design is not representative)

IR picture



- Body inside the MLI is heated
- shroud is cold

yellow = warm; black = cold

Conclusion: corners, edges and wires have a significant contribution to the heat loss
Heat loss trough the wires have to be minimized

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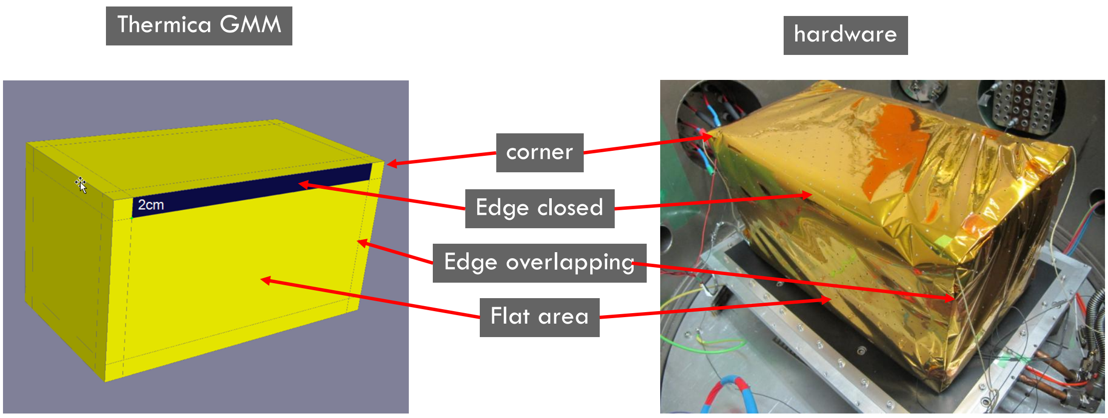
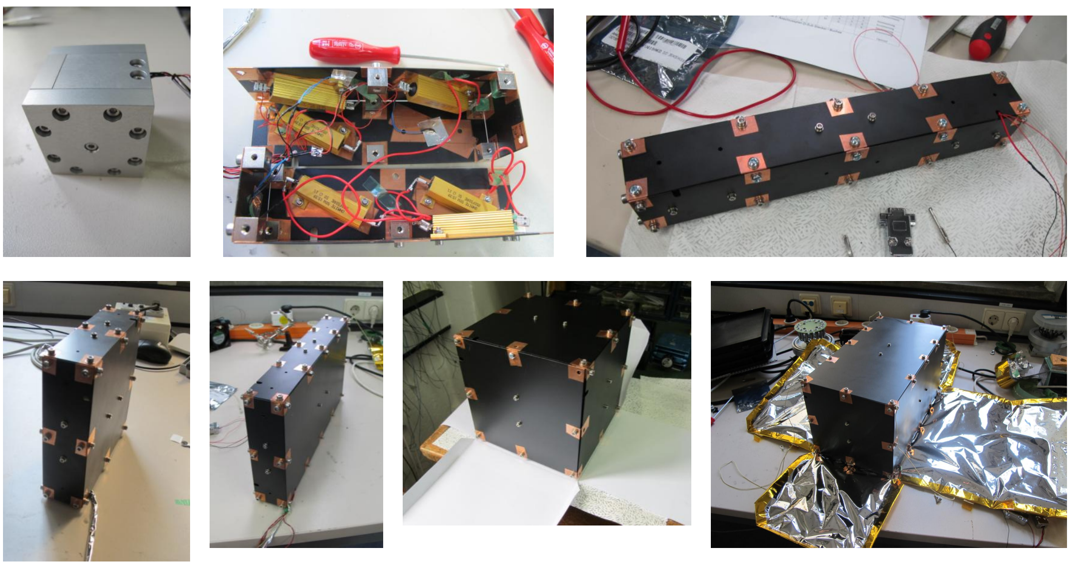
The Model

The is MLI divided into 4 areas
The edge area is defined as 2cm wide



The 7 test bodies with very different dimensions are used. One is tested with different 2 MLI configurations (7 and 12 overlapping edges). 8 tests in total



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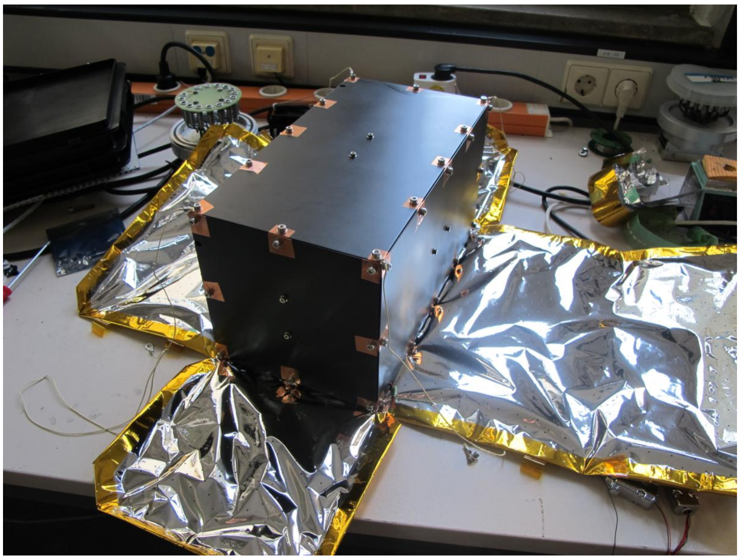
The Approach

- 7 bodies made out of copper are packed in
  - 15 (Mylar VDA on both sides)
  - 2 (Kapton) layer MLI



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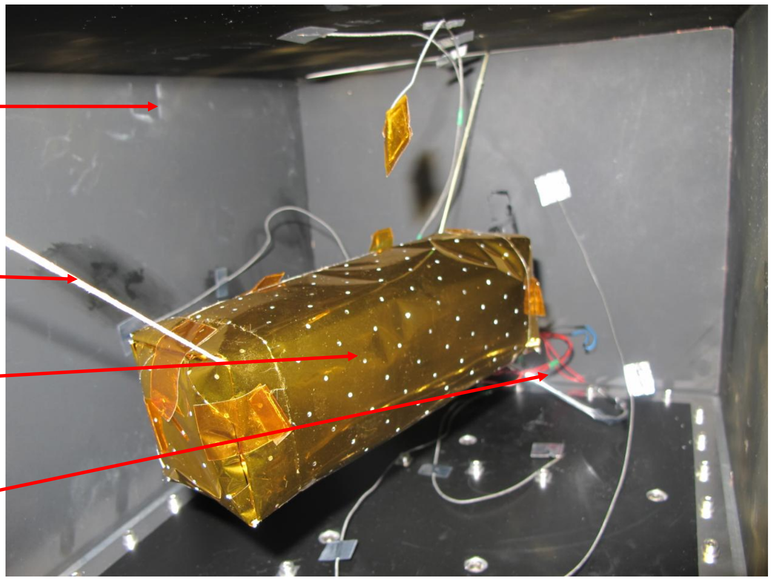
Test body is placed in thermo vacuum chamber

Shroud controls the environment temperature

Supported only by Kevlar strings

Test body in MLI

Thin wires for the heaters and one temperature sensor



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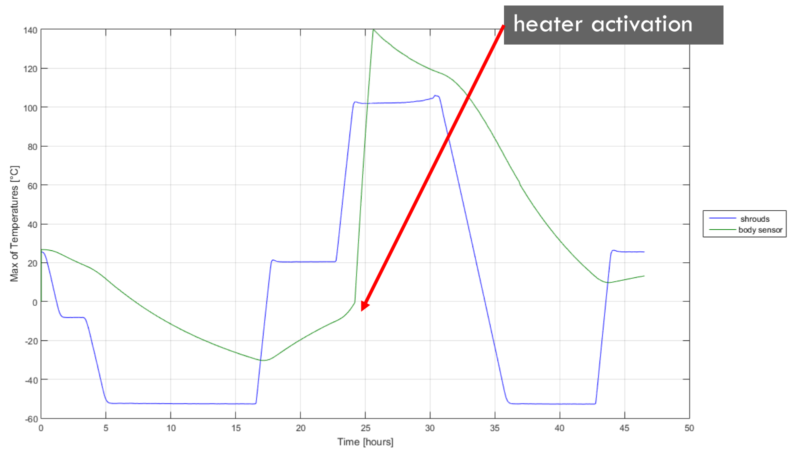
Test procedure

All bodies where tested with a similar procedure in a thermo vacuum chamber.
Different body and environment temperatures where used.



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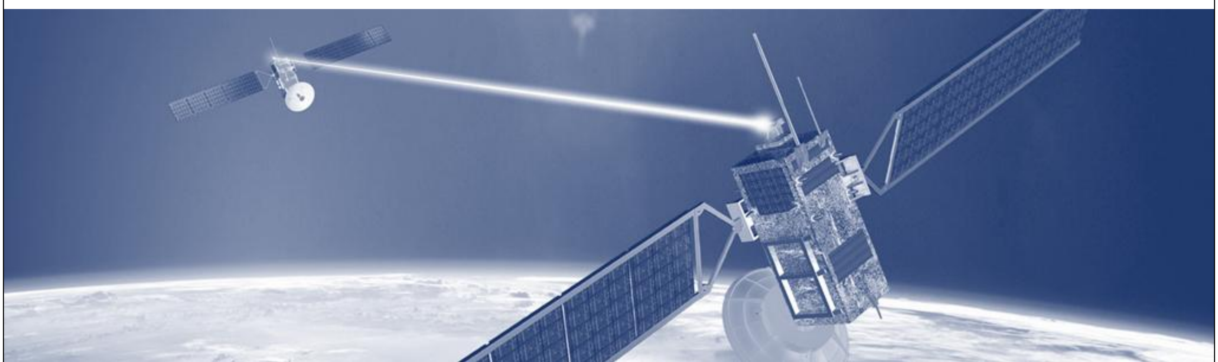

Modelling and correlation

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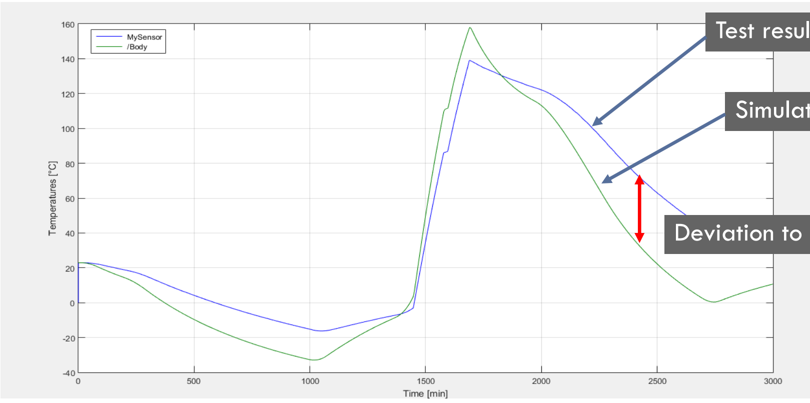
Comparison to simulation (before correlation)

All tests where simulated in Thermica using typical values.
The shroud temperature from the has been mapped onto the shroud nodes.



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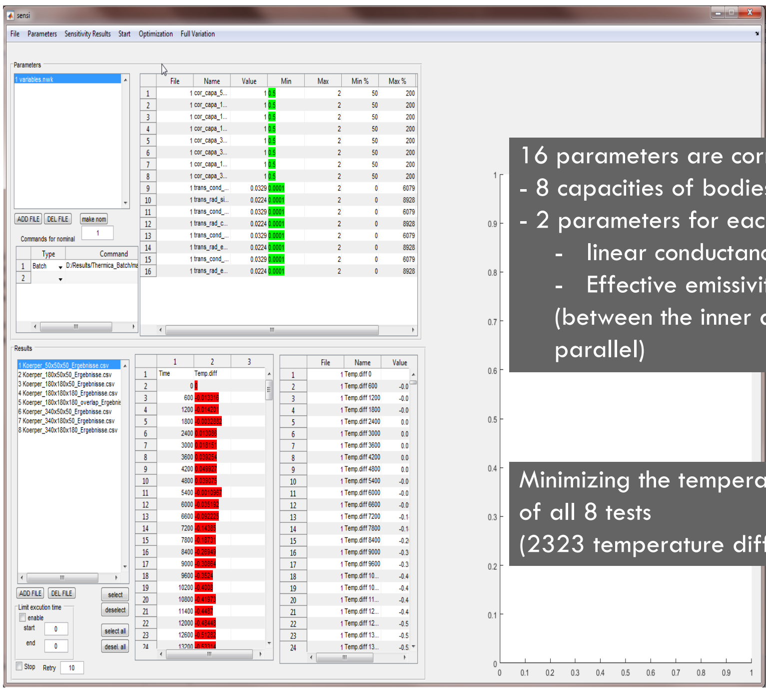
Correlation Software (developed at TESAT)



16 parameters are correlated
- 8 capacities of bodies
- 2 parameters for each MLI area
  - linear conductance W/Km²
  - Effective emissivity

  (between the inner and outer MLI layer in parallel)

Minimizing the temperature differences of all 8 tests
(2323 temperature differences in total)

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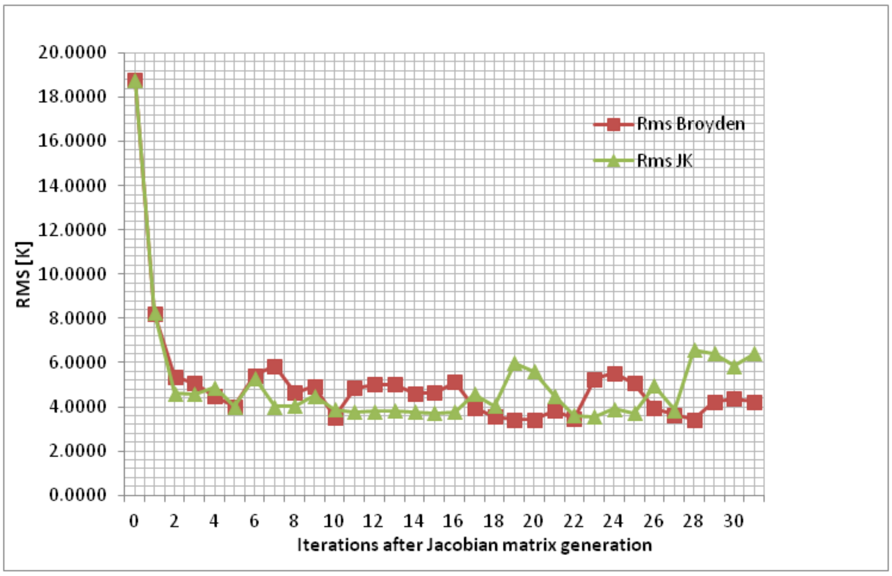
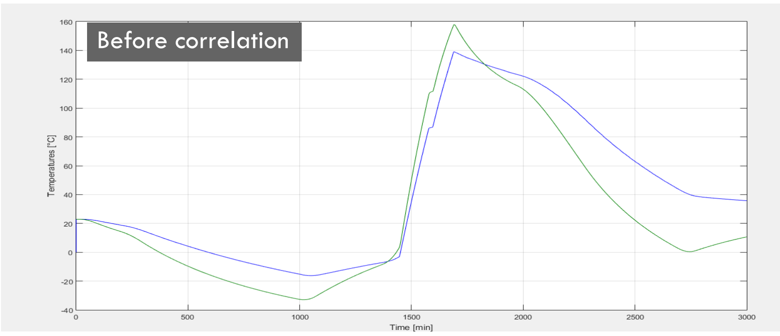
A Broyden class algorithm minimizes the RMS over all temperature differences

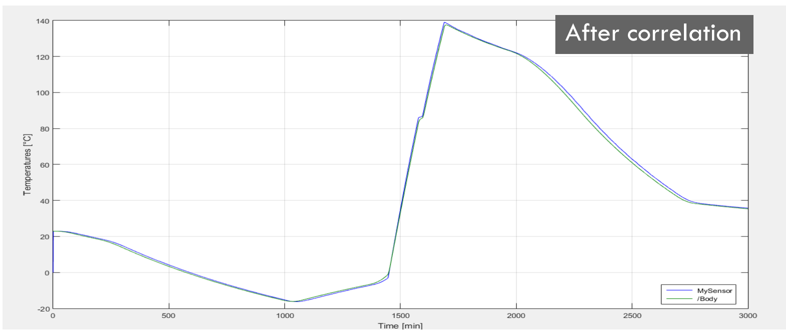


After only 3 iterations a optimum is nearly reached. (16 iterations needed for the Jacobian)
It is not expected that it is possible to minimize the RMS to 0K because the problem is highly over constrained

Correlation results



Green: Simulation
Blue: Test



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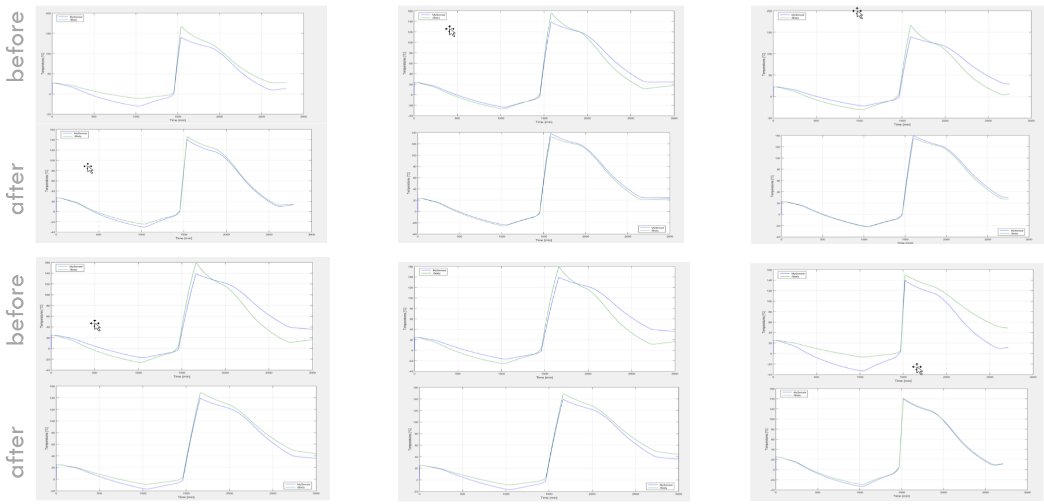
Also the other simulation good fit between test results and simulation



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Resulting MLI parameters from the correlation

Parameter	Effective conductivity*	Effective emissivity*
Flat area	0.004445 W/m²K	0.003365
Corners	1.013198 W/m²K	0.000179
Closed Edges (only bent)	0.000101 W/m²K	0.014994
Edges with overlapping MLI	0.264138 W/m²K	0.007348

*) The conductivity and the and the emissivity must be used in parallel between the inner and outer layer.

These are effective nominal parameters. They fit to the results but their temperature dependency may not be accurate. The corresponding assessment of their accuracy is to discussed tomorrow.

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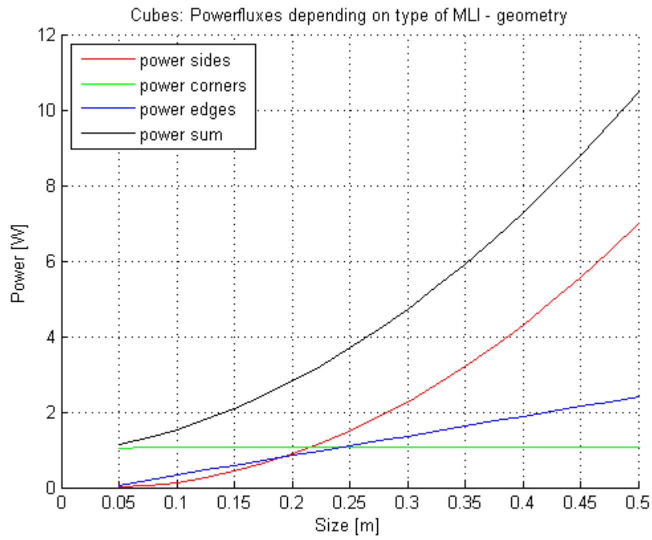
Heatloss of a cube packet in MLI

cube temperature: 100°C
Environment temperature: -40°C



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Conclusion

- The advantages of transient testing are:
  - No complicated and precise calorimeter is necessary
  - Temperatures changes are used which can be measured quite accurate
  - It is not necessary to wait until steady state is reached
  - Each test gives a information for whole range of temperatures instead of one single point
  - Only one temperature sensor is necessary inside the body

  In other words: More data with an easier, faster and cheaper test.

- Correlation
  - Broyden class algorithms needed only a few(<20) iterations to reach an optimum (transient model, 16 parameters, 8 configurations & tests, 2323 temperatures differences)

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PIONEERING WITH PASSION

Outlook

- The method can be used to extend the MLI model for:
  - Different corner angles
  - Stand-offs
  - Flaps
  - Slits
  - Different layer setup
  - Larger bodies
- With more extreme temperatures the temperature dependency can be analyzed with higher accuracy.
- The correlation software(Sensitool) can be obtained by other companies of the Airbus Group

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TESAT SPACECOM
PIONEERING WITH PASSION

Thank you

Gefördert durch:

Bundesministerium
für Wirtschaft
und Energie

aufgrund eines Beschlusses
des Deutschen Bundestages

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Appendix M

Methods to Improve Thermal Test Efficiency (MITTE)

Patrick Coutal
(Airbus Toulouse, France)

James Etchells
(ESA/ESTEC, The Netherlands)

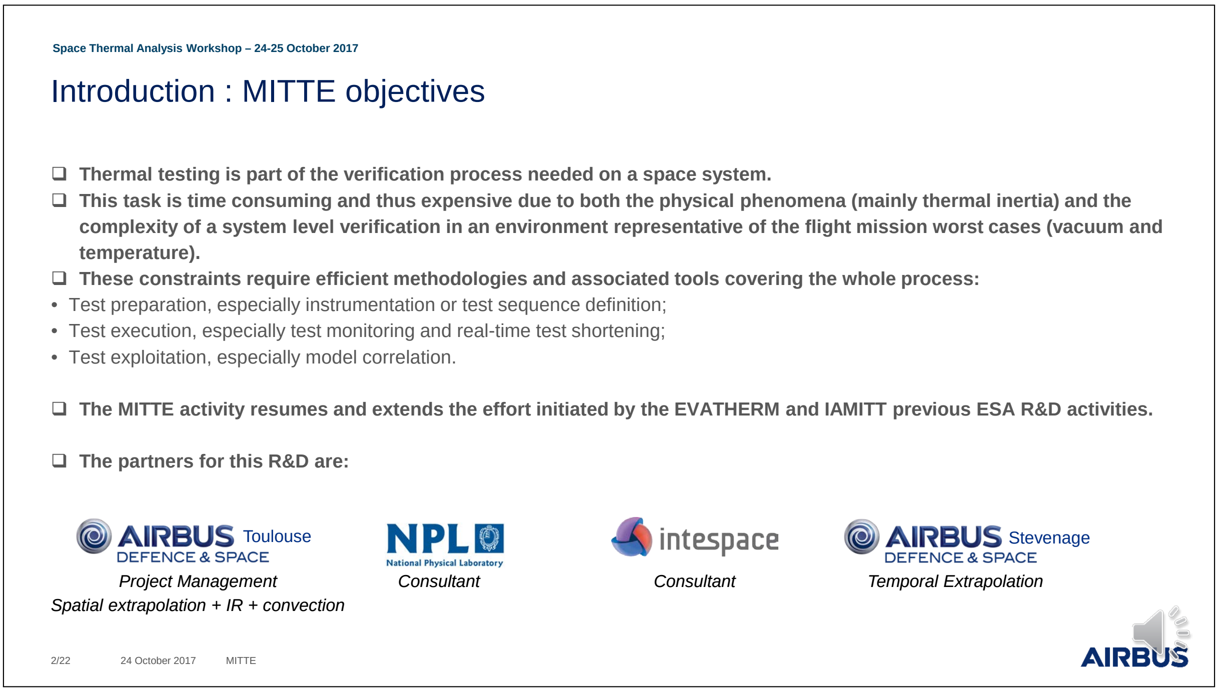
Abstract

Thermal testing is part of the verification process needed on a space system. This necessary task is time-consuming and thus expensive due to both the physical phenomena (mainly thermal inertia) and the complexity of a system level verification in an environment representative of the flight mission worst cases (vacuum and temperature). These constraints require efficient methodologies and associated tools covering the whole process:

- Test preparation, especially instrumentation or test sequence definition;
- Test execution, especially test monitoring and real-time test shortening;
- Test exploitation, especially model correlation.

The ESA TRP Methods to Improve Thermal Test Efficiency (MITTE) resumes and extends the effort initiated by the EVATHERM and IAMITT previous ESA R&D activities. The presentation will then focus on the last developments involving the temporal and spatial extrapolations, the Infrared camera usage and the natural convection modelling in an industrial context.


Methods to Improve Thermal Test Efficiency
Space Thermal Analysis Workshop
DEFENCE AND SPACE
P. Coutal (ADS), J. Etchells (ESA)
24-25 October 2017
esa
AIRBUS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Introduction : MITTE objectives
❑ Thermal testing is part of the verification process needed on a space system.
❑ This task is time consuming and thus expensive due to both the physical phenomena (mainly thermal inertia) and the complexity of a system level verification in an environment representative of the flight mission worst cases (vacuum and temperature).
❑ These constraints require efficient methodologies and associated tools covering the whole process:
• Test preparation, especially instrumentation or test sequence definition;
• Test execution, especially test monitoring and real-time test shortening;
• Test exploitation, especially model correlation.
❑ The MITTE activity resumes and extends the effort initiated by the EVATHERM and IAMITT previous ESA R&D activities.
❑ The partners for this R&D are:
AIRBUS DEFENCE & SPACE Toulouse
Project Management
Spatial extrapolation + IR + convection
NPL National Physical Laboratory
Consultant
intespace
Consultant
AIRBUS DEFENCE & SPACE Stevenage
Temporal Extrapolation
2/22
24 October 2017
MITTE
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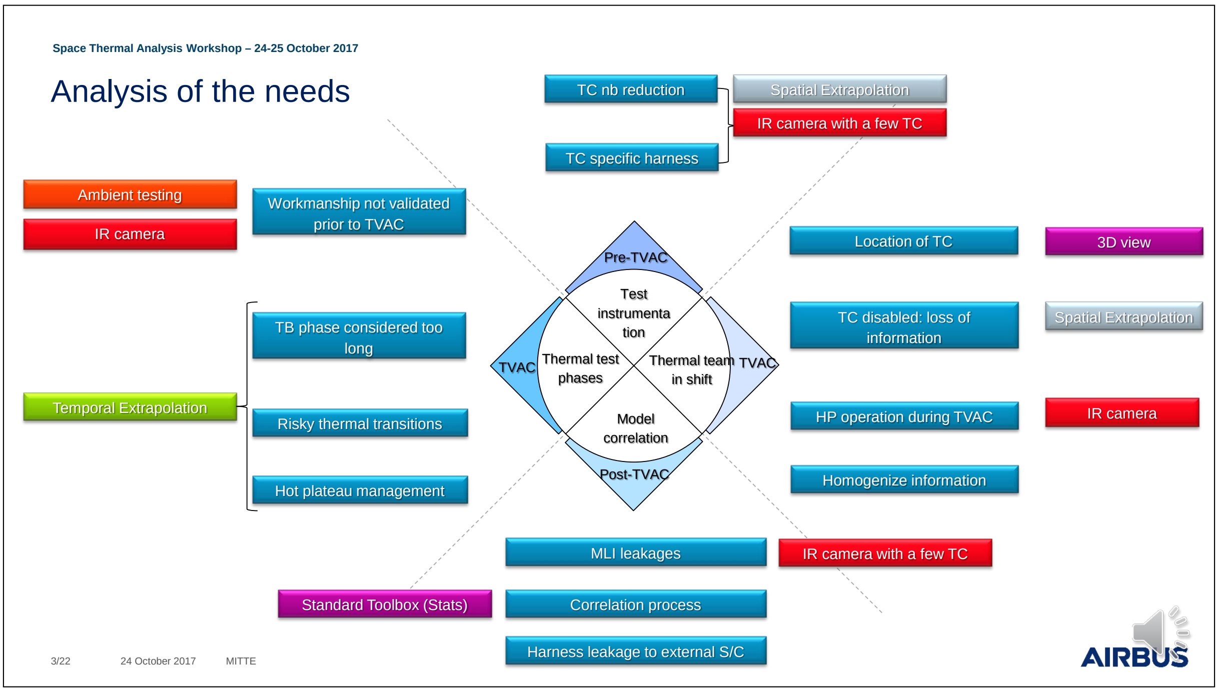
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Analysis of the needs
TC nb reduction
Spatial Extrapolation
IR camera with a few TC
TC specific harness
Ambient testing
IR camera
Workmanship not validated prior to TVAC
Location of TC
3D view
Pre-TVAC
Test instrumentation
TVAC
Thermal test phases
Thermal team in shift
TVAC
Model correlation
Post-TVAC
TC disabled: loss of information
Spatial Extrapolation
TB phase considered too long
Temporal Extrapolation
Risky thermal transitions
HP operation during TVAC
IR camera
Hot plateau management
Homogenize information
MLI leakages
IR camera with a few TC
Standard Toolbox (Stats)
Correlation process
Harness leakage to external S/C
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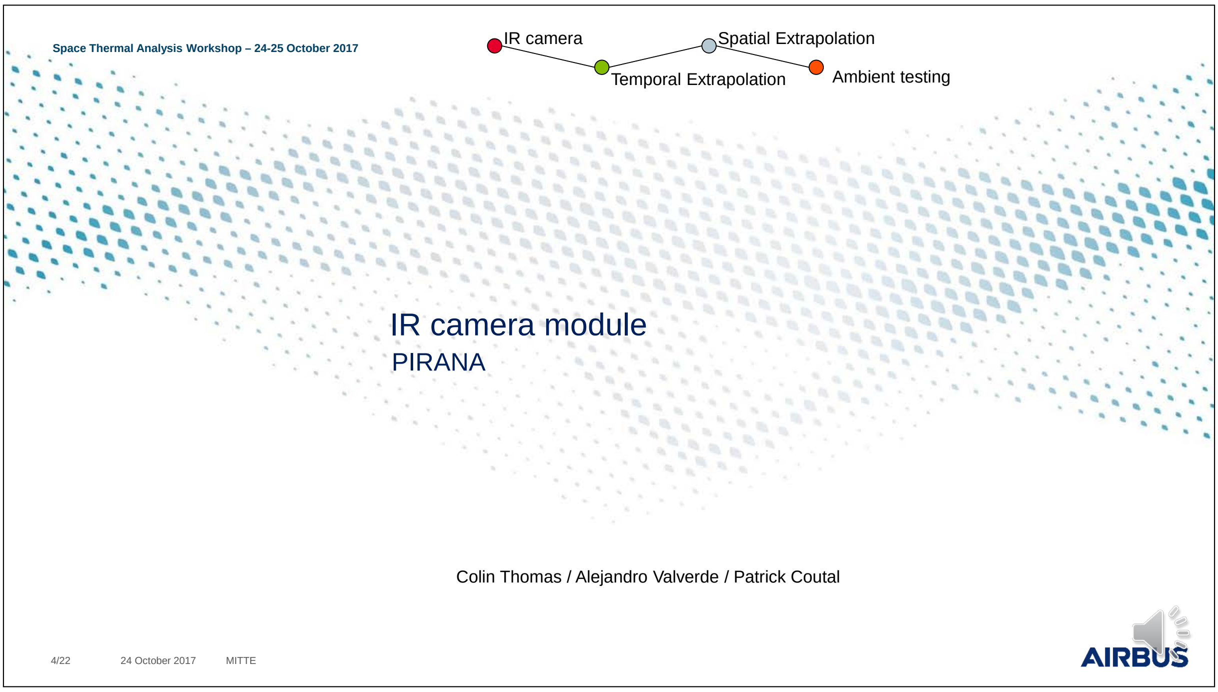
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IR camera
Spatial Extrapolation
Temporal Extrapolation
Ambient testing
IR camera module
PIRANA
Colin Thomas / Alejandro Valverde / Patrick Coutal
4/22
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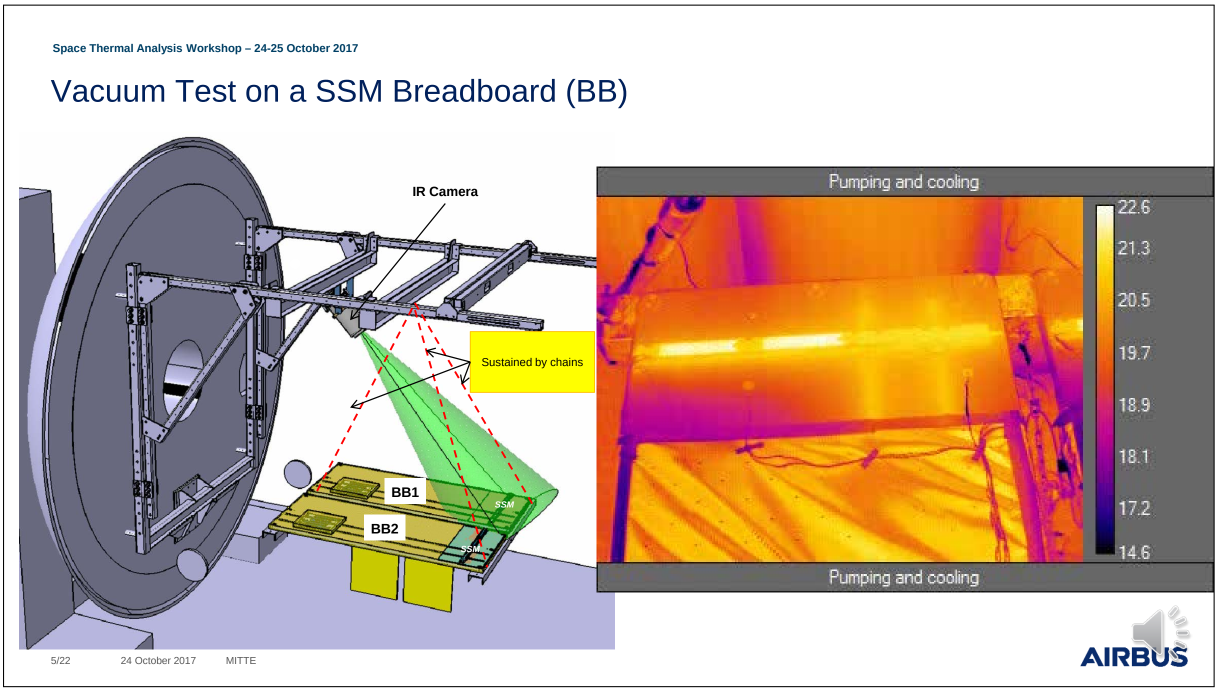

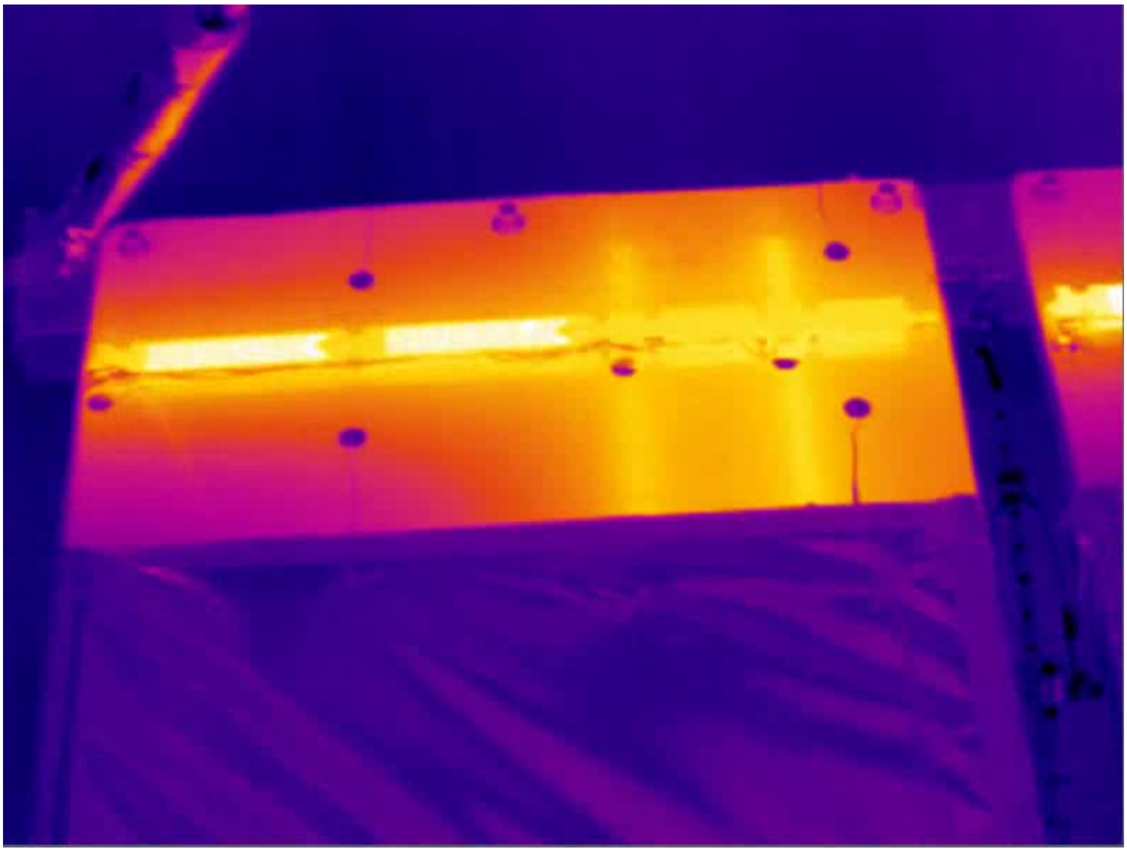

Save the attachment to disk or (double) click on the picture to run the movie.

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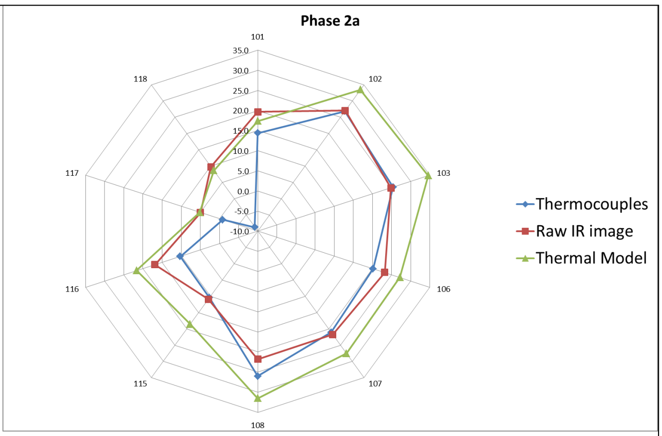
Results



❑ **Qualitative:**

- Embedded heat pipes gluing: confirmed
- Heat pipes horizontality: confirmed
- Heaters local hot spots: +30°C
- Unexpected Events:
  - MLI venting
  - Scotch peel off

❑ **Quantitative:**

- The thermocouples are not trusted everywhere (due to the influence of their wires temperature)
- Improvement of the model correlation by ~4°C taking into account the IR rather than the TC

❑ **Compared to a TC that can be erroneous due to bad gluing or wiring leakage, the camera image is homogeneous and gives more confidence in the measurement. The thermal model is closer to the IR measures.**

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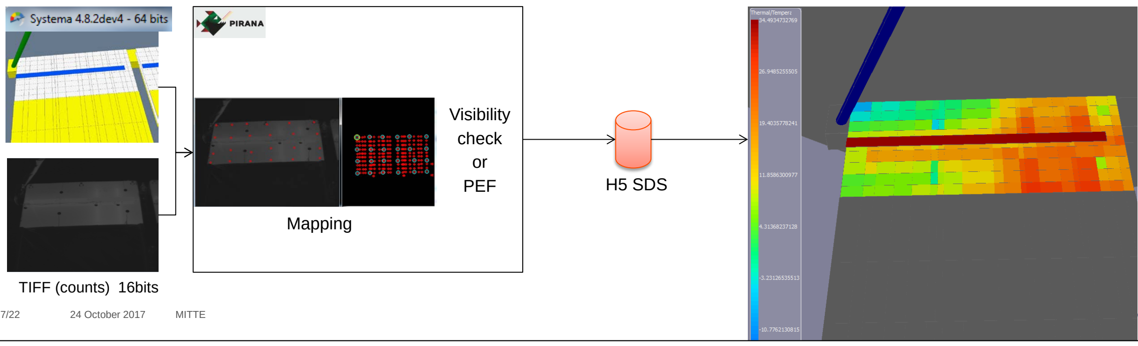
PIRANA: Python InfraRed Acquisition for Nodal Analysis

❑ **Features:**

- Inputs Systema v4 models (.sysmdl/.sysmsh) Step-TAS expected
- Gives the position of the camera in the GMM
- 2 options: with (preferred) or without Systema
- GMM transformed into Quad/Triangles (cutters allowed)
- Reflections from environment removed
- Corrected temperatures exported to the nodal network (h5 format).

❑ **Hypotheses:**

- Out of the camera FOV, every temperature should be known
- Temperatures out of the camera calibration range are not trusted.



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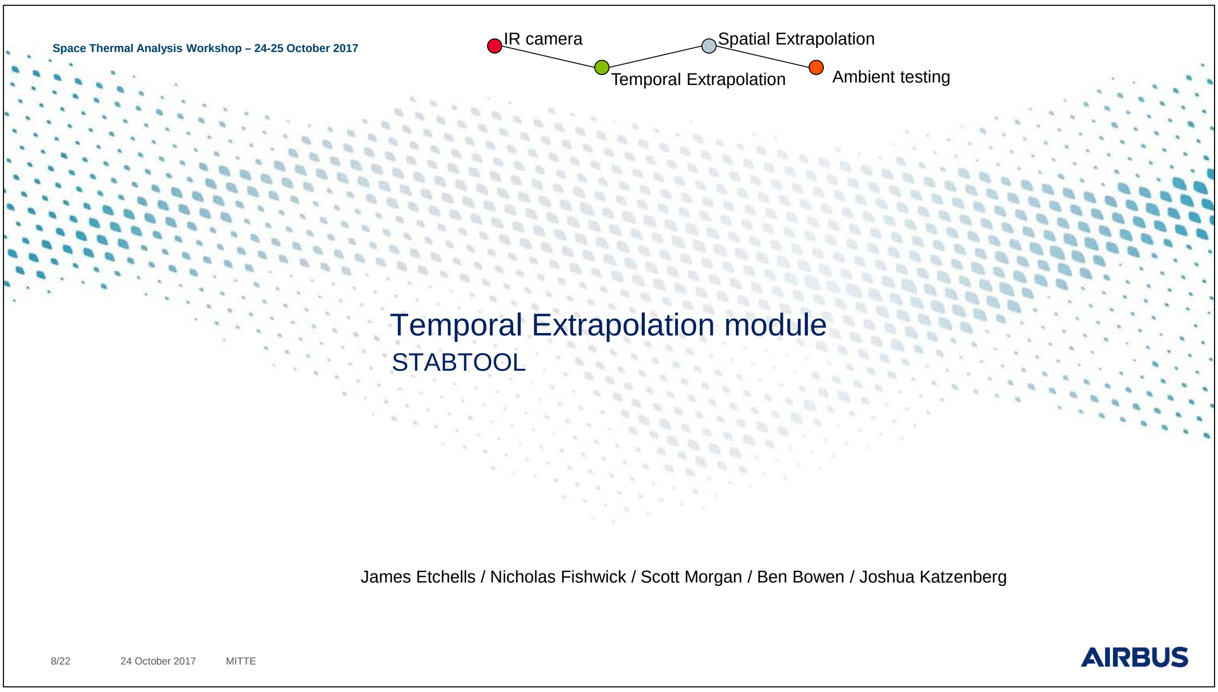

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IR camera
Spatial Extrapolation
Temporal Extrapolation
Ambient testing
Temporal Extrapolation module
STABTOOL
James Etchells / Nicholas Fishwick / Scott Morgan / Ben Bowen / Joshua Katzenberg
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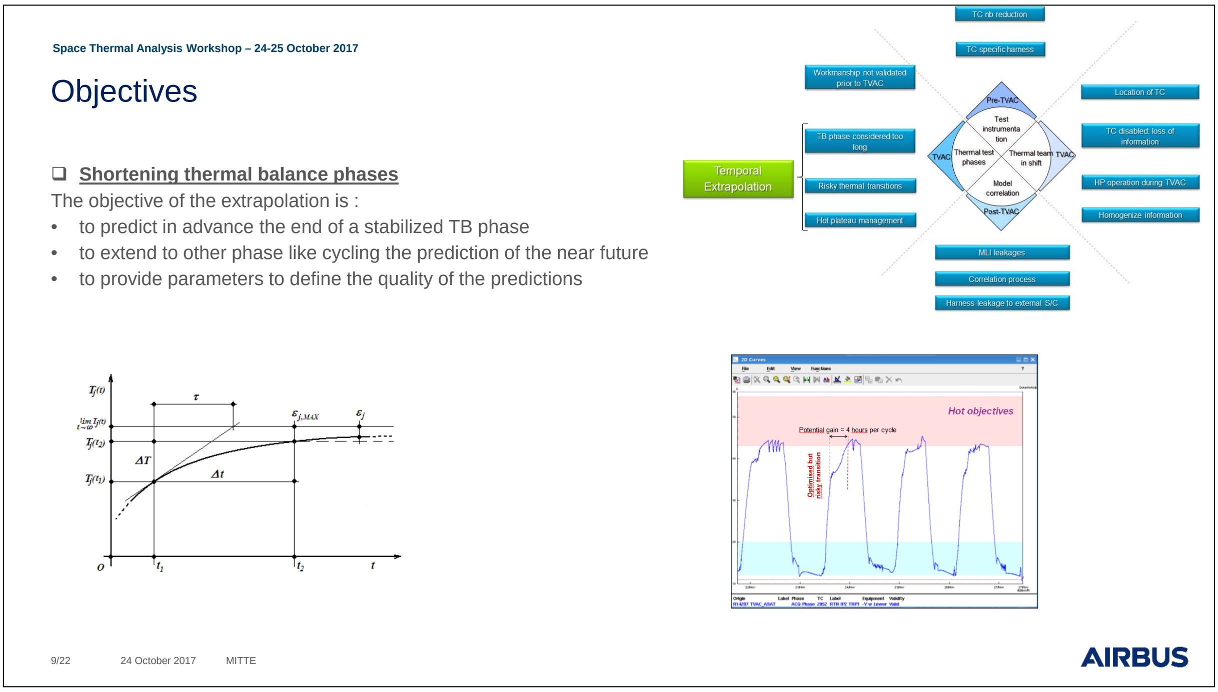

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Objectives
Shortening thermal balance phases
The objective of the extrapolation is :
• to predict in advance the end of a stabilized TB phase
• to extend to other phase like cycling the prediction of the near future
• to provide parameters to define the quality of the predictions
TC nb reduction
TC specific harness
Workmanship not validated prior to TVAC
Location of TC
Pre-TVAC
Test instrumentation
TVAC
Thermal test phases
Thermal team in shift
Model correlation
Post-TVAC
TC disabled: loss of information
TB phase considered too long
Temporal Extrapolation
Risky thermal transitions
HP operation during TVAC
Hot plateau management
Homogenize information
MLI leakages
Correlation process
Harness leakage to external S/C
Hot objectives
Potential gain = 4 hours per cycle
Optimised but risky transition
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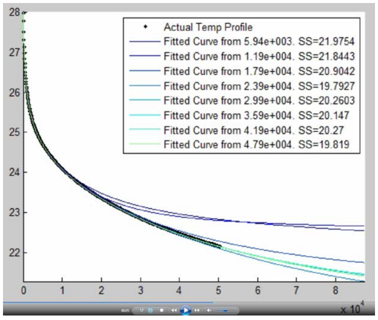
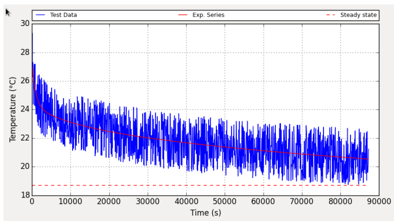
Extrapolation technique: Curve fitting

- The technique retained is the exponential series curve fitting: $$T(t) = a + \sum_{i=1,n} \left(b_i e^{c_i t} \right)$$
- Solver minimising the root mean sum of the deviations between the trial solution and the test data.
- Filtering of acquisition noise via quadratic smoothing
- Focus on using some LISA Pathfinder In-Orbit data from Jan 2017 Cooling Phase to assess how many exponential series terms best match the data.





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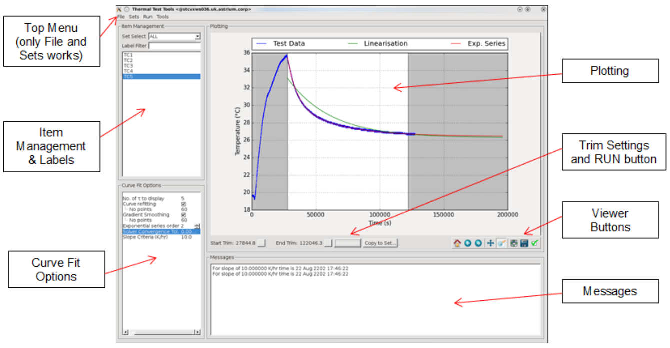
Stab Tool



- **Stab Tool features include:**
  - Some input validation
  - Header Formatting Options
  - Time Formatting Options
  - User Start and End Trim
  - Application of Start and End Trim to sets
  - Coefficient "a" determined from last temperature point
  - Exponential Curve Fitting for one or more exponential terms using the Nelder Mead Algorithm
  - Plotting of Exponential Curve Fitting superposed on the test data
  - Objective function for RSS compared to test measurements

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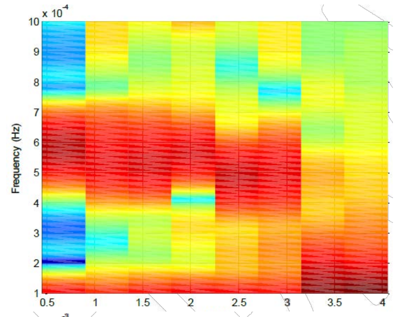
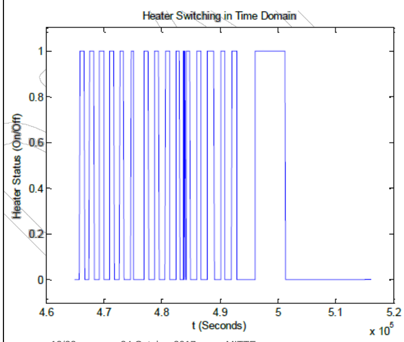
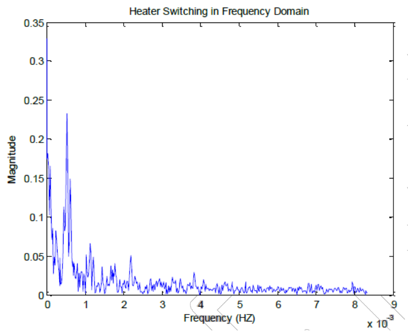
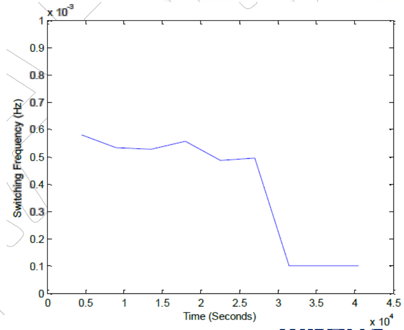
Extrapolation for Heater cycling zones

- **Analysis with Matlab:**
  - Fourier transform applied to the signal
  - Frequency-time spectrogram plot
  - Calculation of heater cycling frequency variation from data
- **Perspectives:**
  - Method not suitable for long-term prediction. Further investigations needed.









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IR camera — Temporal Extrapolation — Spatial Extrapolation — Ambient testing

Spatial Extrapolation module

ESA YGTs (J. Eisenbraun / M. Vaughan) / Marco Scardino

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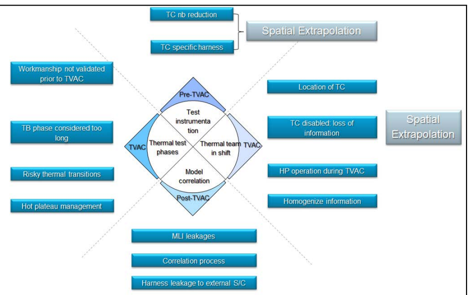
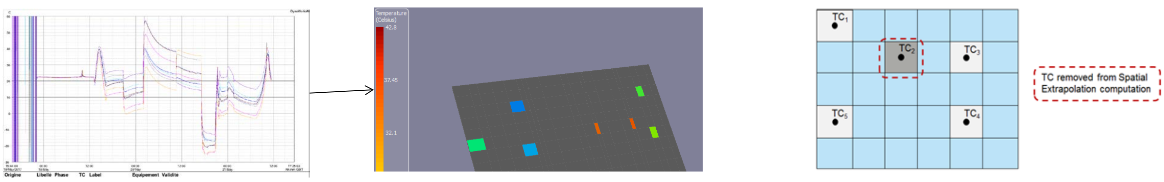
Objectives



Based on the thermal model knowledge, the Spatial extrapolation potentials are:

– ***To extend the vision of the monitored temperatures from 2D curves to maps through the 3D viewer to aid the thermal team***
– ***To challenge the number of thermocouples needed***
– ***To recover a disabled thermocouple information (if a sensor is failing)***



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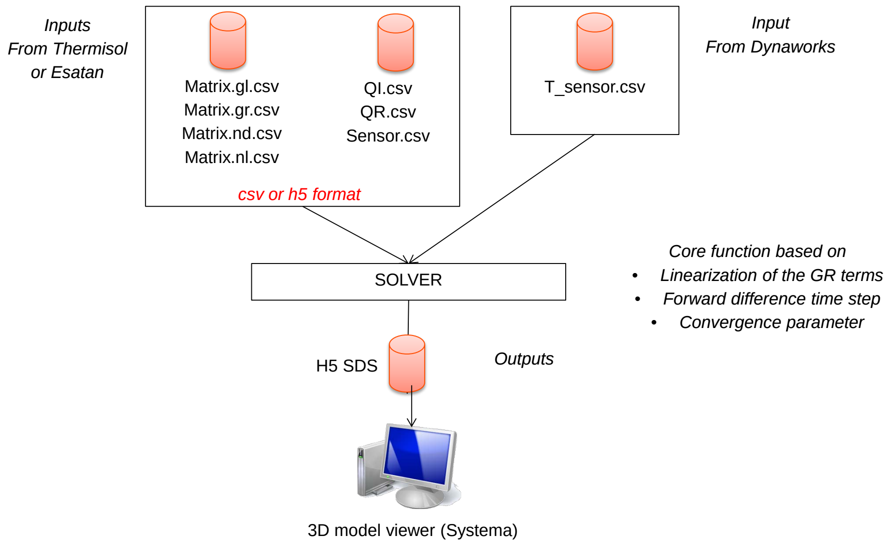
Steady/Transient Solver



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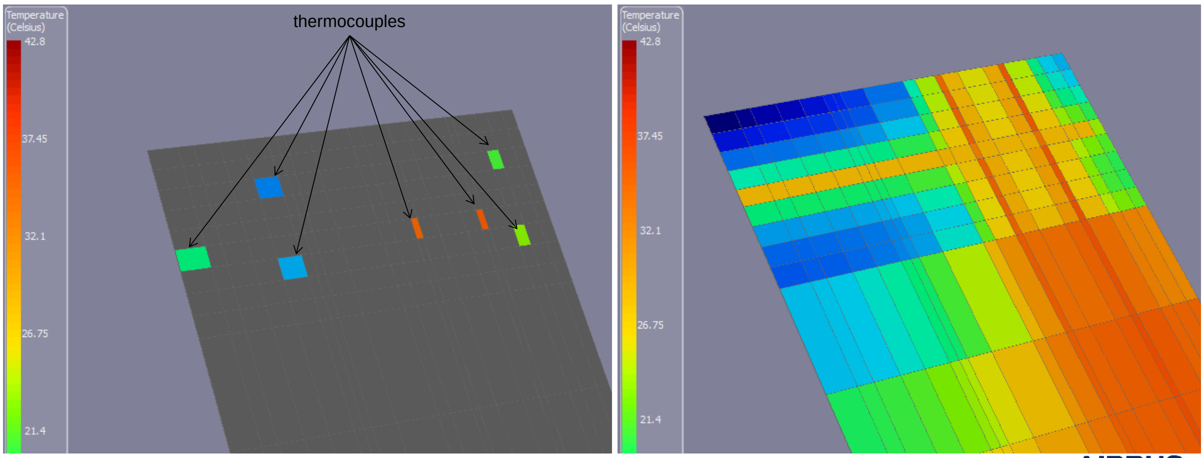
Python tool

- Demonstration on the SSM breadboard



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IR camera
Temporal Extrapolation
Spatial Extrapolation
Ambient testing

Ambient testing

Natural Convection modelling

Benjamin Lagier / Patrick Coutal

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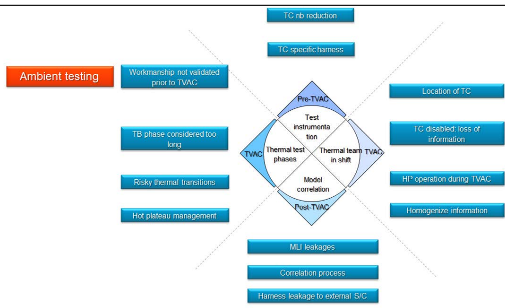
Objectives



- ❑ **The EVATHERM previous work aimed to take advantage of the ambient testing for workmanship validation.**
- ❑ **This goal may be considered only on suitable situations: recurrent S/C or subsystem (constellation, Neosat P/F).**

- ❑ **The last efforts have been put on:**
- Specification of the conducto-convective couplings generation.
- Automatic detection of air cavities (thanks to Systema v4.8.2dev9 under validation process)
- Application of a Computer Fluid Dynamics code on a thermal model representing ambient test prediction to be compared to the nodal method.

- ❑ **Use cases:**
- Alphasat SM SFT (end 2010)
- Micado breadboard (may 2011)

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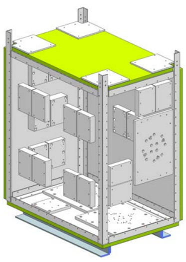
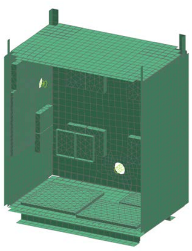
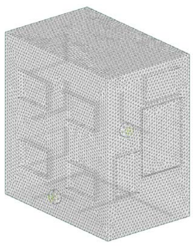
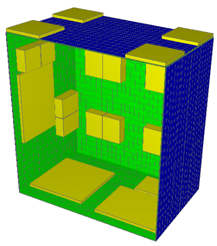
CFD on Micado

- ❑ **NX simulation**
- Full simulation with conduction, radiation and natural convection on the inside and outside of the cavity
- Convection coefficient calculated with simplified boundary layer hypothesis (allow large air node near surface)
- 5 cases with different heating configurations to compare with
- ❑ **Meshing**
- 2D meshing for Nida walls, cleats and outside heaters/ 3D meshing for internal heaters and air volumes


CAD model


NX 2D meshing


NX 3D internal air meshing


Systema 2D meshing (for comparison)

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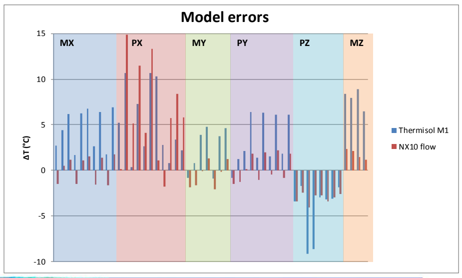
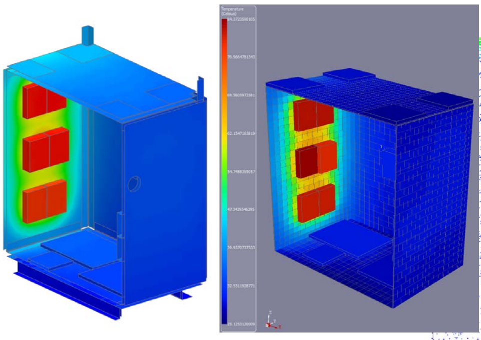
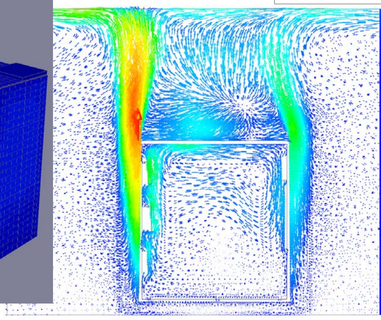
Compared results for PX wall load case



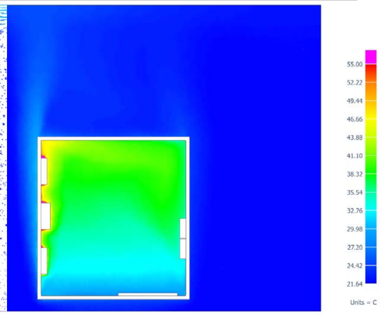
- NX: Good prediction except on dissipative units (<15°C)
- Systema: typically 8°C max discrepancy on units.
- Perspective: multi air nodes could improve Nodal prediction.



Temperature map of the cavity (NX/Systema)



Air velocity vector map



Air temperature

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Conclusion

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Conclusion and next steps
❑ Python Tools available for the ESA community.
❑ Good maturity of the tools.
❑ Demonstration at satellite level to be done in the short term.
❑ Opportunities to go further:
• Integration of the different modules together in a user friendly GUI.
• Heater cycling TE prediction to further investigate.
• Convection modelling with nodal method to enhance.
• Put an IR camera inside a spacecraft
• Remote control of the orientation of the camera inside the test chamber
• Multiple cameras use
Extrapolations
Maturity:
Clean Room test prediction using thermal model
Maturity:
IR camera to measure S/L T°
Maturity:
IR camera data → TMM
Maturity:
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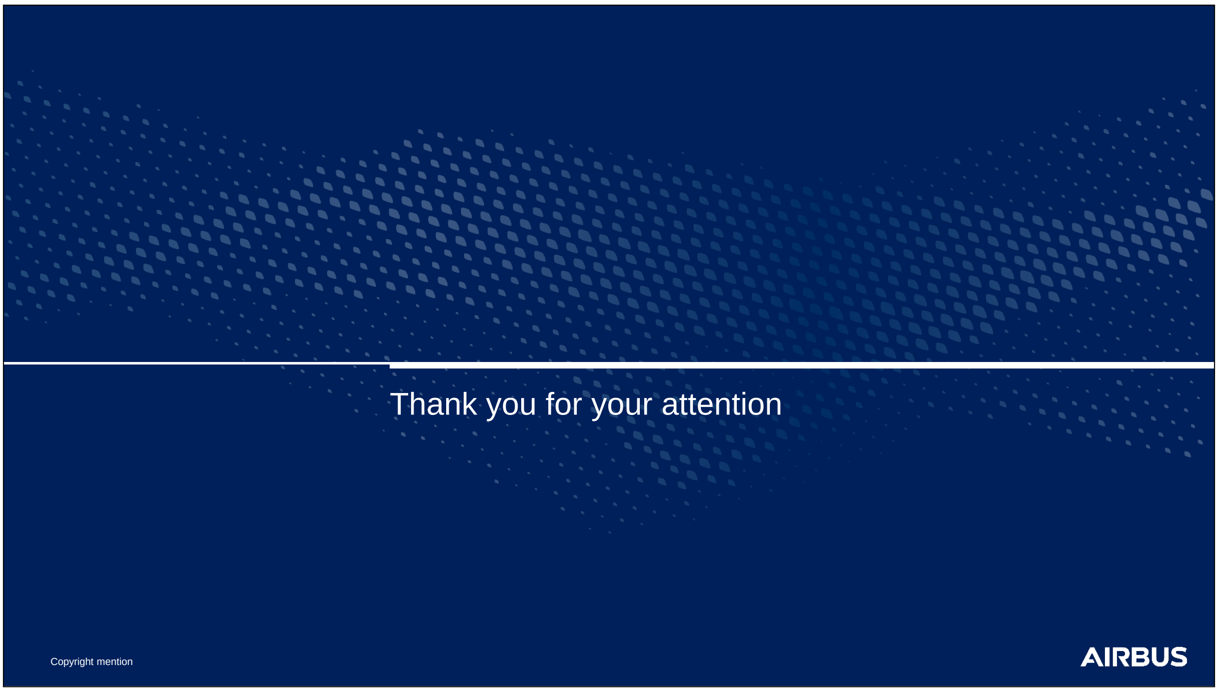
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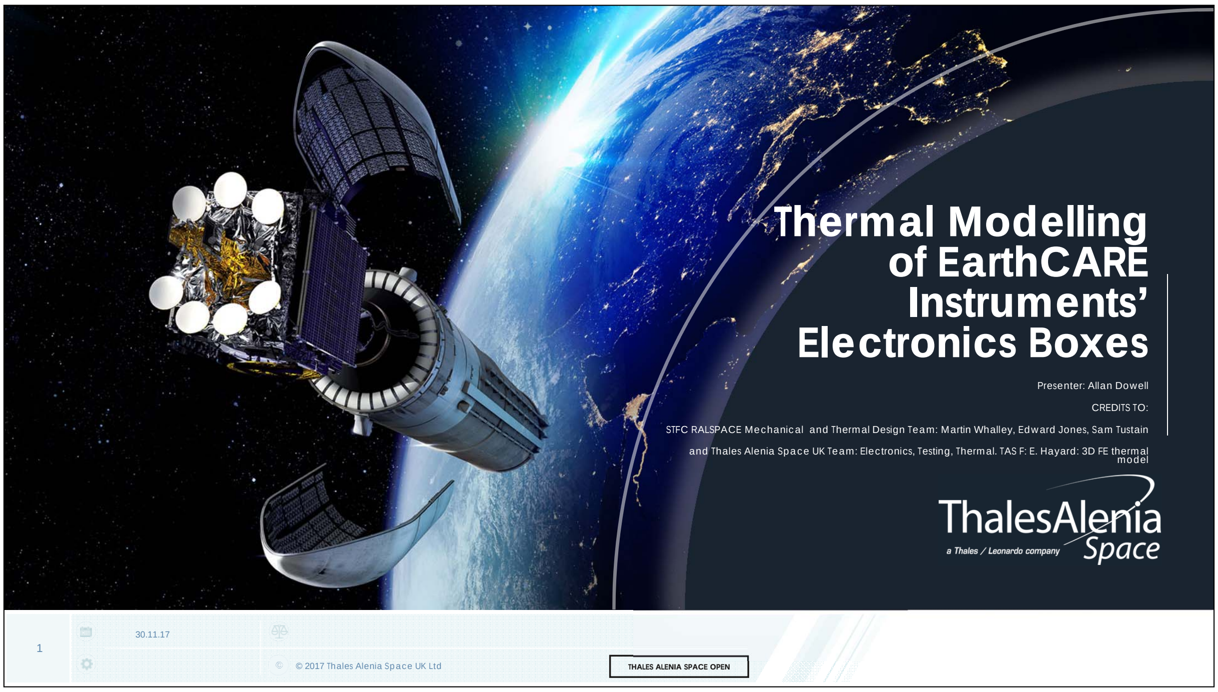
Appendix N

Thermal Modelling of EarthCARE Instruments' Electronics Boxes

Allan Dowell
(Thales Alenia Space, United Kingdom)

Abstract

The EarthCARE spacecraft has electronics boxes for the ATLID, BBR and MSI instruments which were produced by TAS in the UK and STFC RAL Space. The ATLID ACDM was thermally tested. It was found that the thermal design and ESATAN model needed updates to help components meet their derated limits. Various aspects of electronics design were investigated, looking at similar units (such as Cryocooler Electronics) and consulting with other engineers. Attempts were made to auto-generate more detailed 3D FE structure sub-models rapidly to improve predictions.


Thermal Modelling
of EarthCARE
Instruments'
Electronics Boxes
Presenter: Allan Dowell
CREDITS TO:
STFC RALSPACE Mechanical and Thermal Design Team: Martin Whalley, Edward Jones, Sam Tustain
and Thales Alenia Space UK Team: Electronics, Testing, Thermal. TAS F: E. Hayard: 3D FE thermal model
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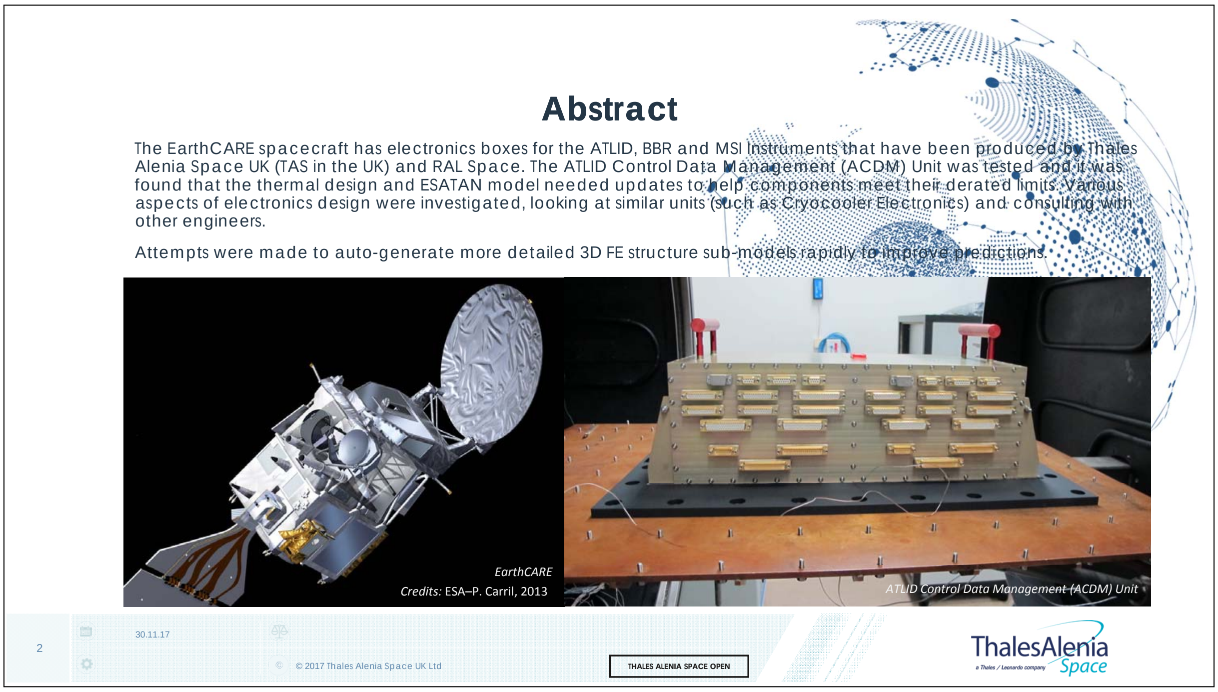
Abstract
The EarthCARE spacecraft has electronics boxes for the ATLID, BBR and MSI Instruments that have been produced by Thales Alenia Space UK (TAS in the UK) and RAL Space. The ATLID Control Data Management (ACDM) Unit was tested and it was found that the thermal design and ESATAN model needed updates to help components meet their derated limits. Various aspects of electronics design were investigated, looking at similar units (such as Cryocooler Electronics) and consulting with other engineers.
Attempts were made to auto-generate more detailed 3D FE structure sub-models rapidly to improve predictions.
EarthCARE
Credits: ESA–P. Carril, 2013
ATLID Control Data Management (ACDM) Unit
2
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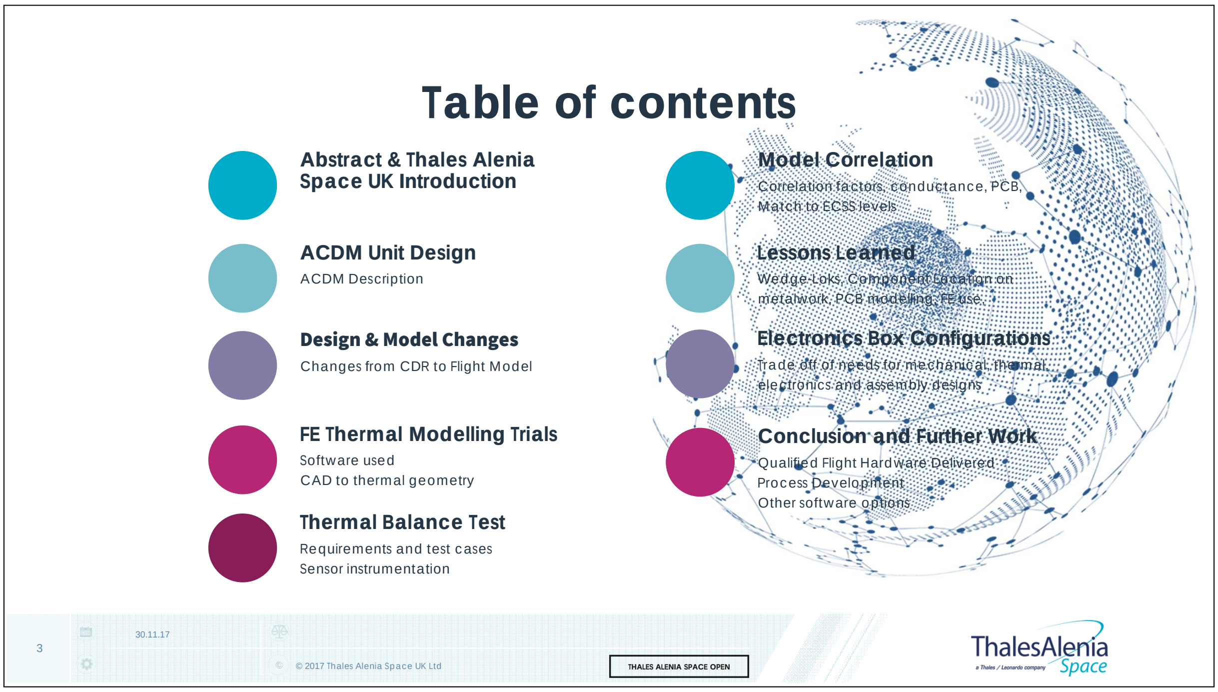
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CAD to thermal geometry
Thermal Balance Test
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Sensor instrumentation
Model Correlation
Correlation factors, conductance, PCB, Match to ECSS levels
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Wedge-Loks, Component Location on metalwork, PCB modelling, FE use.
Electronics Box Configurations
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Other software options
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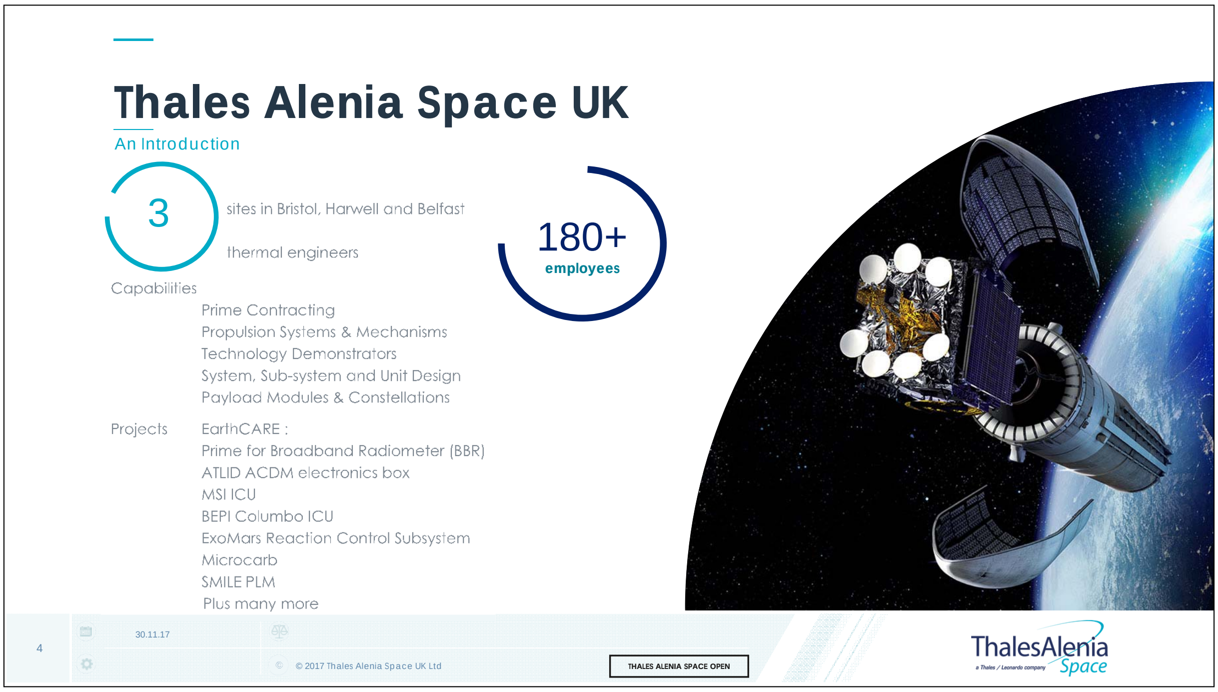
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An Introduction
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sites in Bristol, Harwell and Belfast
thermal engineers
180+
employees
Capabilities
Prime Contracting
Propulsion Systems & Mechanisms
Technology Demonstrators
System, Sub-system and Unit Design
Payload Modules & Constellations
Projects
EarthCARE :
Prime for Broadband Radiometer (BBR)
ATLID ACDM electronics box
MSI ICU
BEPI Columbo ICU
ExoMars Reaction Control Subsystem
Microcarb
SMILE PLM
Plus many more
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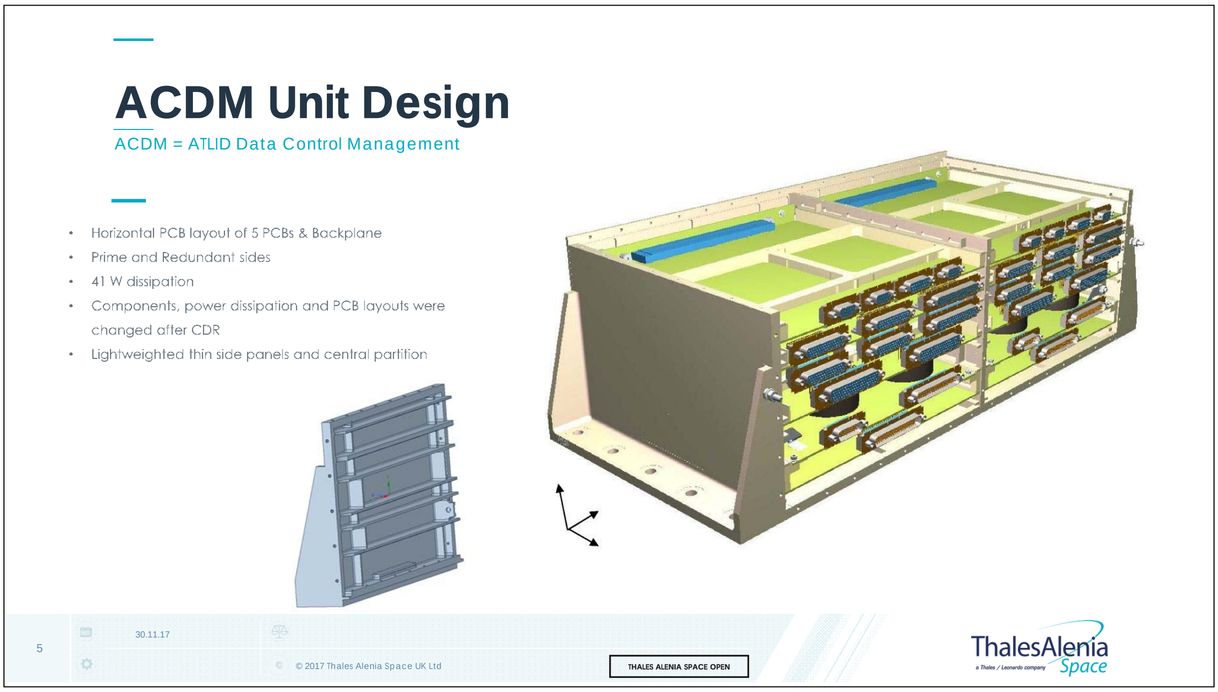
ACDM Unit Design
ACDM = ATLID Data Control Management
Horizontal PCB layout of 5 PCBs & Backplane
Prime and Redundant sides
41 W dissipation
Components, power dissipation and PCB layouts were changed after CDR
Lightweighted thin side panels and central partition
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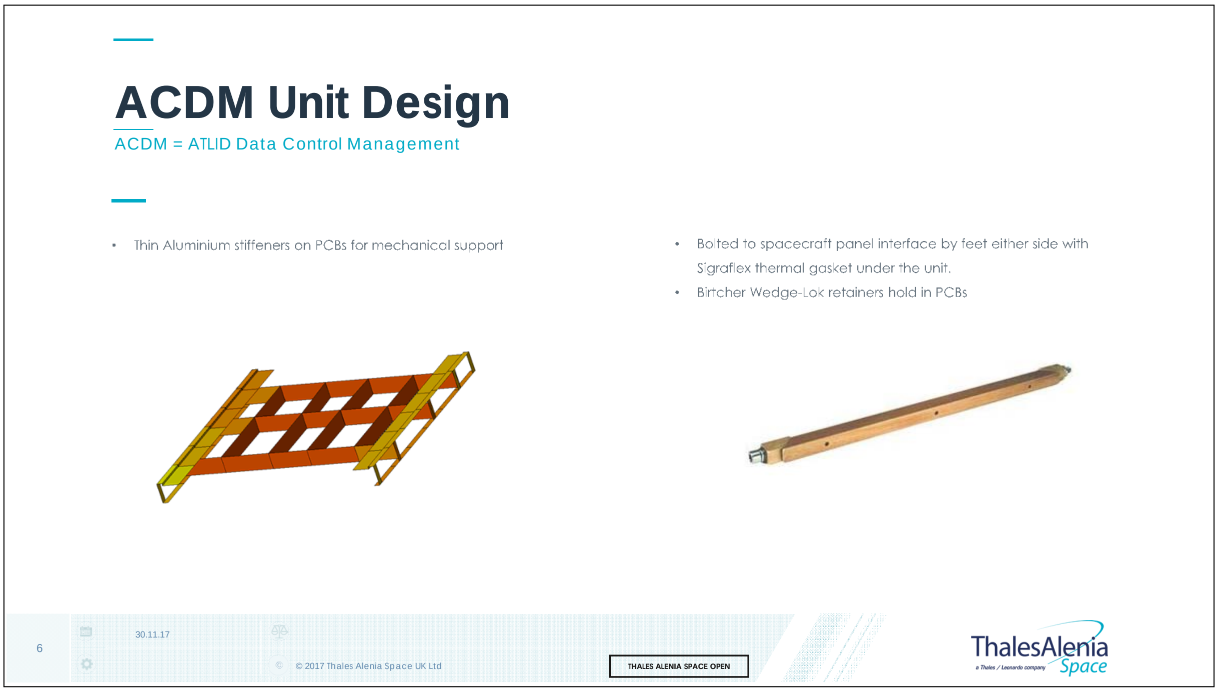
ACDM Unit Design
ACDM = ATLID Data Control Management
Thin Aluminium stiffeners on PCBs for mechanical support
Bolted to spacecraft panel interface by feet either side with Sigraflex thermal gasket under the unit.
Birtcher Wedge-Lok retainers hold in PCBs
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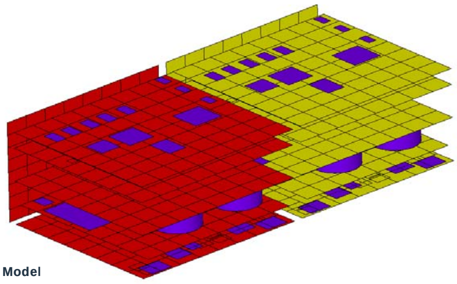
Design & Model Changes

ESATAN-TMS model views

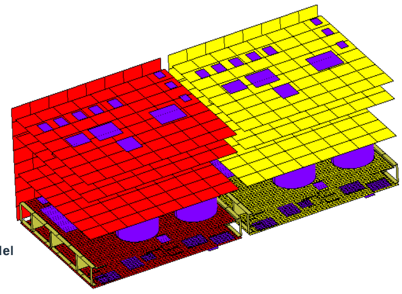
Electronics Design
- Components were moved from high dissipation PCBs to the baseplate
- Extra components were added in parallel on the baseplate to move dissipation location away from the high dissipation PCBs.

Detail
- Lightweighted thin side panels, central partition and PCB stiffeners were modelled in more detail. (Large effect)
- More nodes on higher dissipation PCBs.
- Radiative links omitted due to large file size + slow speed and negligible benefit.

Conductance Couplings
- Birtcher Wedge-Lok retainers hold in PCBs. Their conductive couplings were removed and a contact conductance was used at the PCB to shelf interfaces.
- Spacecraft interface contact conductance was reduced in the centre of the baseplate.



CDR Model



Flight Model

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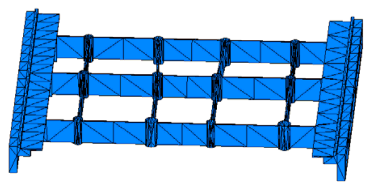
FE Thermal Modelling Trials

Tests to generate conductances rapidly

1) STEP 204 import to e-Therm (TAS tool).
   3D FE mesh created.
   Automatic conductances generated to include a table in DTMM.

2) STEP conversion in CADBench to an ESATAN-TMS (2017 sp2) 2D FE mesh or FD geometry
- Then found that you have to add a thickness
- Slow for complicated shapes



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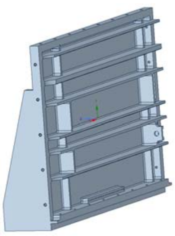
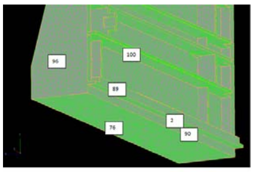
FE Thermal Modelling Trials

Side Panel Example

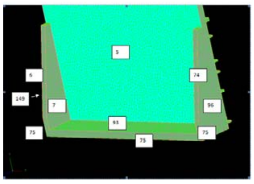
CAD View



Side of unit: e-Therm View



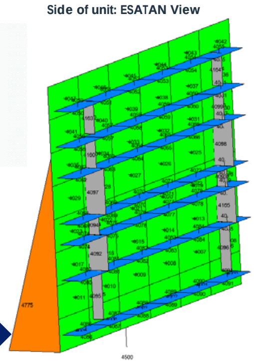
- STEP 204 imported to e-Therm.
- 3D FE meshing of volume
- Conductances (GLs) generated automatically.



3D FE

- STEP 204 imported to ESATAN 2D (via CADBench reduction)
- Manual meshing of surface
- Conductances (GLs) generated fairly manually.

Side of unit: ESATAN View

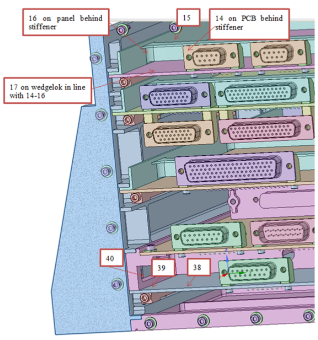


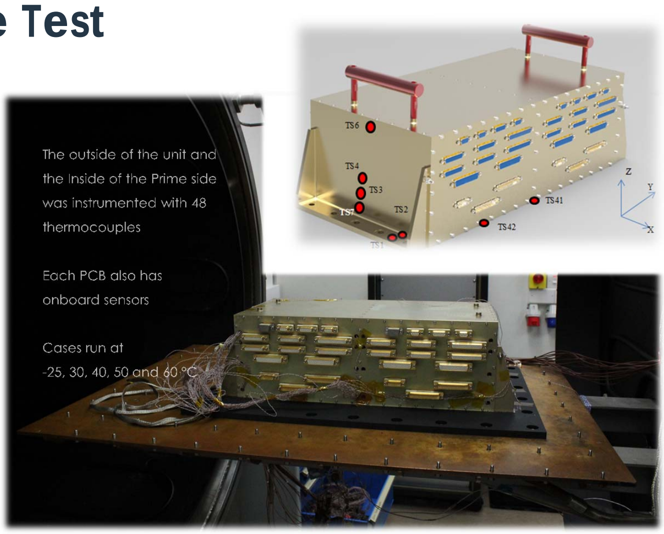
2D FD

Thermal Balance Test

Temperature Requirements

Minimum Qual/Accept	Design	Maximum Accept/Qual
-20 / -15	-10 to +50	+55 / +60





Model Correlation

ACDM - ATLID Data Control Management Unit Description

Correlation Factors added – mostly for conductances

PCBs in-plane conductance (Breaks in copper planes)

PCB Stiffeners

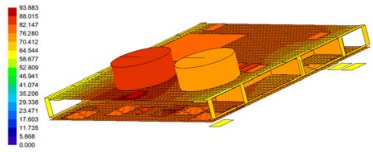
Backplane conductive link added

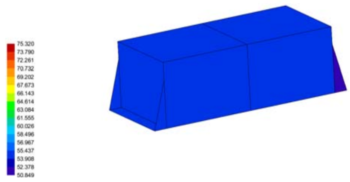
A few components' Case-to-Board

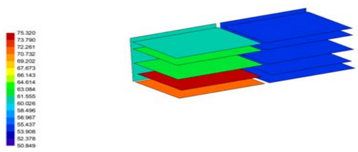
PCB and stiffeners to structure

Match to ECSS requirements

- Average of difference <2 K
- Standard Deviation <3 K
- Good correlation for TB test to Detailed TMM
- Good correlation for Detailed TMM to Reduced TMM (deliverable spacecraft sub-model)







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Lessons Learned

Some lessons learned from ACDM

- Component Mounting
  - MOSFET with flat SMD Carrier packages were originally used on PCBs.
  - It can be better to screw high dissipation MOSFETs with a TO-254 package onto the metal panels of the unit. Especially where the panels will be heat sinked – e.g. radiator panel interfaces etc.
- Metalwork lightweighting and thickness
  - There must be a trade-off between reducing the mass budget and thermal conductance. This can be hard to model between mechanical and thermal with ESATAN which prevent rapid iteration.
- PCB modelling
  - The ESATAN model had 2D averaged properties
  - It can be better to use a 3D stack of layers to model the through and parallel to plane conductance. This can be strongly affected by very small details breaking the continuity of copper layers.
- FE use
  - Can be very useful to generate conductance rapidly for complicated objects.
  - When integrated in with other sub-systems – trade-offs can be done rapidly in high detail.

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Lessons Learned

Some lessons learned from ACDM

Contact Conductances

- Retainer Conductance
  - Datasheet values were too optimistic because the test method is different to the way the parts are used. Only apply a contact conductance between pressured surfaces (when tightened).
- Centres of base panels bowing on wide units
  - Potentially a gap can occur between the centre of a unit and spacecraft interface because of the width between the feet.
- Thermal Gaskets
  - Datasheet values were too optimistic to use as measurements are typically lower.
    - Assumed an average of 200 W/m^2.K assumed across the baseplate. Higher under bolted feet whilst lower under the centre.

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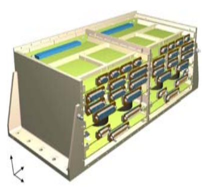
Electronics Box Configurations

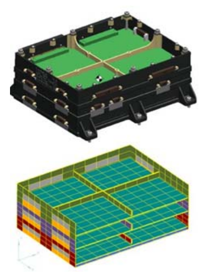
Trade off of needs for mechanical, thermal, electronics and assembly designs

- Trade off of needs for mechanical, thermal, electronics and assembly designs
- Box Layout Horizontal or Vertical PCBs
- Single side panels or Modular
- PCBs fixed by Wedge-Lok style retainers or fasteners on rails
- Components placement – PCB or metal structure
- Heat sinks – thermal adhesives, Cho-therm, copper
- Straps – copper, aluminium, Annealed Pyrolitic Graphite (APG)

Box with 6 panels



Modular Stacked Box



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Conclusion and Further Work

Conclusion

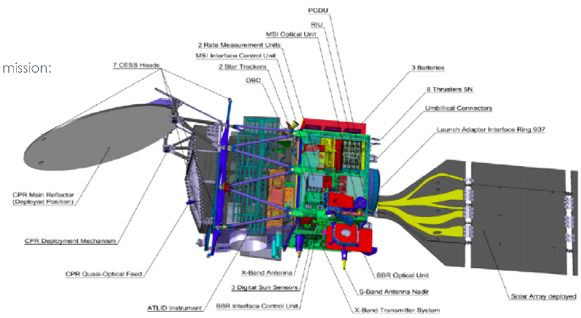
Successful delivery to Airbus and ESA of qualified hardware ready for the EarthCARE mission:

- Broadband Radiometer (BBR) Instrument
- BBR ICU
- Multi Spectral Imager (MSI) ICU
- ATLID Control and Data Management (ACDM) Unit

ESATAN-TMS and CADBench could have 3D Volume FE Meshing added as a feature

Further Work: Process Development

- FloTherm PCB for initial studies
- Automating CAD to Thermal model
  - STEP 204 import in MSC PATRAN/NASTRAN or similar for future trials
  - Testing simple 3D Finite Element meshes against Finite Difference models.
- Automate electronics design (ICEDA) to Thermal model



EarthCARE view. Credit: ESA

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Appendix O

Quality assessment for parameters obtained with model correlation

Jan Klement
(Tesat-Spacecom GmbH, Germany)

Abstract

"Just because it is correlated it doesn't mean that is has anything to do with the reality". It is clear that parameters obtained from a model correlation can be completely wrong. The main question is how near to the real physical value are they. To partially answer this question an approach is proposed to estimate the uncertainty from parameters obtained from a model correlation.

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Quality assessment for parameters obtained with model correlation

Jan Klement

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An correlation accuracy estimate

„Just because it is correlated it doesn‘t mean that is has anything to do with the reality.“

… but how near can it be?

An approach to estimate the accuracy of correlated values

Warning: Several assumptions and simplifications are implicitly made.

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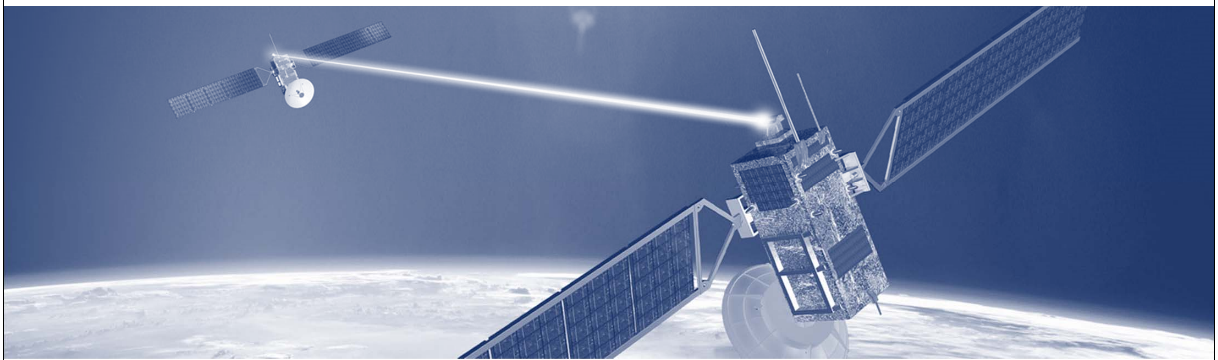

Observability - Does the parameter have an relevant effect?

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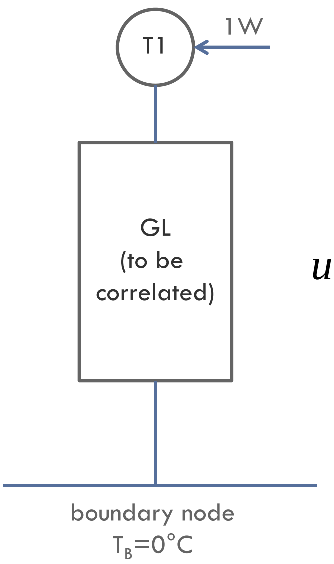
Accuracy of one parameter



$$GL = \frac{\dot{Q}}{T_1 - T_B}$$

Uncertainty estimation according to the Gaussian error propagation

$$u_{GL} \approx \sqrt{\left(\frac{dGL}{dT_B} u_{TB}\right)^2 + \left(\frac{dGL}{dT_1} u_{T1}\right)^2 + \left(\frac{dGL}{d\dot{Q}} u_{\dot{Q}}\right)^2}$$

Neglecting the uncertainty of Q and T_B

$$u_{GL} \geq \frac{dGL}{dT_1} u_{T1}$$

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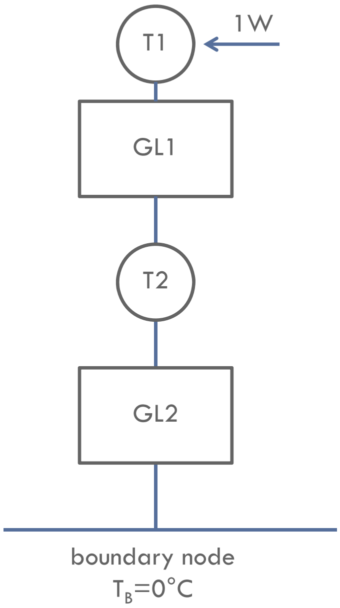
EXPANDING THE APPROACH MORE COMPLEX CORREALTIONS



The model is approximated by a Jacobian Matrix derived from a sensitivity analysis:

$$J = \begin{bmatrix} \boxed{\begin{matrix} \dfrac{\partial T_1}{\partial GL_1} \\ \dfrac{\partial T_2}{\partial GL_1} \end{matrix}} & \begin{matrix} \dfrac{\partial T_1}{\partial GL_2} \\ \dfrac{\partial T_2}{\partial GL_2} \end{matrix} \end{bmatrix}$$

results

parameter

Only one accurate measurement is needed. Therefore the most largest effect is selected. In other words: the biggest absolute value of each column. I.e. for GL_1:

$$d_{GL1solo} := \left\| \begin{matrix} \dfrac{\partial T_1}{\partial GL_1} \\ \dfrac{\partial T_2}{\partial GL_1} \end{matrix} \right\|_{\max} = \left\| \begin{matrix} 1K^2/W \\ 0K^2/W \end{matrix} \right\|_{\max} = \frac{\partial T_1}{\partial GL_1} = 1K^2/W$$

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THE OBSERVABILITY FACTOR

The resulting uncertainty for GL1 is:

$$u_{GL1} \geq \left(d_{GL1solo}\right)^{-1} u_{T1}$$

The observability factor this value normalized to the parameter value

$$o_{GL1} := \frac{\left(d_{GL1solo}\right)^{-1} u_{T1}}{GL_1}$$

If this value is large (approx >0.5):
GL_1 cannot be correlated because the parameter has no observable effect.
If it is small: it has to be checked if there are other parameter influencing T_1

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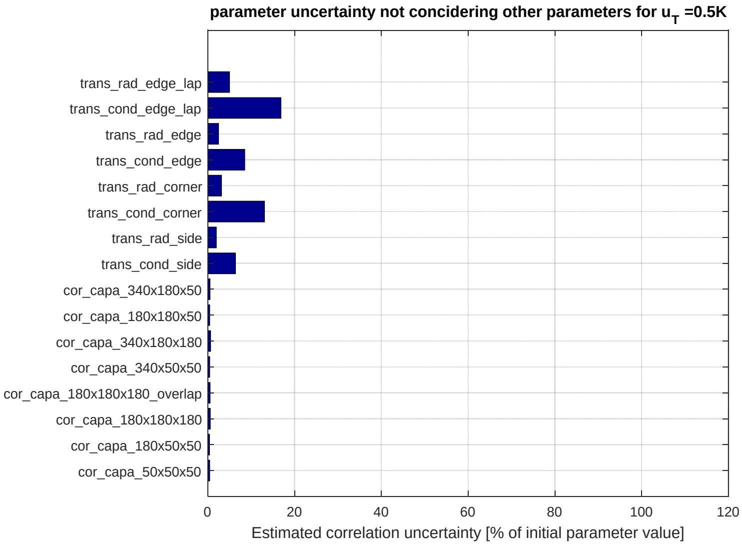
Observability factor of the MLI model (not considering parameter interference)



Small values (<10%) mean that all parameters have a measurable effect

Graph and data by Lena Bötsch and Jonas Klose 30.11.2017 7

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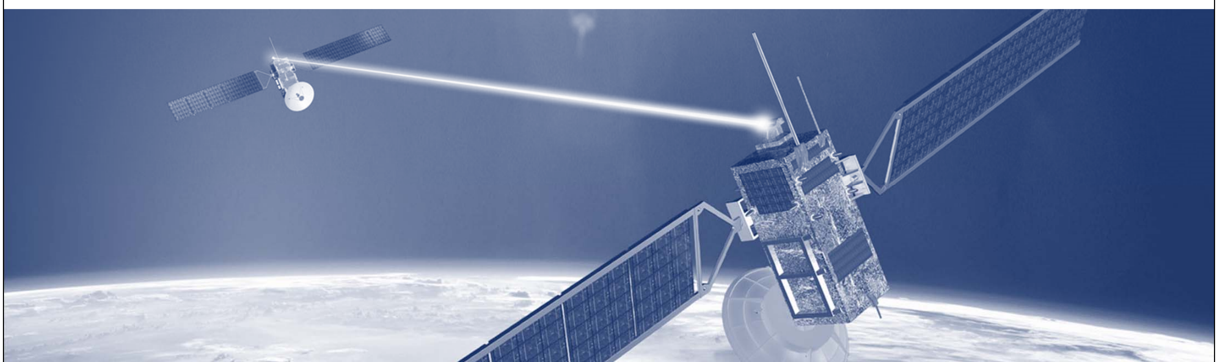

The Independency - Can the parameter be discerned from other parameters?

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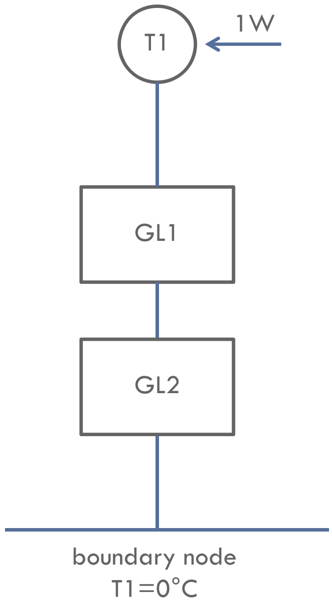
Two non-independant parameters



GL1, GL2 cannot be correlated
if only T2 is known
→ The columns in the Jacobian matrix for
GL1, GL2 are not independent

$$J = \begin{bmatrix} \frac{\partial T_1}{\partial GL_1} & \frac{\partial T_1}{\partial GL_2} \end{bmatrix} = \begin{bmatrix} 1 & 1 \end{bmatrix} \frac{K}{W/K}$$

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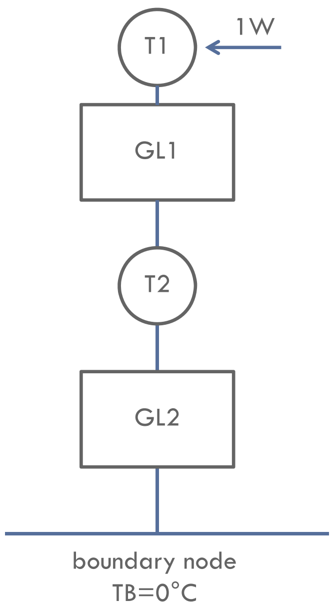
Two independendent parameters



GL1 and GL2 can be discerned by
using additional data (T2).
In other words:
→The columns of J are linear independent

$$J = \begin{bmatrix} \frac{\partial T_1}{\partial GL_1} & \frac{\partial T_1}{\partial GL_2} \\ \frac{\partial T_2}{\partial GL_1} & \frac{\partial T_2}{\partial GL_2} \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 1 & 0 \end{bmatrix} \frac{K}{W/K}$$

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Quantifying the independency

To consider that a combination of the other parameters could explain the observed effect a linear sum of their Jacobian matrix columns is subtracted from the parameter column.
The worst combination(min) is used.

$$f_{GL1}(a) := \left\| \begin{pmatrix} \frac{\partial T_1}{\partial GL_1} \\ \frac{\partial T_2}{\partial GL_1} \end{pmatrix} - a_1 \begin{pmatrix} \frac{\partial T_1}{\partial GL_2} \\ \frac{\partial T_2}{\partial GL_2} \end{pmatrix} - a_2 \begin{pmatrix} \frac{\partial T_1}{\partial GL_3} \\ \frac{\partial T_2}{\partial GL_3} \end{pmatrix} \ldots - a_{n-1} \begin{pmatrix} \frac{\partial T_1}{\partial GL_n} \\ \frac{\partial T_2}{\partial GL_n} \end{pmatrix} \right\|_{\max}$$

$$d_{GL1\min} := \min\{ f_{GL1}(a) \mid a \in R^{n-1} \}$$

$$u_{GL1} \geq \left(d_{GL1\min}\right)^{-1} u_{T2}$$

$$i_{GL1} := \frac{\left(d_{GL1\min}\right)^{-1} u_{T2}}{GL1}$$

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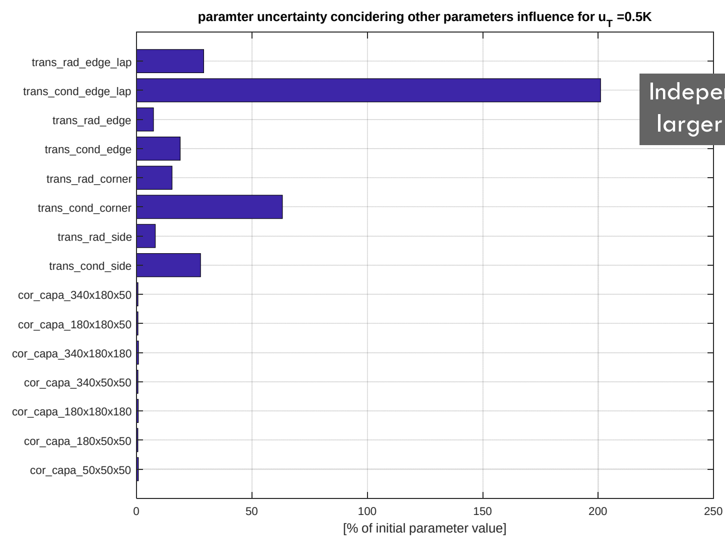
Parameter independency of the MLI model - First try



Independency factor is larger than 200%

Reason: There are always the same number of overlapping edges as normal ones.
Solution: Perform a test with a body only with overlapping edges.

Graph and data by Lena Bötsch and Jonas Klose 30.11.2017 12

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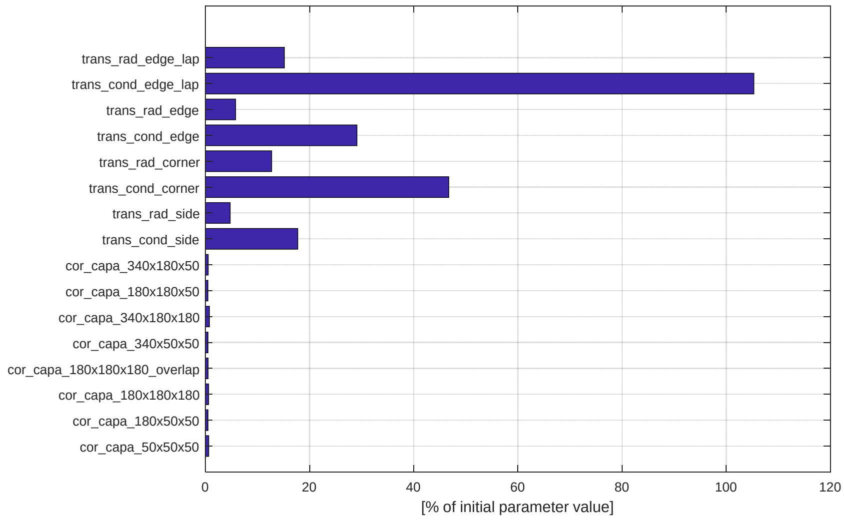
Parameter independency of the MLI model (with additional test)



Small values (<20%) can be discerned from the other parameters

Larger values (>20%) mean values can't be discerned from the other values

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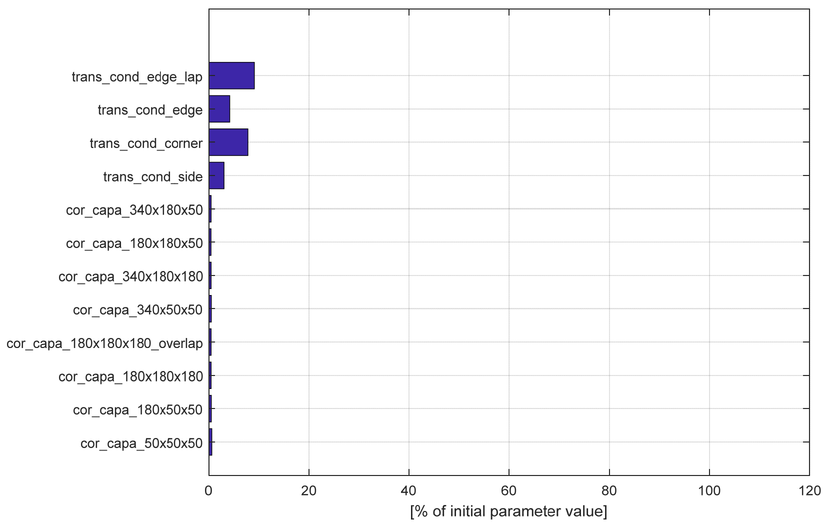
Parameter independency if the emissivity is constant



Graph and data by Lena Bötsch and Jonas Klose 30.11.2017 14

SUMMARY

» For a successful correlation...

» Each parameter must have an relevant effect onto at least one temperature
  » This is quantified with the "observability factor" (o)

» Each parameter must have an effect which cannot be caused by other parameters
  » This is quantified with the "independency factor" (i)

» If still isn't possible to correlate:
  » Model error?
  » Measurement error?
  » Different definitions between model and measurement?
  » Correlation Algorithm?

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CONCLUSION FOR THE MLI MODEL

» All parameters have an relevant effect, but not all are independent.

» Parameters with an low independency factor like the capacity can be accurately correlated.

» The parameter for the edge thermal conductivity large uncertainty. This value can only be seen as an effective value without any physical meaning.

» But the main influencing parameter is the parallel emissivity. If this is removed the independency factors are quite low.

» Therefore when used in combination the model returns realistic heat fluxes within the temperature range tested, despite the individual values might be incorrect.

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aufgrund eines Beschlusses
des Deutschen Bundestages
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Appendix P

FiPS®

Thermal Fluid-Structure Interaction

Patricia Netzlaf
(Ariane Group, Germany)

Abstract

From 2012 to today the DLR has been supporting the enhancement of FiPS®(Final Phase Simulator), an in-house developed software tool for coupled simulations, in the frame of the launcher maturation projects PREPARE (completed) and PROCEED (ongoing). This is the presentation of the achievements of the work package "FiPS®" of these two projects.
Before the PREPARE project began in 2012, a first implementation of FiPS®was used to simulate the mutual influence of upper stage movement and propellant sloshing only. In the course of further development, the feature of a thermal coupling between FLOW- 3D (CFD tool) and ESATAN-TMS (thermal tool) was implemented into FiPS®. This enables the simulation of both dynamic and thermal fluid-structure interactions at the same time.
The thermal coupling is realized by a "one-to-one" approach between FLOW-3D and ESATAN-TMS. FLOW-3D uses the finite volumes method: A volume containing the geometry of interest is subdivided into smaller 3D cells. FLOW-3D's role within the thermal coupling is to calculate propellant motion and temperature distribution in the propellant's liquid and gaseous phase. ESATAN-TMS on the contrary uses the finite differences method: An object is broken down to subcomponents represented by nodes. The task of ESATAN-TMS is to compute heat conduction within the tank wall in this context. By means of a "one-to-one" approach, data exchange is realized between one FLOW-3D tank wall cell and one ESATAN-TMS transition node. This way, quantities of state, like temperature and heat flux, are transferred between the two tools at run-time. Visualization of simulation results is realized in form of diagrams and 3D animations.
Adding the feature of the thermal coupling was a logical consequence when considering cryogenic liquids as propellants. For the first time, temperature development in propellants and surrounding tank wall structures can be resolved with high precision, as the considered system reacts at simulation run-time to the motion of the propellant. Precision is only limited to the accuracy of the implemented software tools. As a consequence of temperature changes, evaporation rates and thus pressure development can be derived. This aids the improved design of structures, propulsion systems, insulations, attitude control systems, mission profiles and other design disciplines.

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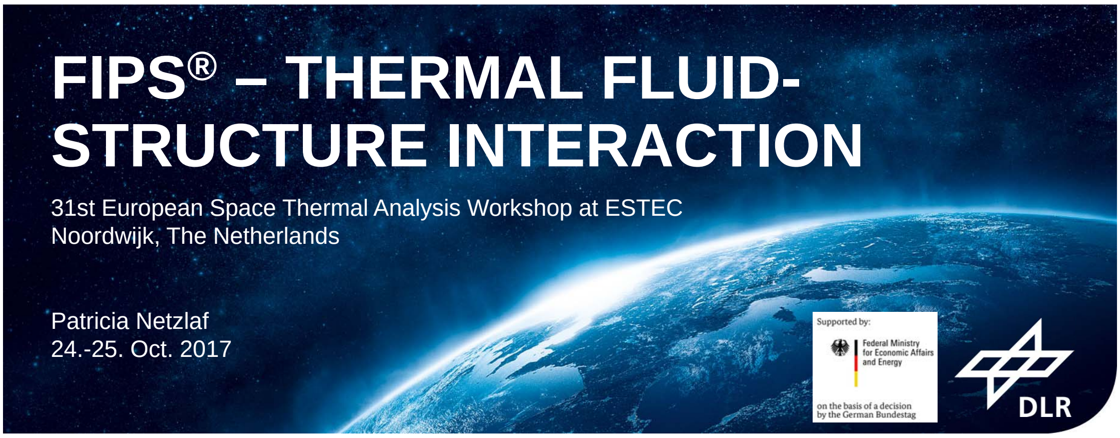
PROCEED



OUTLINE

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01
BACKGROUND

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WHAT IS FIPS®?

- **FiPS® = Final Phase Simulator**
  - **Final phase of upper stage flight before (last) payload release**
- **Purpose: Realistic consideration of the system “upper stage”, or any other conceivable vehicle, during its flight with respect to vehicle motion and liquid propellant response (and vice versa)**
- **Open and closed loop control of vehicle motion is possible**
  - **FiPS® serves as a developing environment for space flight controllers**
- **Coupled analysis:**
  - **Dynamic interaction between vehicle dry mass (rigid body) and liquid propellant sloshing**
  - **Thermal interaction between vehicle structure (tank walls) and propellant (liquid and gas)**

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02

FUNCTIONAL BACKGROUND

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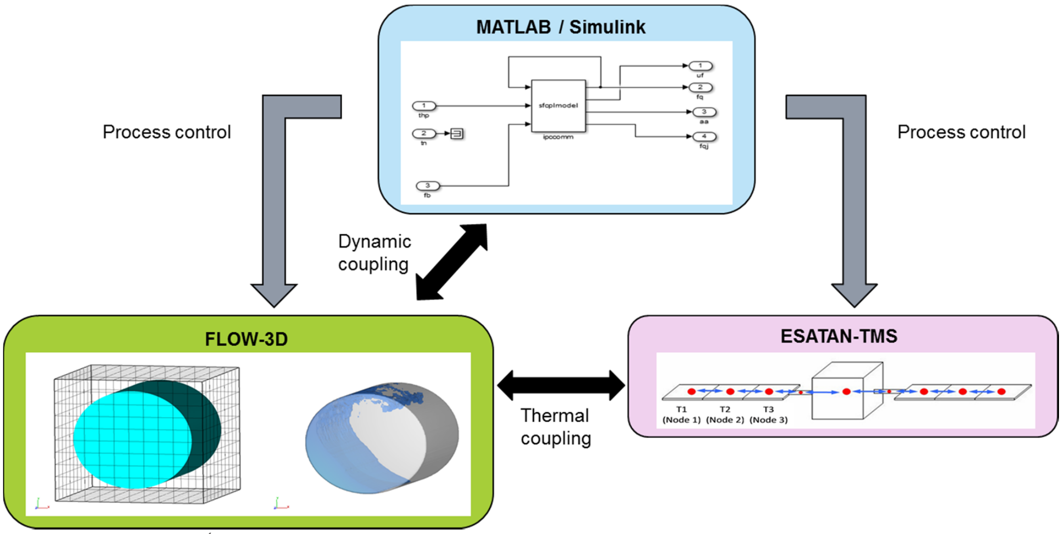
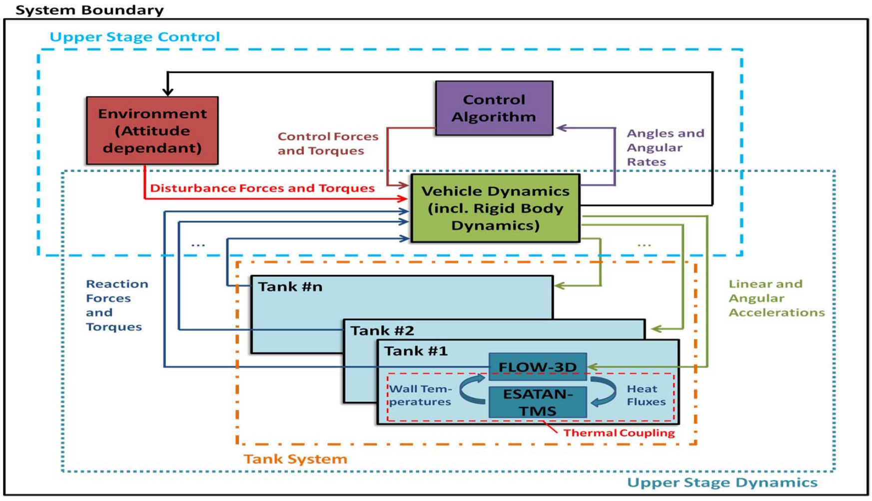
BUILDING BLOCKS



SIMULATOR SCHEMATIC



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03
THERMAL COUPLING

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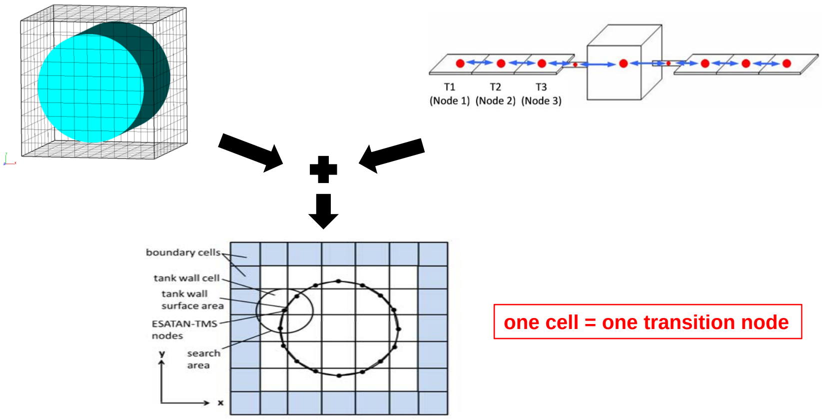
MODELLING APPROACH

FLOW-3D (CFD)

- Finite volume method

ESATAN-TMS (THERMAL)

- Finite differences method



one cell = one transition node

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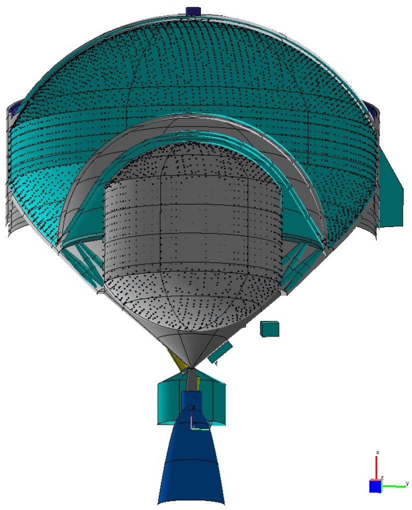
MODELLING IMPLEMENTATION

- **Problem: ESATAN upper stage tank modelling not as fine as FLOW-3D meshing**
- **Solution: Several transition nodes assigned to adjacent ESATAN shells/solids**
- Heat fluxes from FLOW-3D are summed up before rendering to ESATAN-TMS by means of the transition nodes
- All transition nodes assigned to a single ESATAN shell/solid receive the shell's/solid's temperature
- **Exchange of data at runtime (time step size regulated by FLOW-3D)**



ESC-A U/S ESATAN model

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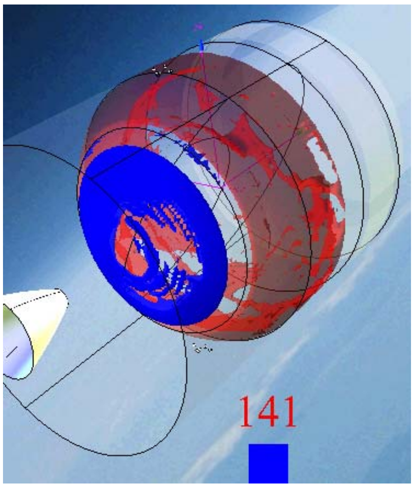
04

VISUALIZATION

VISUALIZATION BASICS

- **General:**
- **VRML and Java used for visualization**
- **Vehicle motion information retrieved from MATLAB/Simulink**
- **Liquid propellant location (distribution and motion) provided by FLOW-3D**

- **Dynamic mode only:**
- **Each liquid propellant is assigned a color (monochromatic)**
- **Focus is laid on vehicle and liquid propellant dynamical behavior due to mission flight profile only**



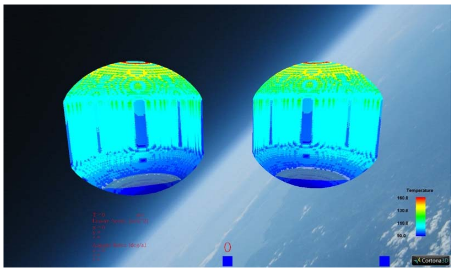
A5 ME U/S model

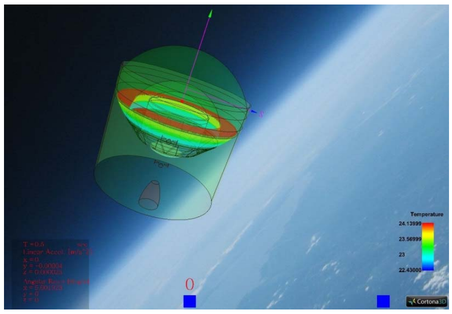
VISUALIZATION ENHANCED

- **Dynamic and thermal mode combined:**

- **Tank view:**
- Tank wall temperatures shown in swung-open view per tank
- Liquid propellant is shown as a greyed-out half-transparent mass

- **Vehicle view:**
- One propellant is assigned a color according to its temperature distribution at a time. Meanwhile, the other propellant is greyed-out
- It can be switched between the propellants, depending on which one is desired to be shown and to be colored due to its temperature distribution





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05
SUMMARY & OUTLOOK

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SUMMARY

- **FiPS® is a tool to simulate coupled processes of a vehicle's system**
  - Basis of FiPS® is the coupling of rigid body dynamics with liquid propellant motion
- **Thermal coupling added to FiPS®**
  - Exchange of thermal data between FLOW-3D and ESATAN-TMS at runtime during a simulation
  - FLOW-3D gives heat fluxes to ESATAN-TMS; ESATAN-TMS gives tank wall temperatures to FLOW-3D
  - Pressure development inside of the tanks can be used as an input for thruster models (propulsion)
- **Visualization**
  - Liquid propellant and tank wall temperature can be displayed in different view modes

OUTLOOK

- **Concurrent developments**
  - Implementation of a full vehicle ESATAN-TMS thermal model: Enables simulation of entire vehicles thermal household taking into account both conductive and radiative calculations (the latter depending on orbit propagation)
  - a FiPS® remote version: network communication between customer and FiPS®; customer can test & and apply (analysis) own control algorithms without revelation of own know-how; customer can conduct sensitive applications with access restrictions
- **Applications**
  - So far: Ariane 5 (ESC-A, ESC-B, ME), ATV, MPCV (Orion), LNG (liquid natural gas) tank ships, satellites
  - Currently: A6, Eurofighter, NGSAR

ACKNOWLEDGEMENTS

Supported by:

Federal Ministry for Economic Affairs and Energy

on the basis of a decision by the German Bundestag

DLR

This work is funded by the German Federal Ministry of Economic Affairs and Energy (contract code 50 RL 1620) and administered by the German Space Agency (DLR).

Their support is greatly appreciated.

The author of this publication is responsible for its content.
Die Verantwortung für den Inhalt dieser Veröffentlichung liegt beim Autoren.

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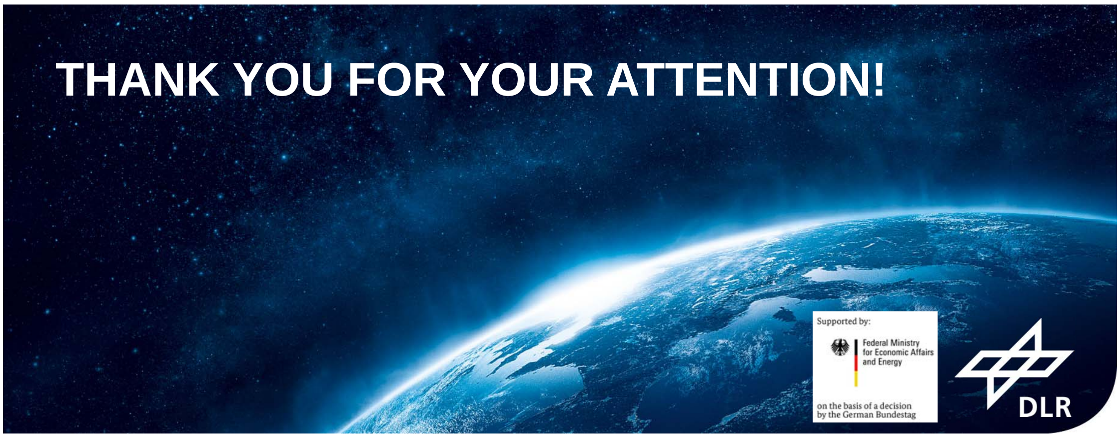

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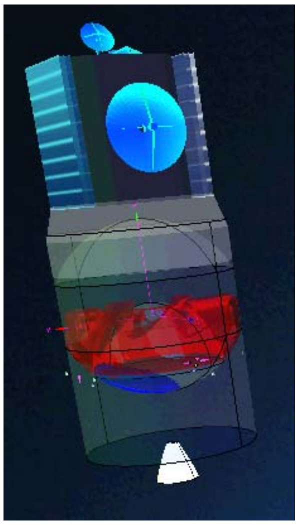

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Appendix Q

Multi-dimensional Ablation and Thermal Response Program for atmospheric entries

Viola Renato
(University of Strathclyde, Scotland UK)

Abstract

The method presented herein couples a reduced order aerodynamic model (HyFlow) and an ablative material response code (ARC) to produce three dimensional estimations of the external flow characteristics and the internal TPS behaviour during an atmospheric entry. Both codes have been internally developed at Strathclyde University.

The ablative material solver is a unidimensional code, based on the explicit finite difference method which has the capability of evaluating the internal temperature gradients, the pyrolysis phenomenon progression, the change of state and density in the material and the production of pyrolysis gases. If the material B tables are available, the code can also calculate the charred material mass flux and the material recession rate.

In this methodology, the ARC program is applied on a grid of points surrounding the entire geometry to produce an evaluation of the TPS behaviour on the whole spacecraft surface. The coupling of these two codes has been designed to produce fast three dimensional analyses to better evaluate the differences introduced by small changes in the spacecraft trajectory and geometry or in the TPS composition. This methodology has been previously utilized to evaluate both Earth and Martian entry trajectories (Stardust and Pathfinder missions). For this workshop, the study of the ARD re-entry is presented with a comparison against results generated by higher order codes and flight data. This case is of particular interest because it presents an angle of attack which makes the case non axis-symmetrical. The approach presented herein always performs three dimensional calculations of the atmospheric entry, therefore the symmetry of the flux or the lack of this symmetry does not influence the computational time. Consequently, complex non symmetric cases are just as easy to simulate as symmetric ones. The code is also able to simulate a capsule made by different TPS of different thickness. The entire re-entry trajectory run can vary from a few minutes to half an hour depending on the trajectory duration and the spacecraft mesh; the ARD re entry takes around 20 minutes for a trajectory duration of 240 s and for a mesh formed by around a thousand vertices.

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Multi-dimensional Ablation and Thermal Response Program for Re-Entry Analysis

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Table of content

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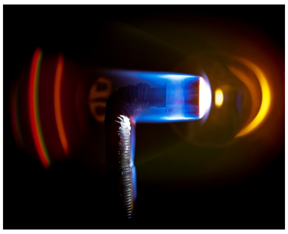
Non-Reusable Thermal Protection Systems: Ablative Material

- High number of different materials.
- Pyrolysis.
- Long and expensive design process.



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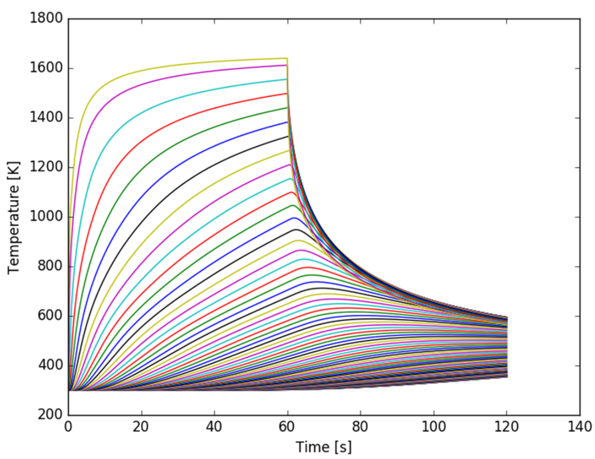
Material thermal response code (1/2)

- One-dimensional, based on finite differences.
- Calculates the temperature gradients.
- Evaluates the pyrolysis progression.
- Determines the change of state and density in the material.
- Computes the production of pyrolysis gases, the charred material mass flux and the surface recession rate.
- Applied on geometry vertices to produce three dimensional assessments.



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Material thermal response code (2/2)

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Main equations:

- Arrhenius equation: degradation

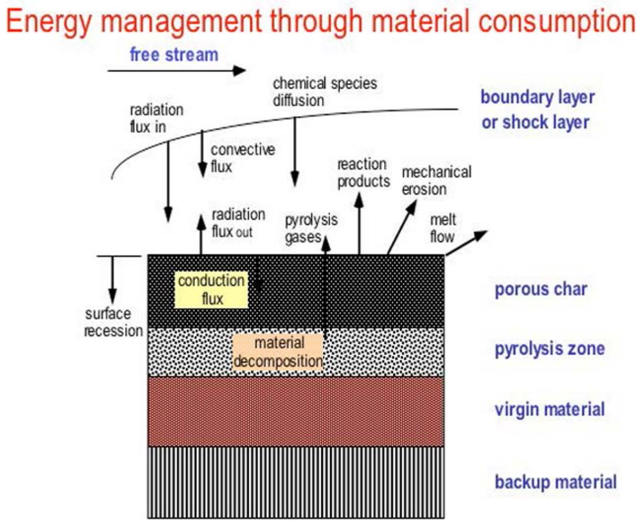
$$\frac{\partial \rho_i}{\partial t} = A_i \left(\frac{\rho_i - \rho_{ic}}{\rho_{iv} - \rho_{ic}} \right)^{\phi_i} e^{-E_i/T}.$$

- In depth energy balance:

$$\rho c_p \frac{\partial T}{\partial t} = \frac{\partial}{\partial x}\left(\lambda \frac{\partial T}{\partial x}\right) + (h_g - \bar{h})\frac{\partial \rho}{\partial t} + \dot{S} \rho c_p \frac{\partial T}{\partial x} + \dot{m}_g \frac{\partial h_g}{\partial x},$$

- External surface energy balance:

$$\rho_e u_e C_H (H_r - h_{ew}) + \rho_e u_e C_M [\Sigma (z_{ie}^* - z_{iw}^*) h_i^{T_w} - B' h_w] + \dot{m}_c h_c + \dot{m}_g h_g + \alpha_w q_{rad} - F \sigma \epsilon_w T_w^4 - q_{cond} = 0.$$



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Aero-Thermodynamic Model

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- In house reduced order code instead of a more commonly used CFD tool.
- Based on a combination of compression and expansion panel methods.
- Assumption of thermally and calorically perfect gas.
- Can be used for the entire entry trajectory (prediction for both free-molecular flow and continuum flow conditions).
- The Reynolds analogy is employed for the determination of the heat flux on the entire geometry but the area around the stagnation point where the Fay-Riddell formula is utilized.

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Code Coupling

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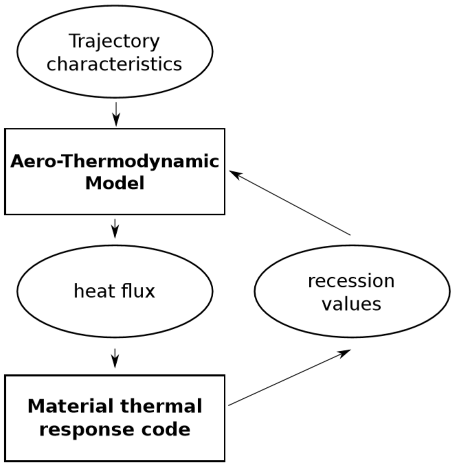
The steps in the simulations are:

- HyFlow estimates the three dimensional heat flux around the geometry for first time instance during entry.
- The one dimensional material code is applied on every geometry vertex.
- An evaluation of the material behaviour on the entire geometry is generated.
- The recession values are implemented and the new geometry is created.
- The same steps are repeated until the completion of the entry trajectory.



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Material model

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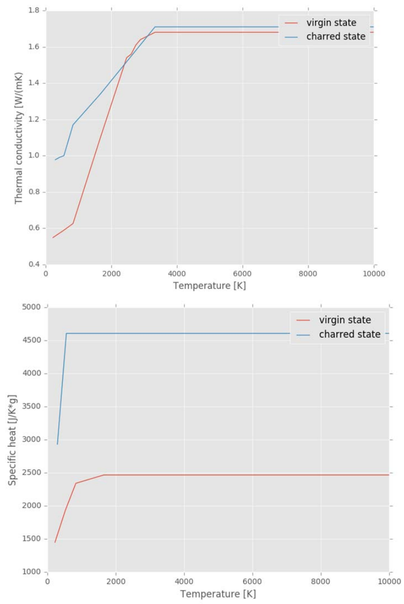
Thermo-chemical characteristics:

- Arrhenius equation terms (pre-exponential factor, activation energy, decomposition reaction order).
- Virgin and charred density.
- Virgin and charred thermal conductivity as a function of temperature.
- Virgin and charred specific heat as a function of temperature.
- Enthalpy of formation and pyrolysis



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Test case: The Atmospheric Re-entry Demonstrator ARD

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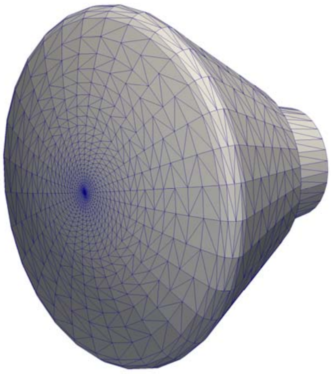
- Material: ALEASTRASIL
- Thickness: 20 mm

Time instances for the entry trajectory:



time (s)	velocity (m/s)	altitude (km)
4886.56	7554.83	78.7536
4912.72	7470.65	74.4595
4930.99	7329.8	71.4605
4952.04	7073.58	68.0047
4970.82	6786.07	64.9223
4990.45	6467.55	61.7003
5012.07	6097.09	58.1505
5021.5	5924.88	56.603
5040.82	5514.98	53.4314
5060.58	4949.71	50.1874
5078.88	4338.34	47.1828
5096.83	3733.77	44.2373
5116.45	3074.3	41.0169
5133.22	2526.46	38.263
5155.41	1851.32	34.6205
5178.19	1266.9	30.8815
5198.89	838.137	27.4829
5218.11	547.725	24.3278
5237.66	310.017	21.1195
5262.31	199.981	17.0727
5273.39	173.541	15.2532

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Results: Heat Flux

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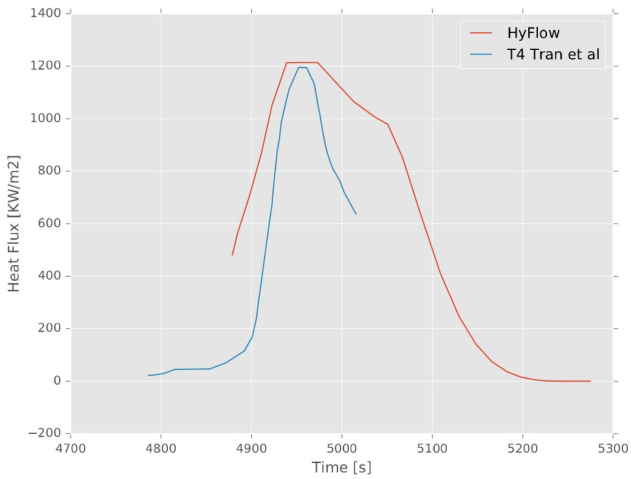

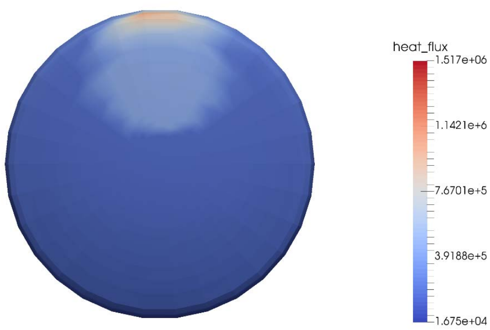

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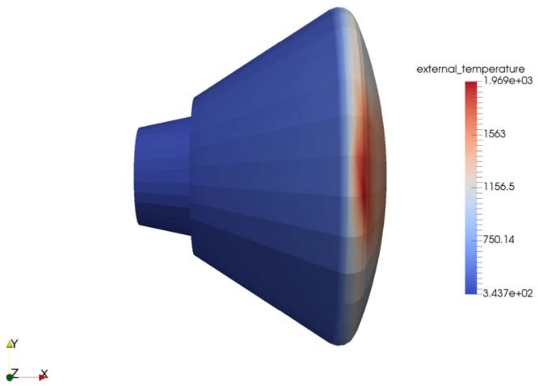
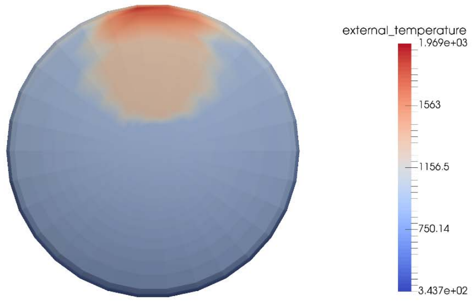
Results: Temperatures (1/2)





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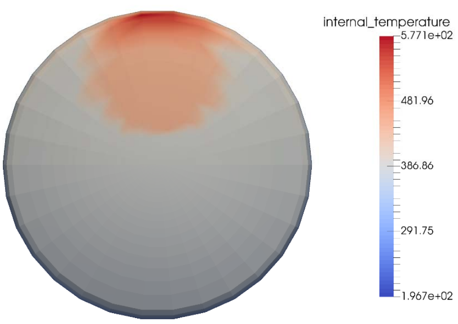
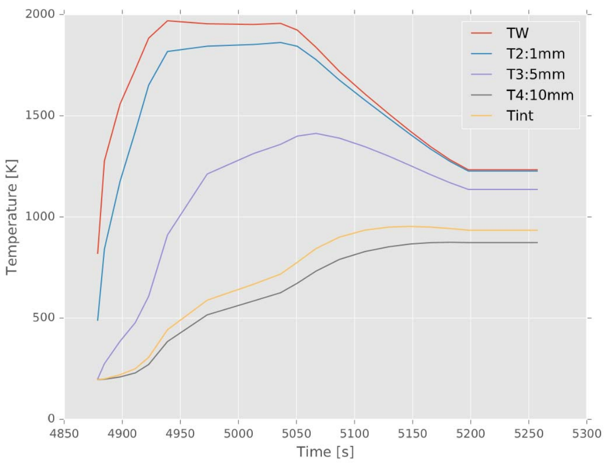
Results: Temperatures (2/2)





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Results: Recession

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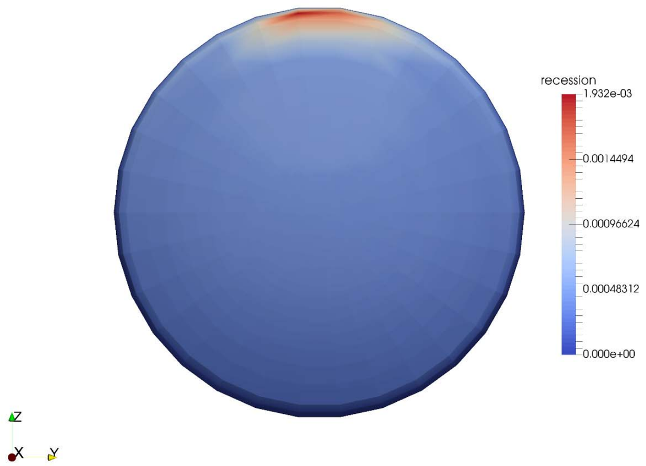

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Conclusions & future work

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Conclusions:

- The results presented show that it is possible to use the presented approach to evaluate the internal material behaviour and external flux aerodynamics during the atmospheric entry phase of a space mission in three-dimensional space.
- Short computational time: from 4 minutes to half an hour depending on the geometry and the re-entry duration.

Future work:

- The verification of the method on a real TPS structure: different materials for different parts of the spacecraft geometry and different thicknesses.
- Coupling of the thermal response code with a more precise/reliable aero-thermodynamic model: on-going.

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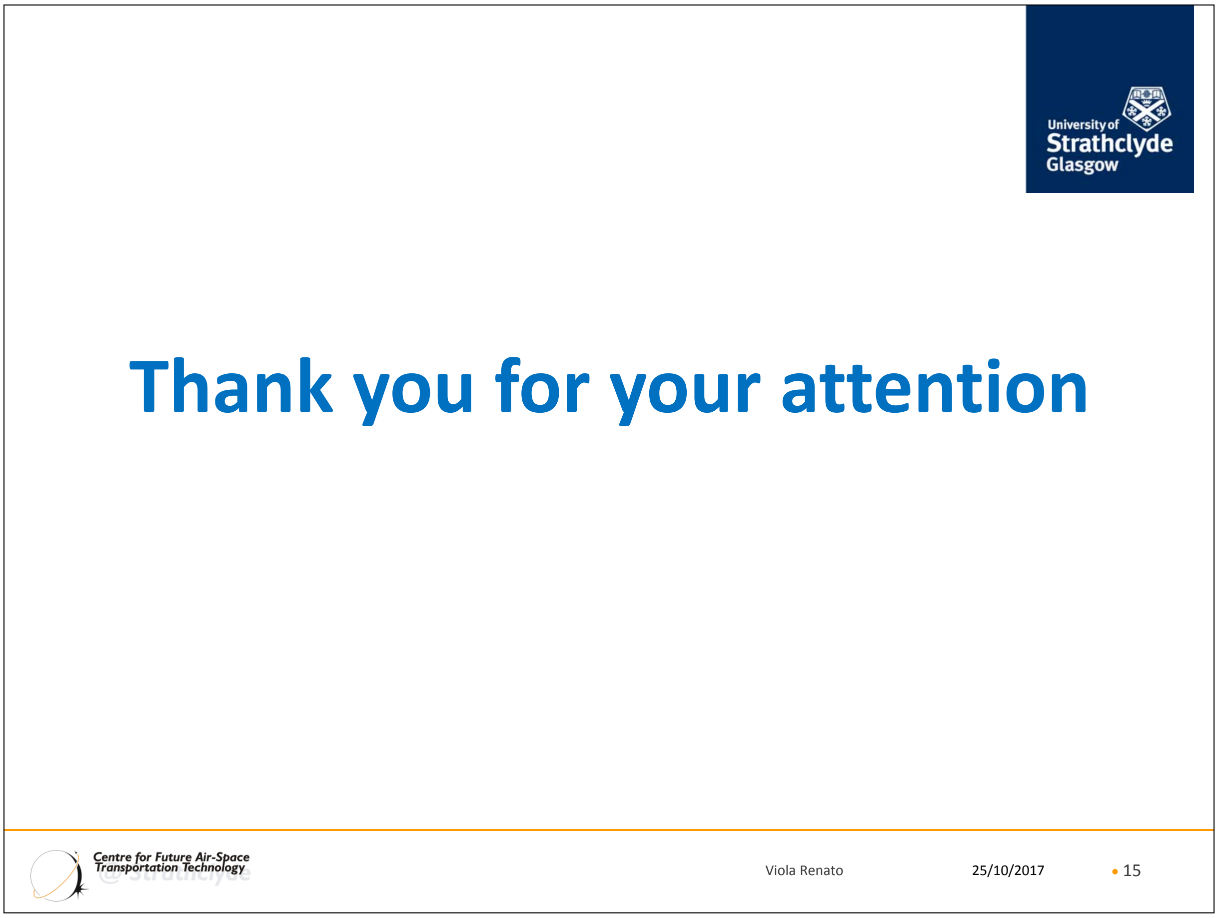
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Glasgow
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Transportation Technology
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Appendix R

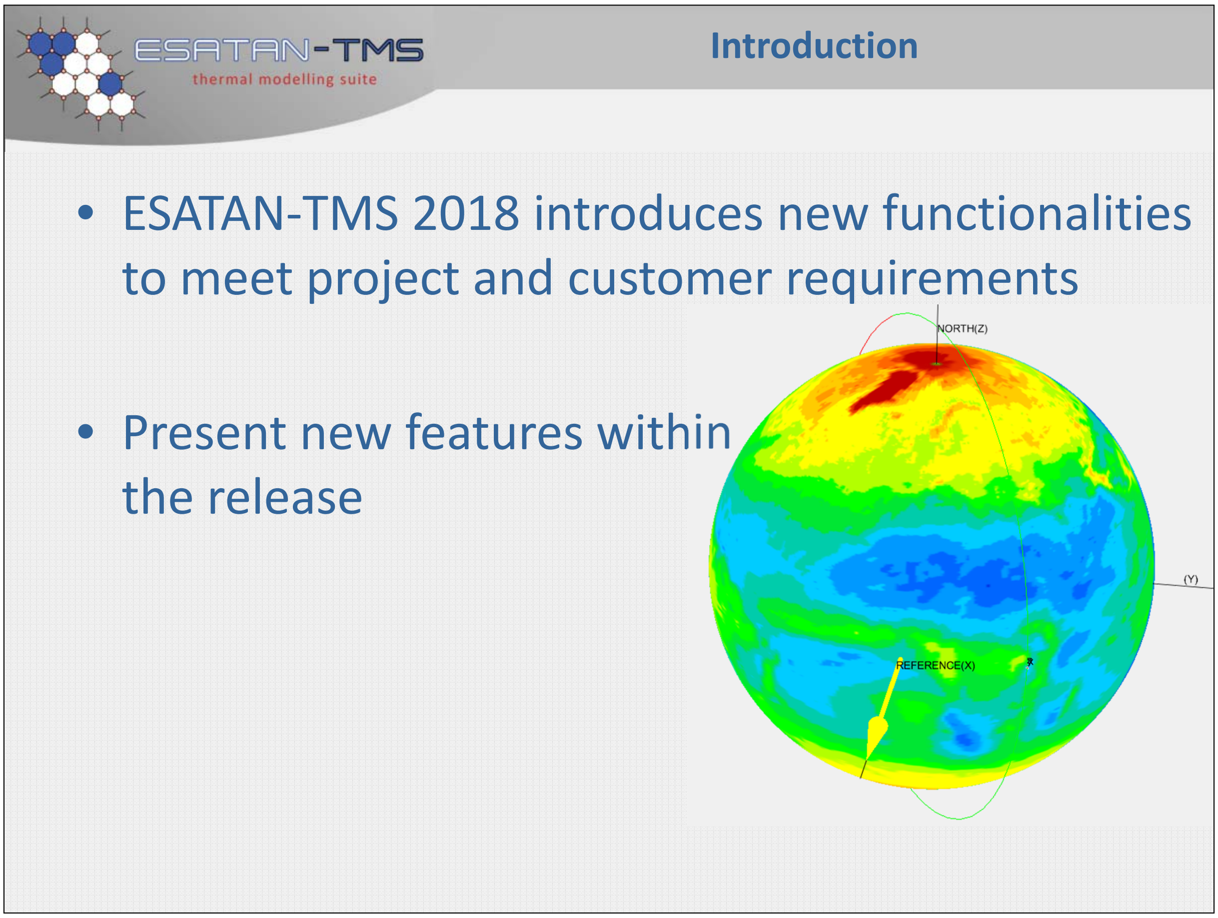
ESATAN Thermal Modelling Suite
Product Developments

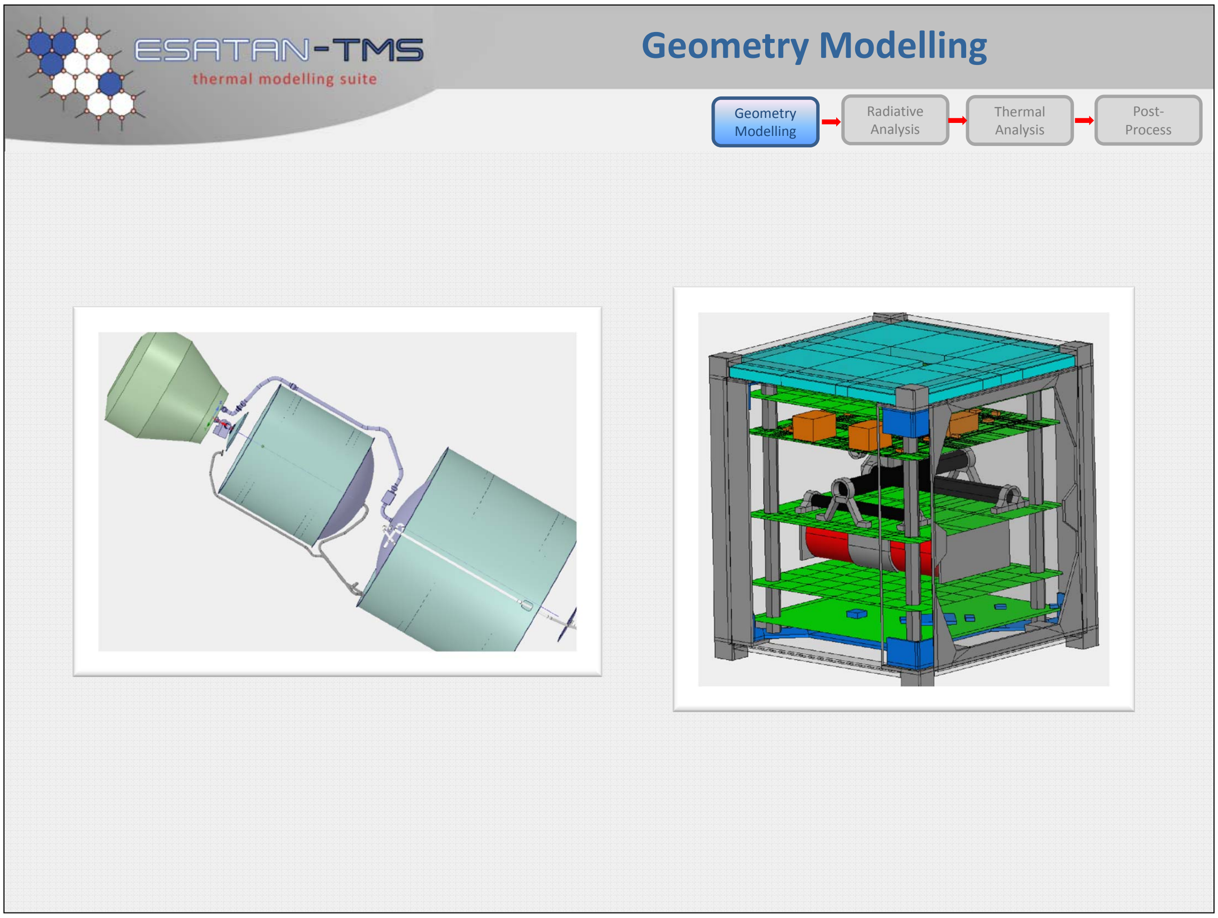
Chris Kirtley
(ITP Engines UK, United Kingdom)

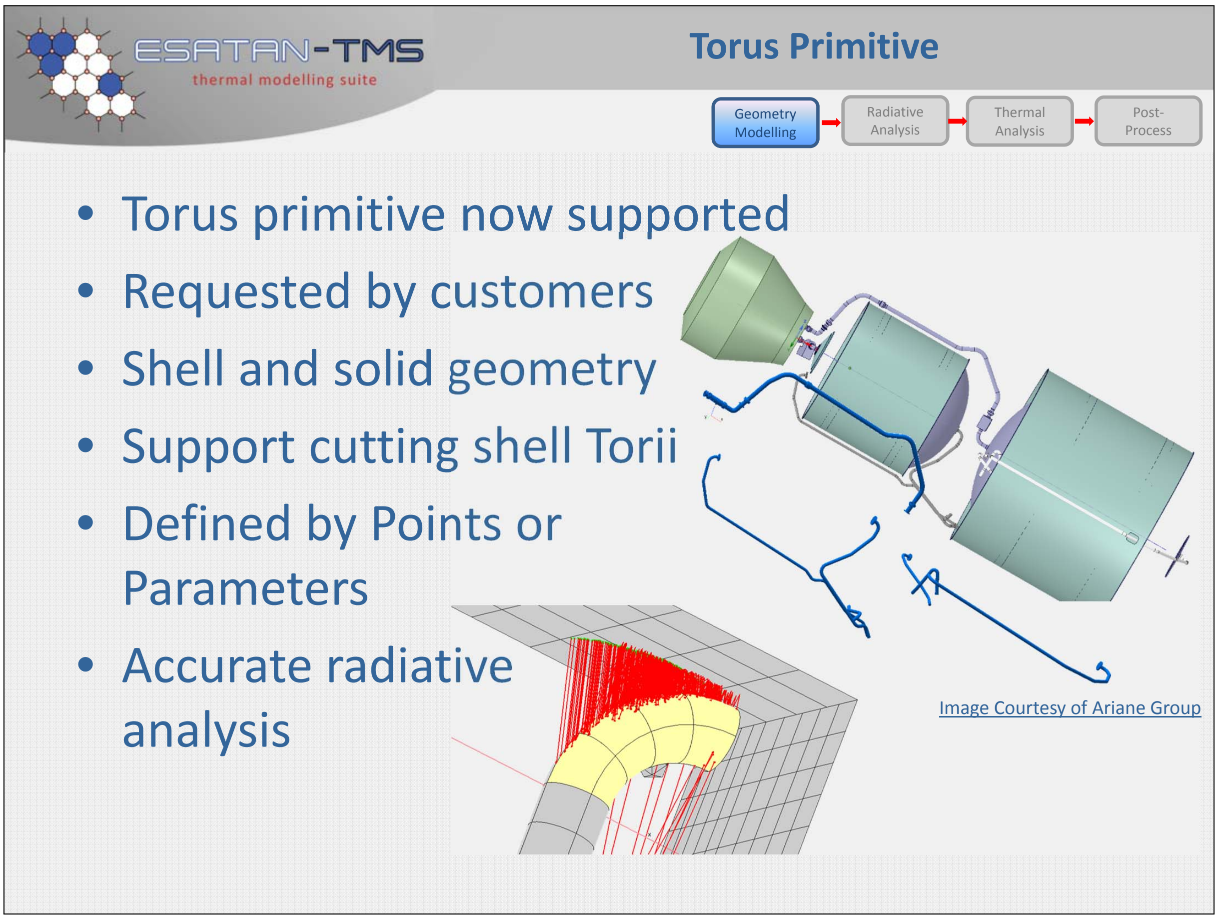
Abstract

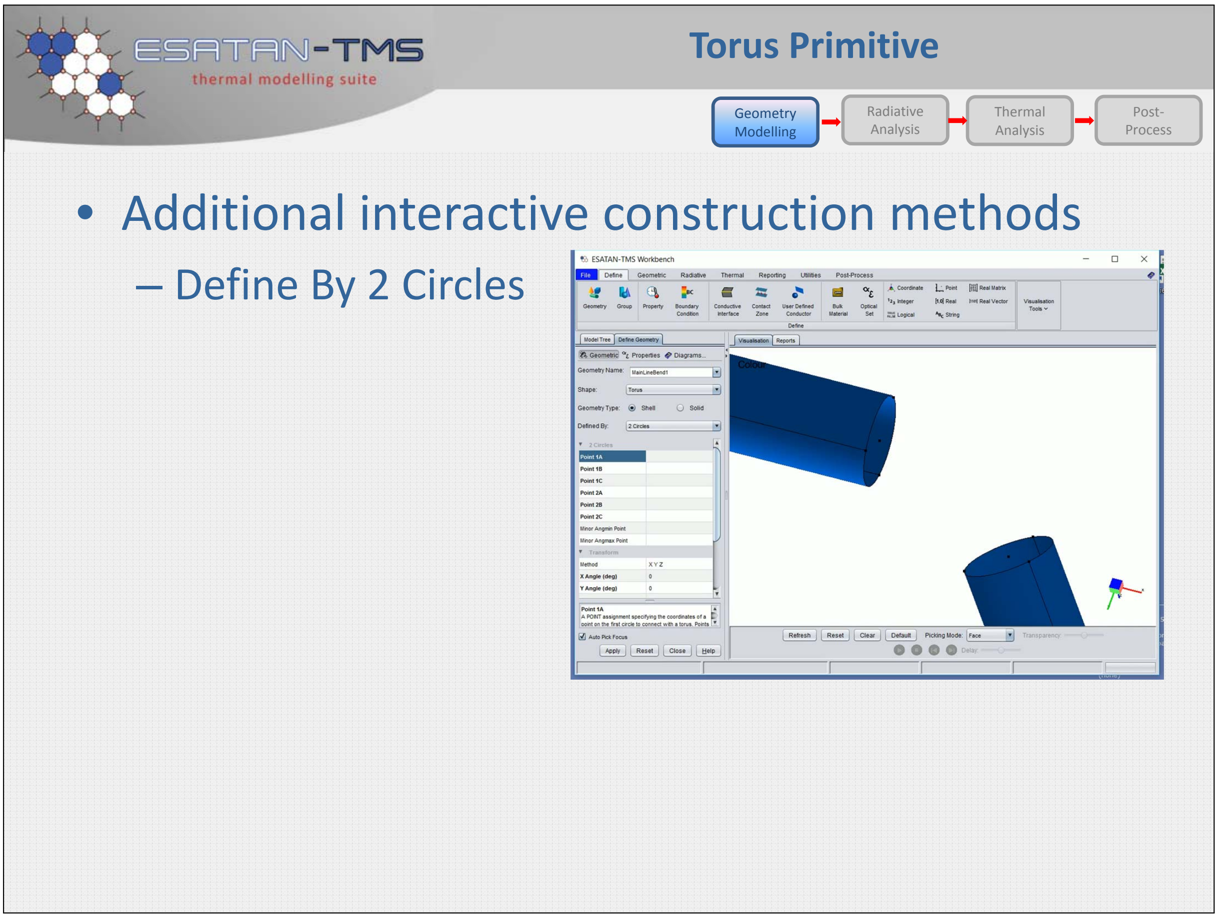
A major focus of ESATAN-TMS development this year has been on providing facilities within Workbench to meet current and future requirements of space projects, and to provide features in direct response to requests from Customers. This presentation will outline all the developments going into ESATAN-TMS 2018.

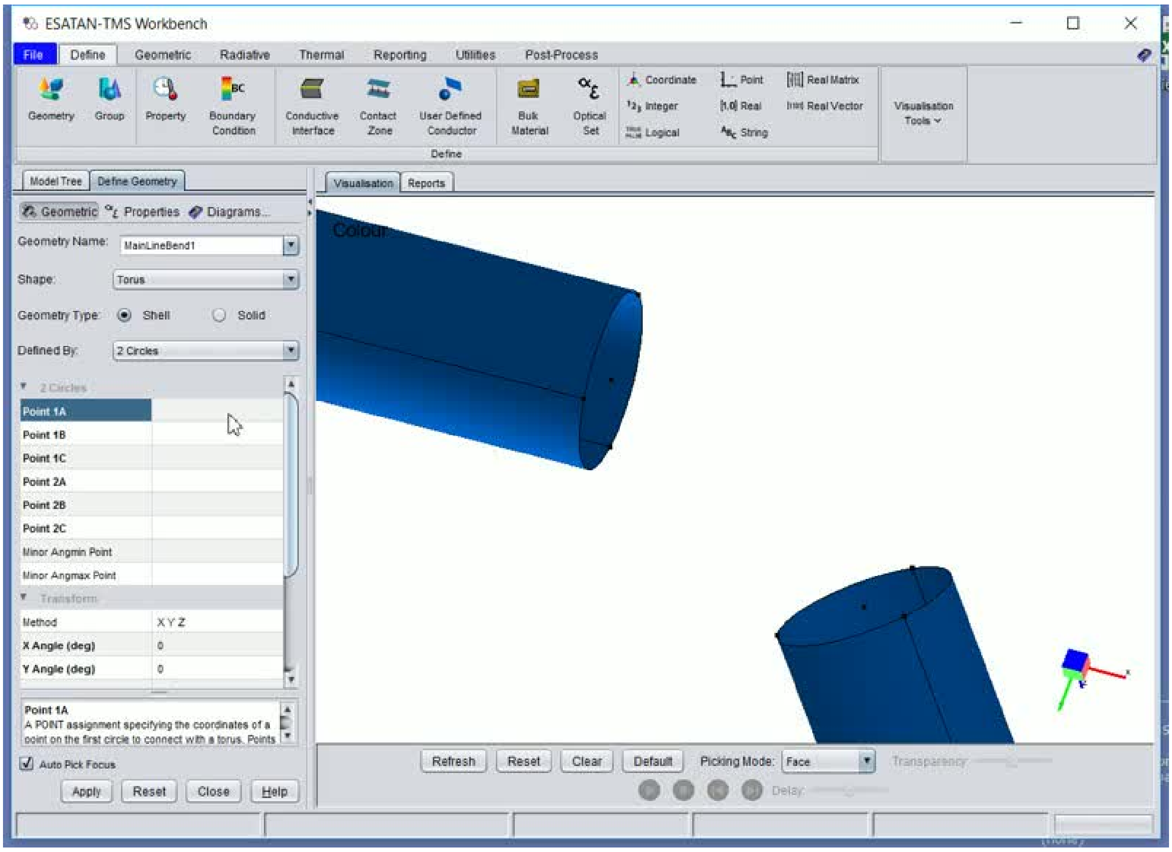

ESATAN-TMS
thermal modelling suite
ESATAN-TMS
Product Status
Chris Kirtley
31st European Thermal & ECLS Software Workshop
24 – 25 October 2017, ESA/Estec, Noordwijk, The Netherlands


ESATAN-TMS
thermal modelling suite
Introduction
• ESATAN-TMS 2018 introduces new functionalities to meet project and customer requirements
• Present new features within the release
NORTH(Z)
(Y)
REFERENCE(X)


ESATAN-TMS
thermal modelling suite
Geometry Modelling
Geometry Modelling
Radiative Analysis
Thermal Analysis
Post-Process


ESATAN-TMS
thermal modelling suite
Torus Primitive
Geometry Modelling
Radiative Analysis
Thermal Analysis
Post-Process
• Torus primitive now supported
• Requested by customers
• Shell and solid geometry
• Support cutting shell Torii
• Defined by Points or Parameters
• Accurate radiative analysis
Image Courtesy of Ariane Group





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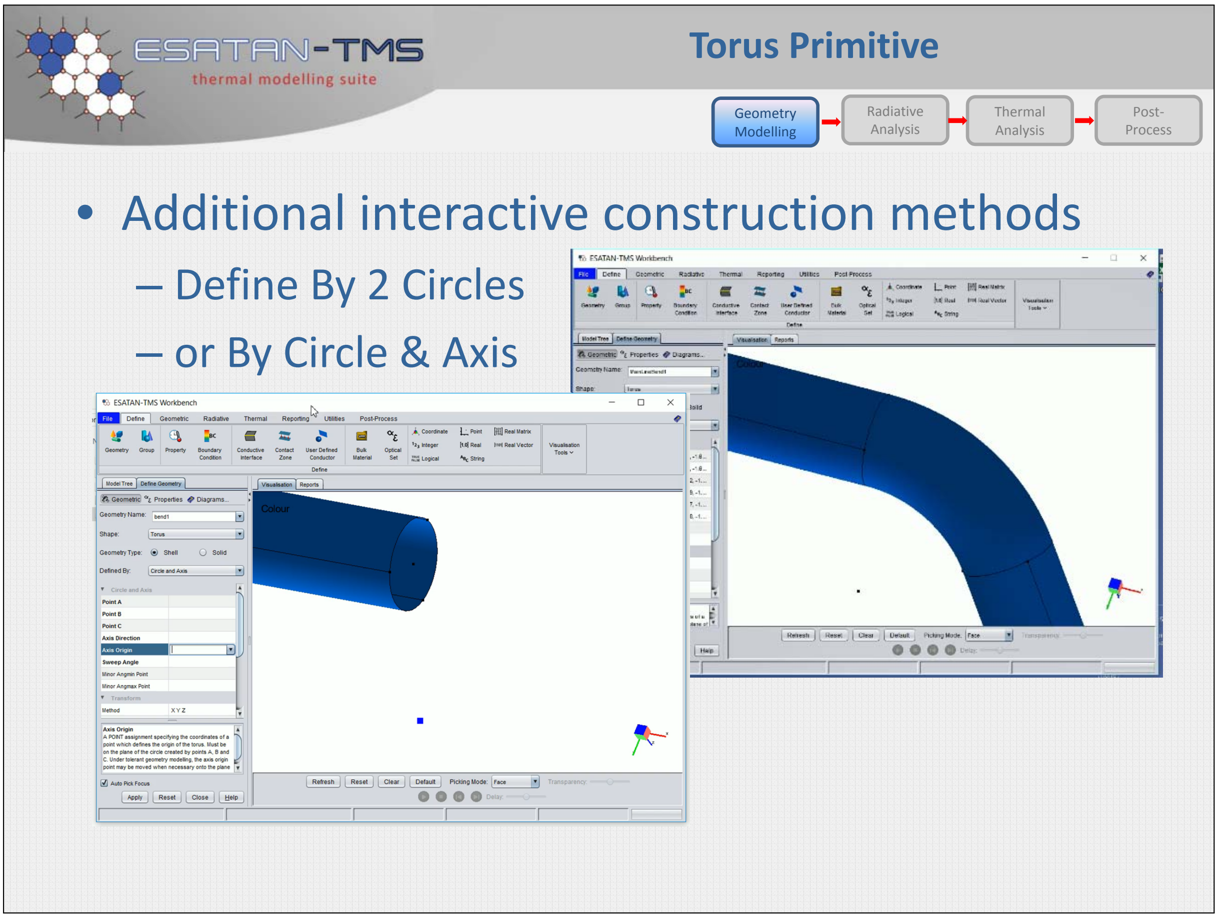

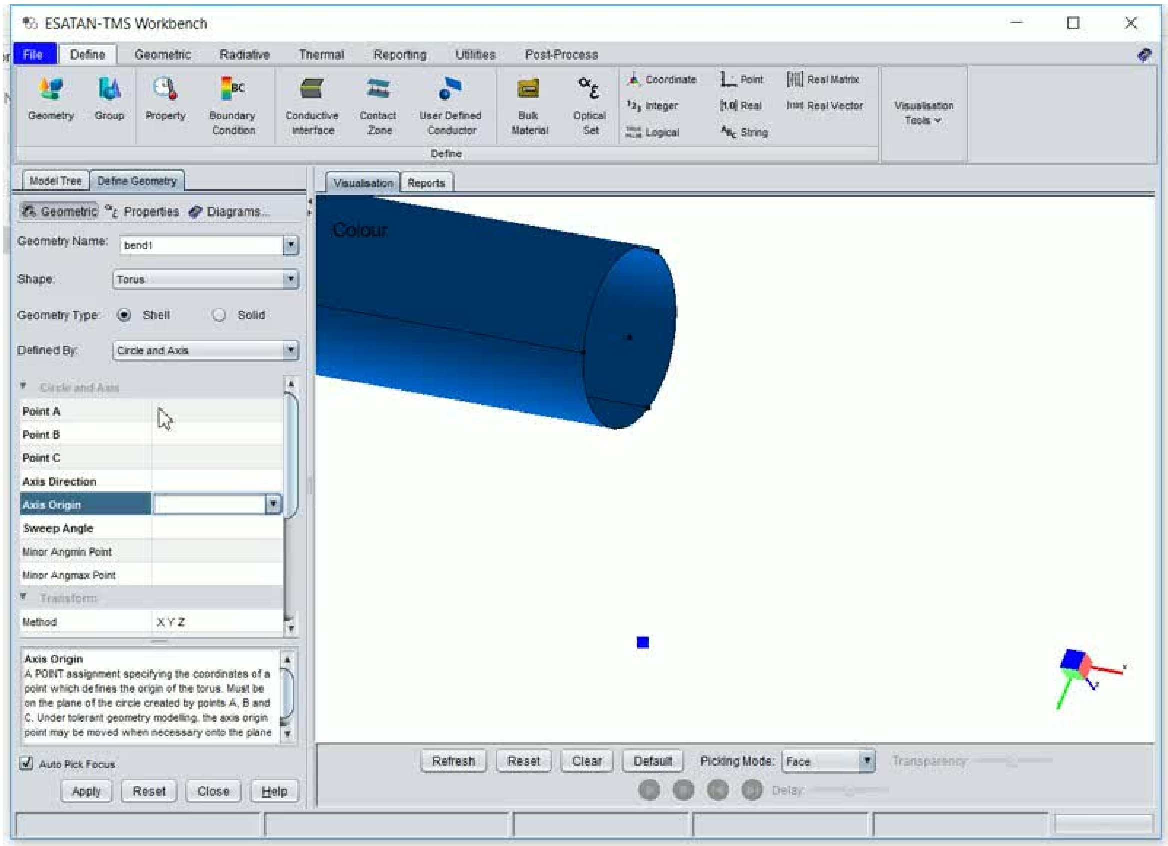

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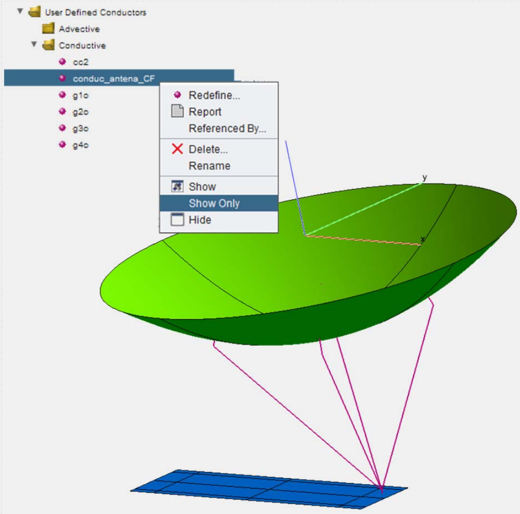
ESATAN-TMS thermal modelling suite

Extended Visualisation

Geometry Modelling → Radiative Analysis → Thermal Analysis → Post-Process

- Easy visualisation of application regions
  - Boundary Conditions
  - Contact Zones, Conductor Interfaces
  - User Defined Conductors
- Extended display control
  - Now at face level



ESATAN-TMS thermal modelling suite

Extended Visualisation

Geometry Modelling → Radiative Analysis → Thermal Analysis → Post-Process

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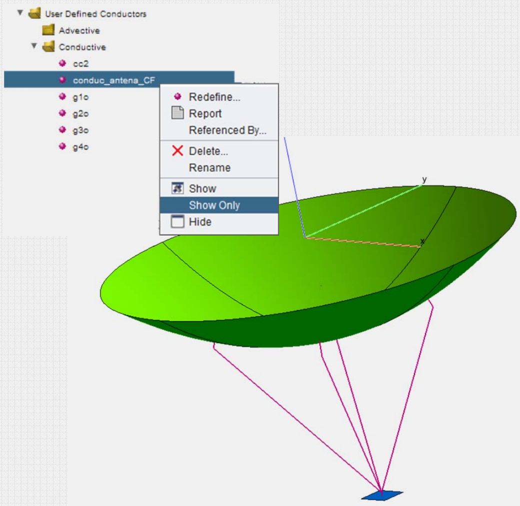

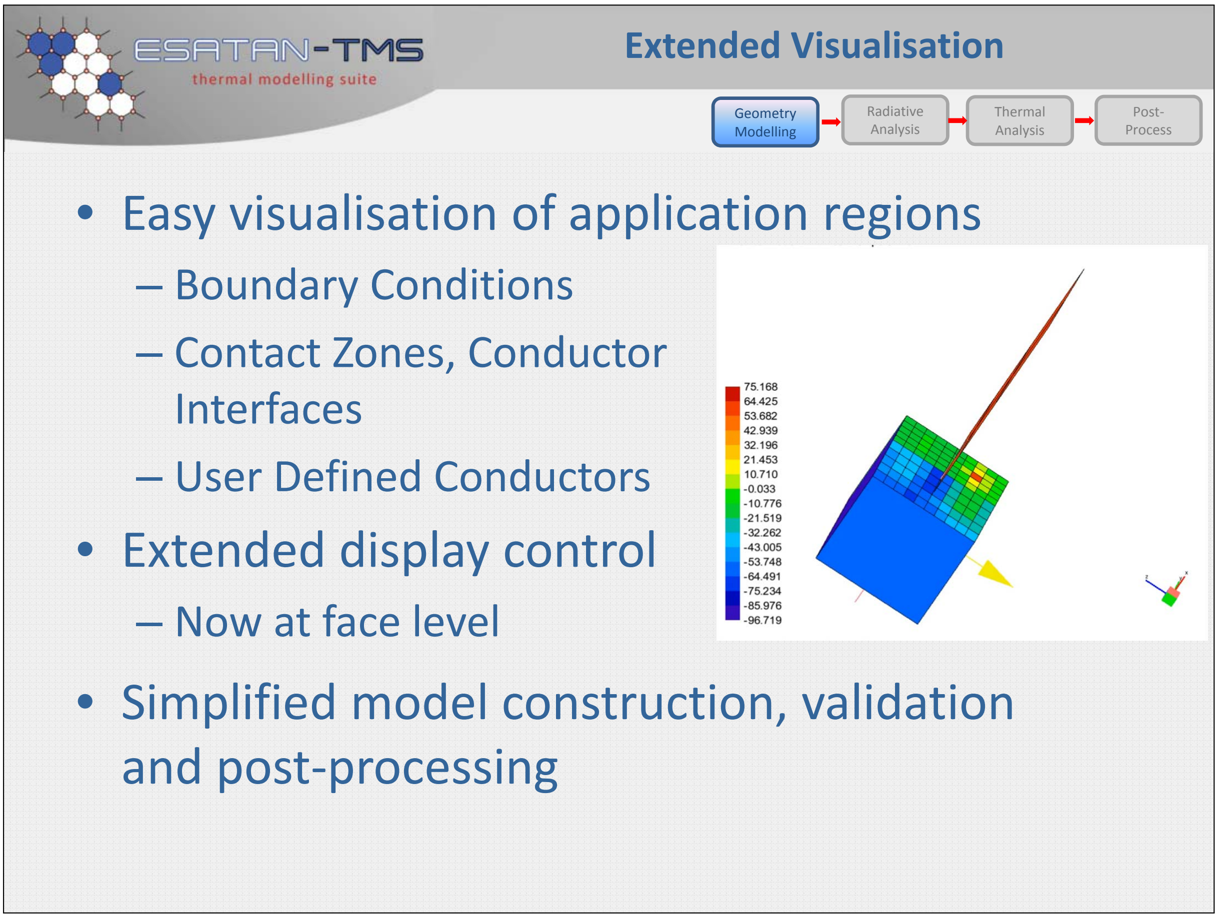

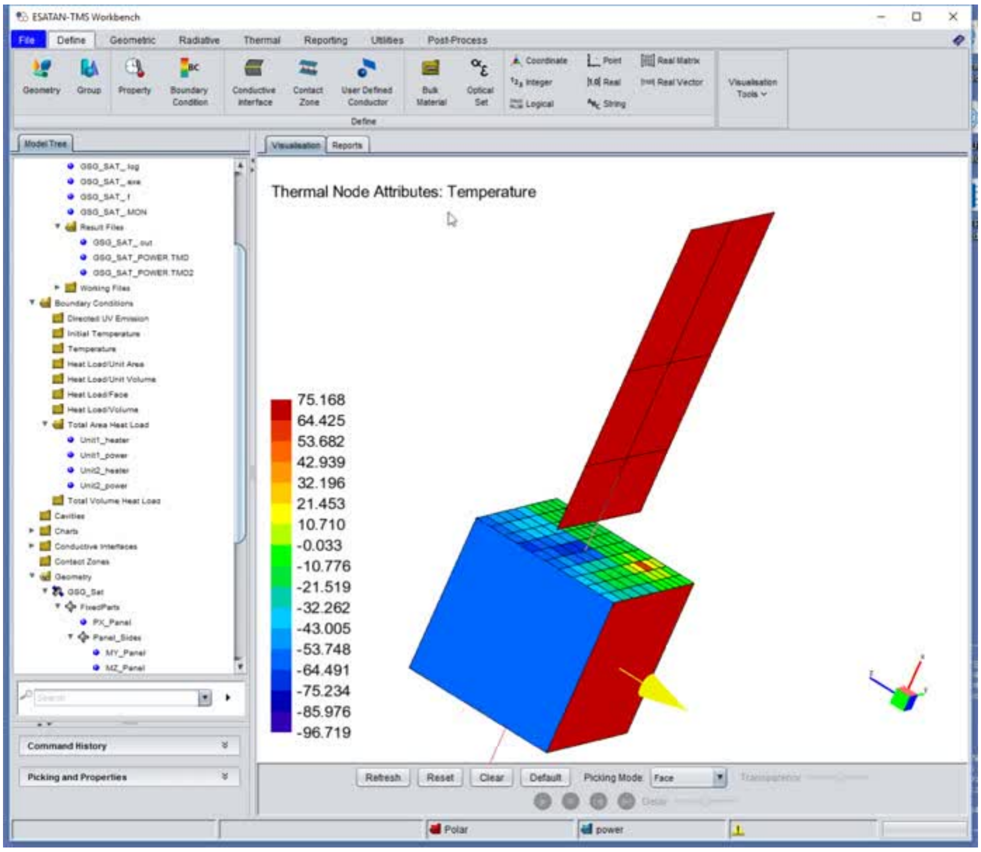

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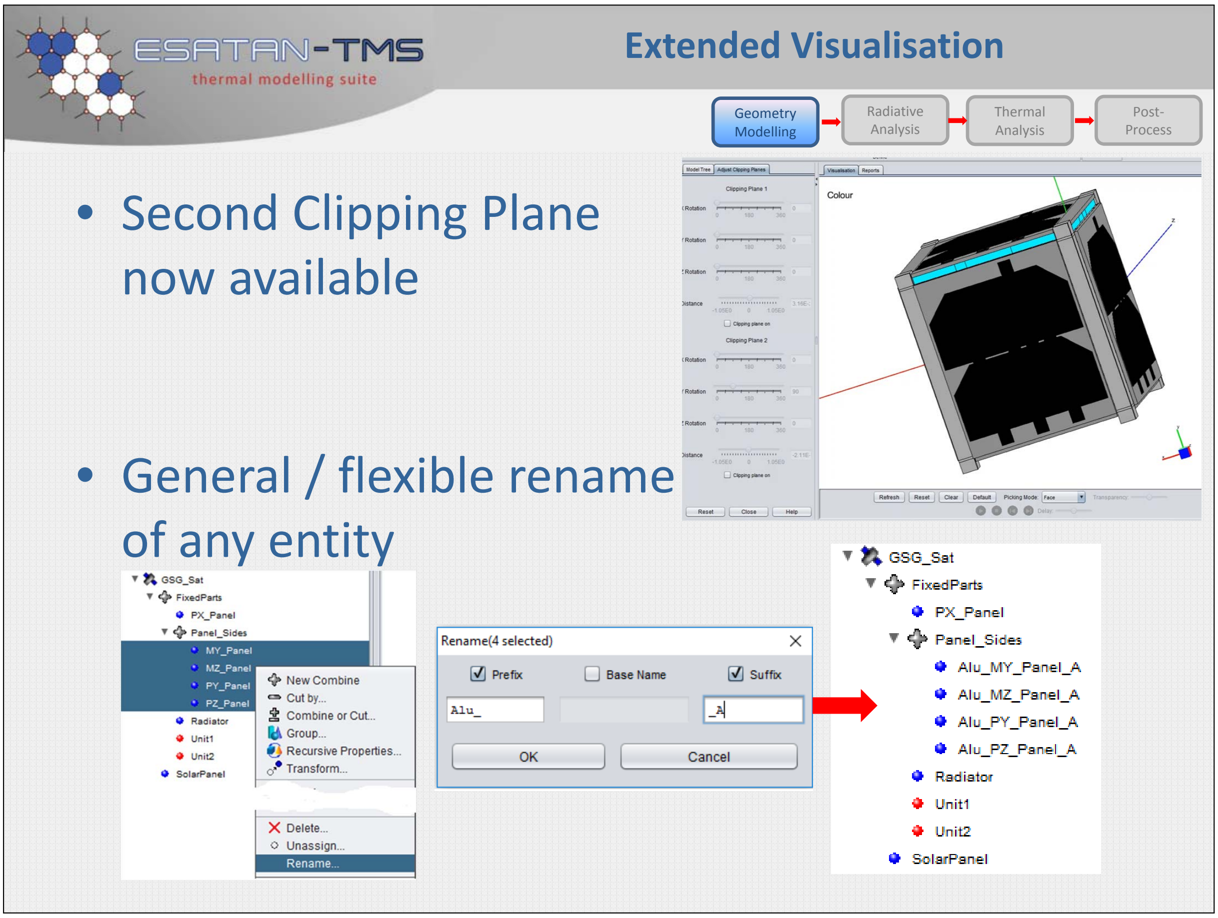

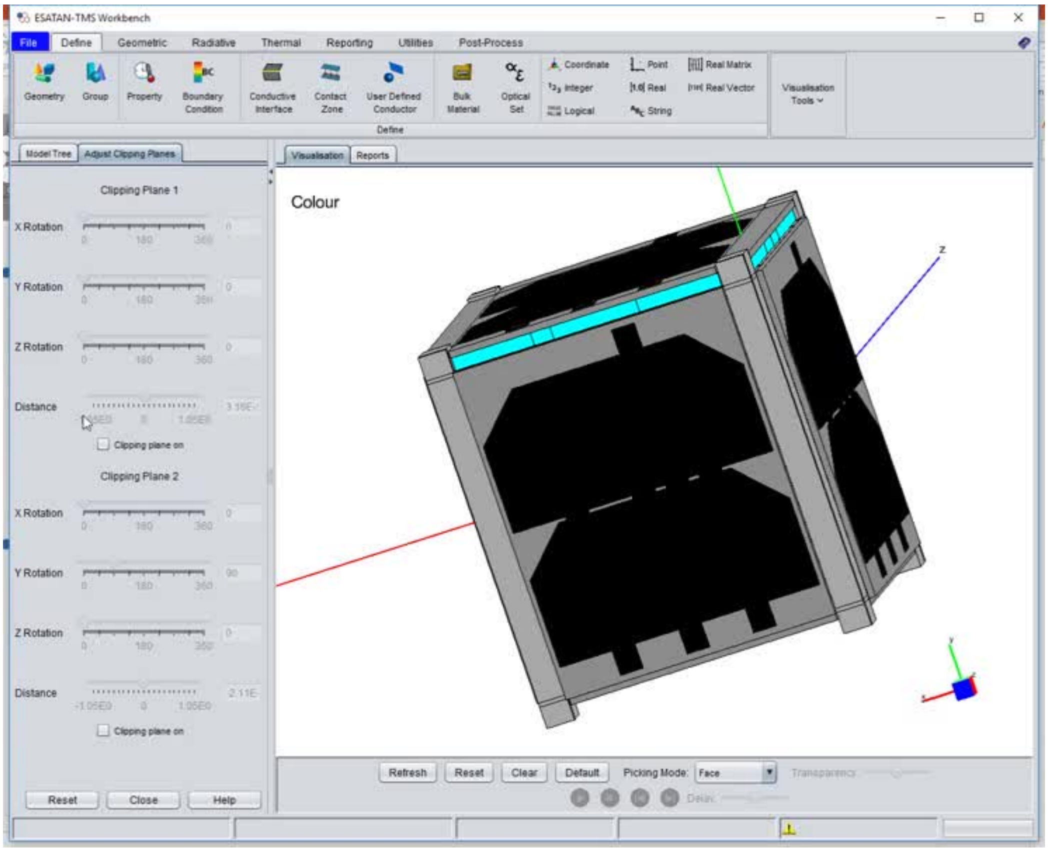

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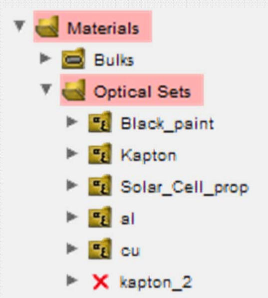
ESATAN-TMS thermal modelling suite

Extended Visualisation

Geometry Modelling → Radiative Analysis → Thermal Analysis → Post-Process

- Extended highlighting of errors
  - Help with model construction and validation

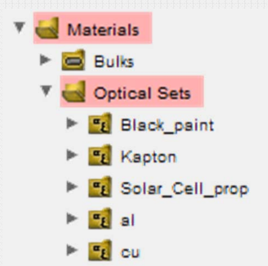


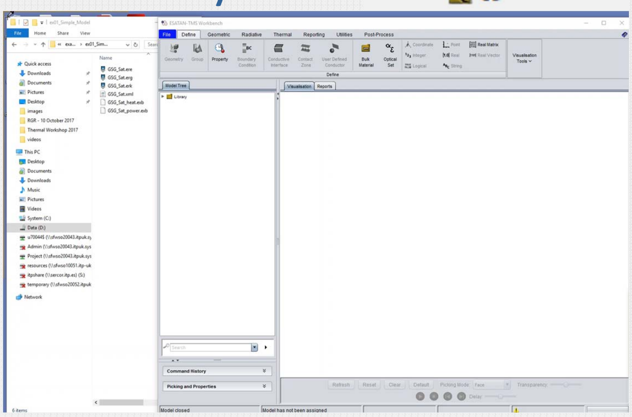
ESATAN-TMS thermal modelling suite

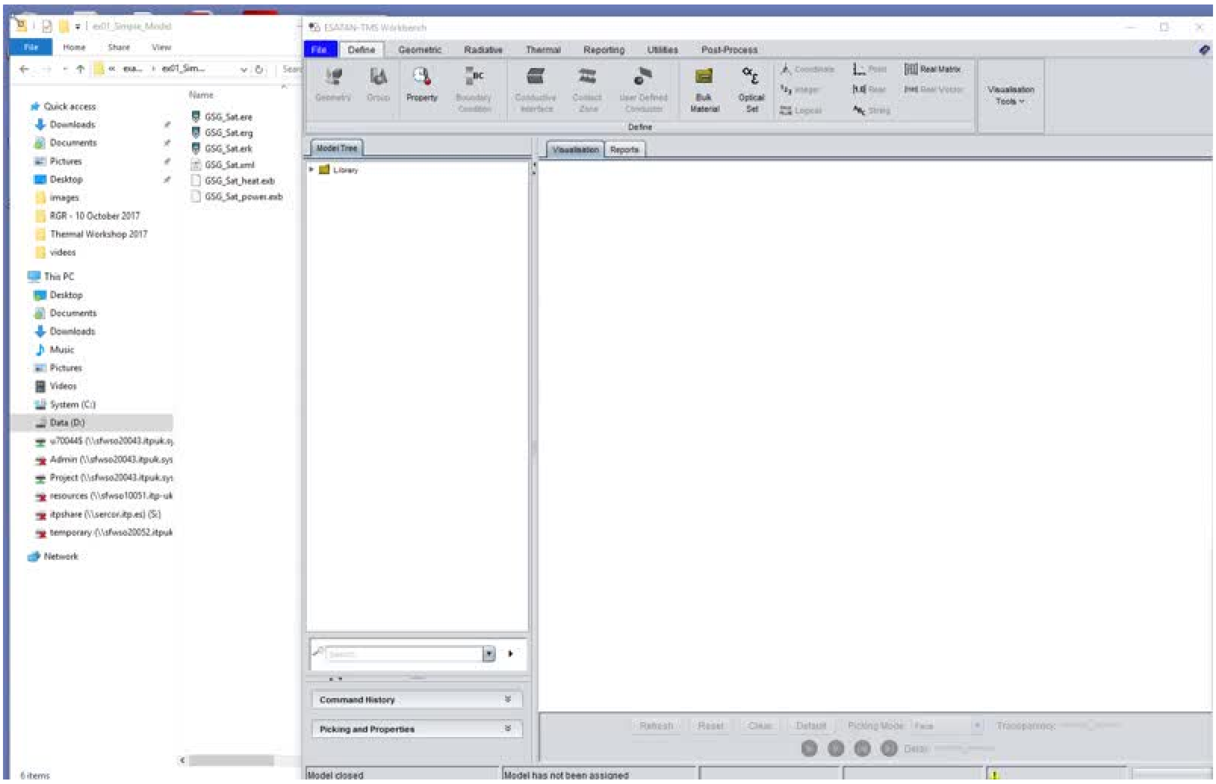
Extended Visualisation

Geometry Modelling → Radiative Analysis → Thermal Analysis → Post-Process

- Extended highlighting of errors
  - Help with model construction and validation
- Improve Workbench usability
  - Drag-and-drop of language files







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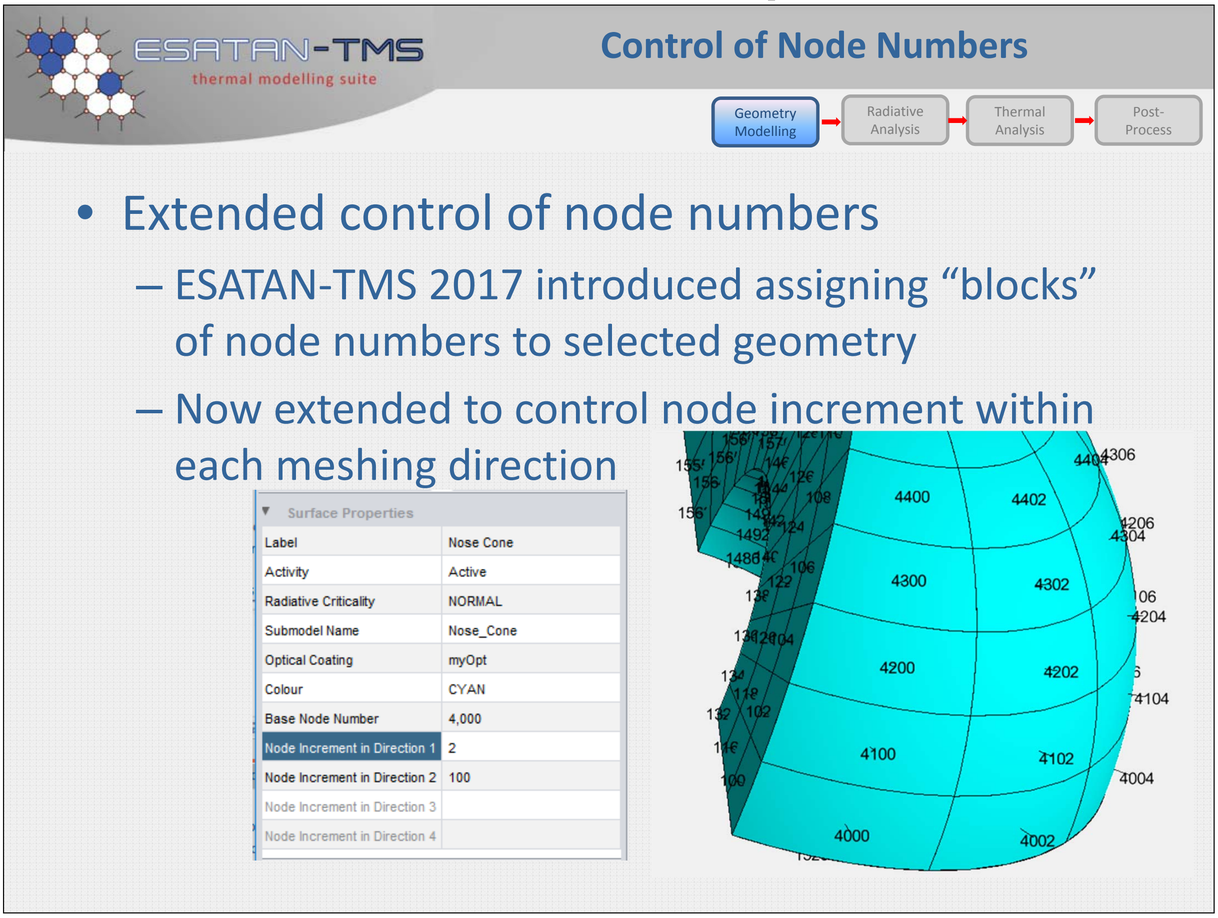
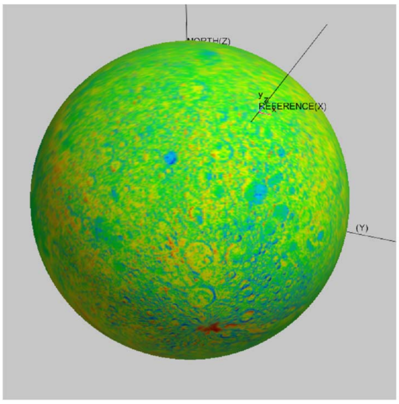
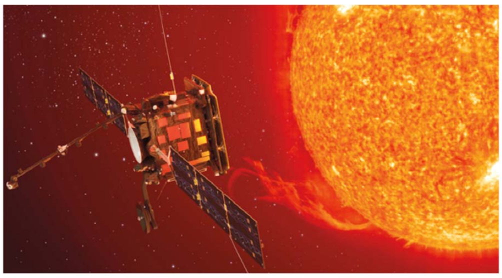


ESATAN-TMS thermal modelling suite

Radiative Analysis

Geometry Modelling → Radiative Analysis → Thermal Analysis → Post-Process

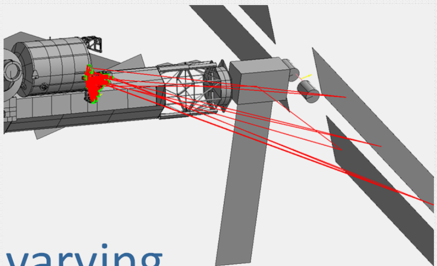




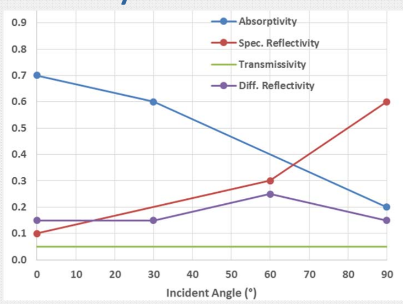
ESATAN-TMS thermal modelling suite

Extended Radiative Analysis

Geometry Modelling → Radiative Analysis → Thermal Analysis → Post-Process



- Requirement from projects to model angle-dependent surface optical properties
- Support for optical properties varying with incident angle of radiation
  - Emissivity, transmissivity and reflectivity
  - Diffuse reflectivity automatically derived
- Hemispherical value calculated

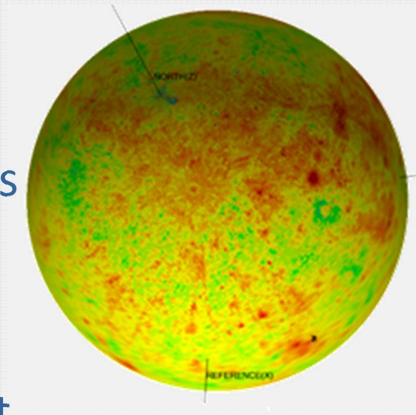


ESATAN-TMS
thermal modelling suite

Extended Radiative Analysis

Geometry Modelling → Radiative Analysis → Thermal Analysis → Post-Process

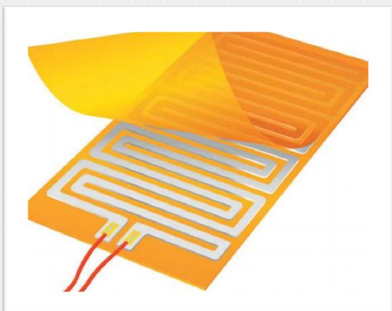
- Model variation in planet albedo reflectance
- Requested by many customers
- Definition of albedo at given longitude and latitude positions
- Option to import albedo map
- Improved planet display
- Report temperature / albedo at selected points
- Vector displaying the Planet Sun direction

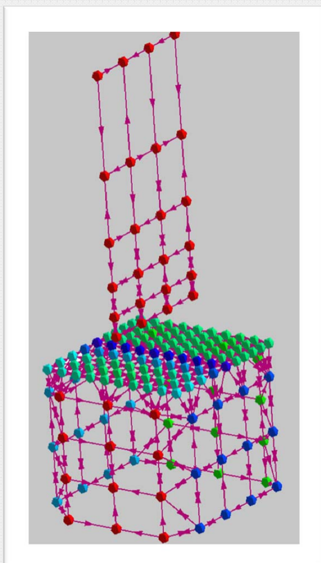


ESATAN-TMS
thermal modelling suite

Thermal Analysis

Geometry Modelling → Radiative Analysis → Thermal Analysis → Post-Process



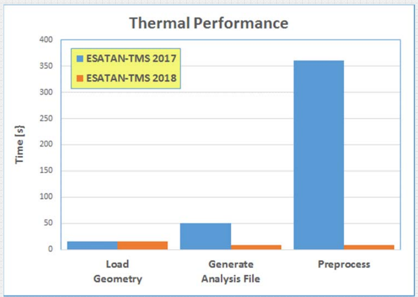


ESATAN-TMS thermal modelling suite

Integration of Data

Geometry Modelling → Radiative Analysis → Thermal Analysis → Post-Process

- Efficient data handling is key to providing an effective thermal modelling environment
- ESATAN-TMS 2016 introduced optimised solution with the ACD file
  - Significant improvements in performance
  - Significant reduction in file size and memory
- Now extended to store property data (arrays/tables)
  - Time or/and temperature
  - General 2D/3D

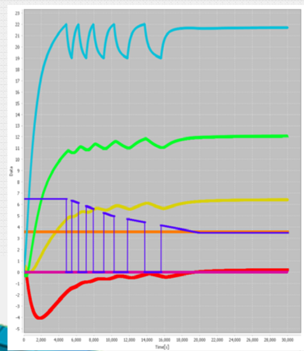


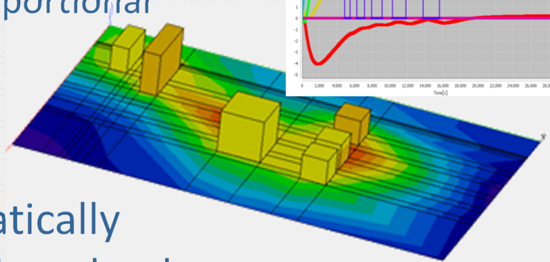
ESATAN-TMS thermal modelling suite

Thermostatic Control

Geometry Modelling → Radiative Analysis → Thermal Analysis → Post-Process

- Thermostatically controlled heaters
  - Define control within Workbench
  - Steady state and transient operation
    - Transient: On/Off or Proportional
    - Steady State: Fixed, Set-point or Proportional
  - Set-point mode automatically calculates steady state heat loads
  - Library routines to define and report heater status
    - Applied load, duty cycle, number of switches, …



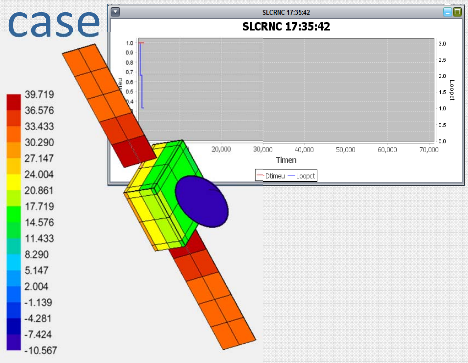


ESATAN-TMS thermal modelling suite

Initial Temperatures

Geometry Modelling → Radiative Analysis → Thermal Analysis → Post-Process

- Common practice to chain cases, initialising temperatures from previous case
  - Currently supported by SAVET / FETCHT
  - Request from customers to increase flexibility
- Initialise temperatures from a selected TMD file at a given time
- Cases easily rerun without Preprocessing

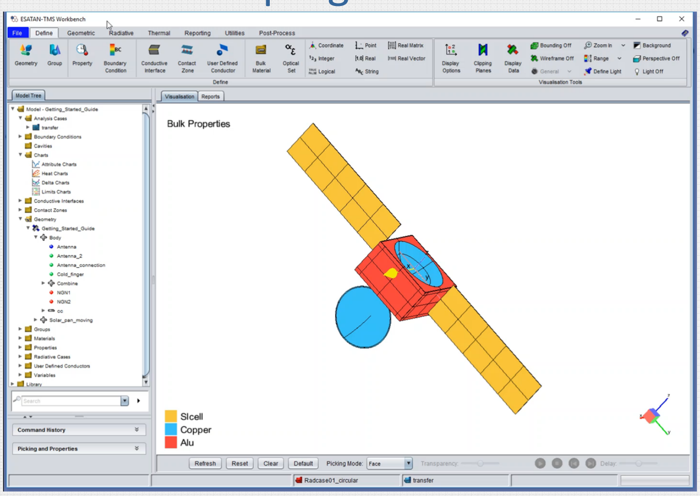


ESATAN-TMS thermal modelling suite

Analysis Monitor

Geometry Modelling → Radiative Analysis → Thermal Analysis → Post-Process

- Extended control of thermal analysis
  - Launch analysis in the background
  - View progress

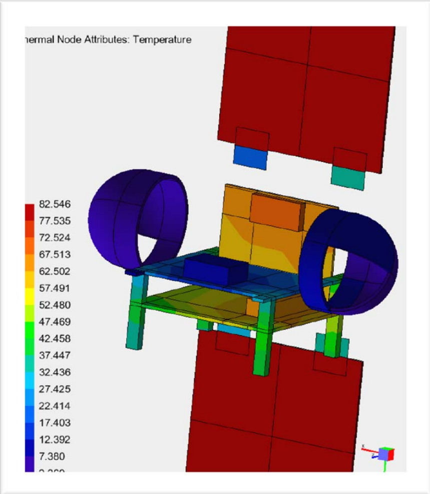


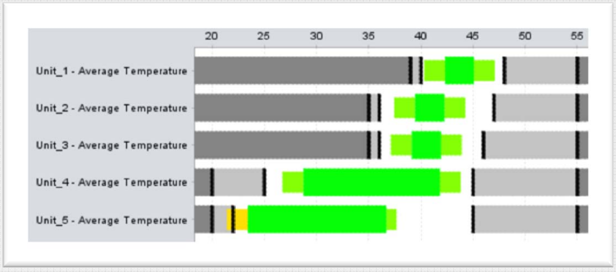
- Close/reopen the model
- Post-process results to assess progress
- Terminate / Stop analysis if required

ESATAN-TMS thermal modelling suite

Post-process

Geometry Modelling → Radiative Analysis → Thermal Analysis → Post-Process



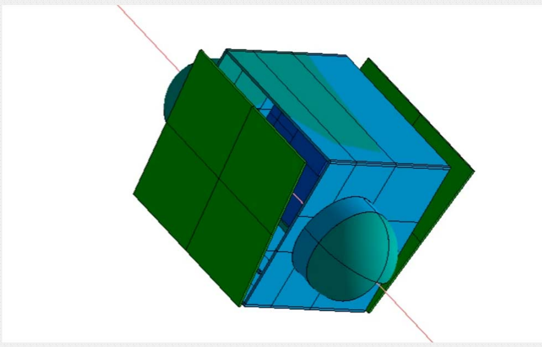


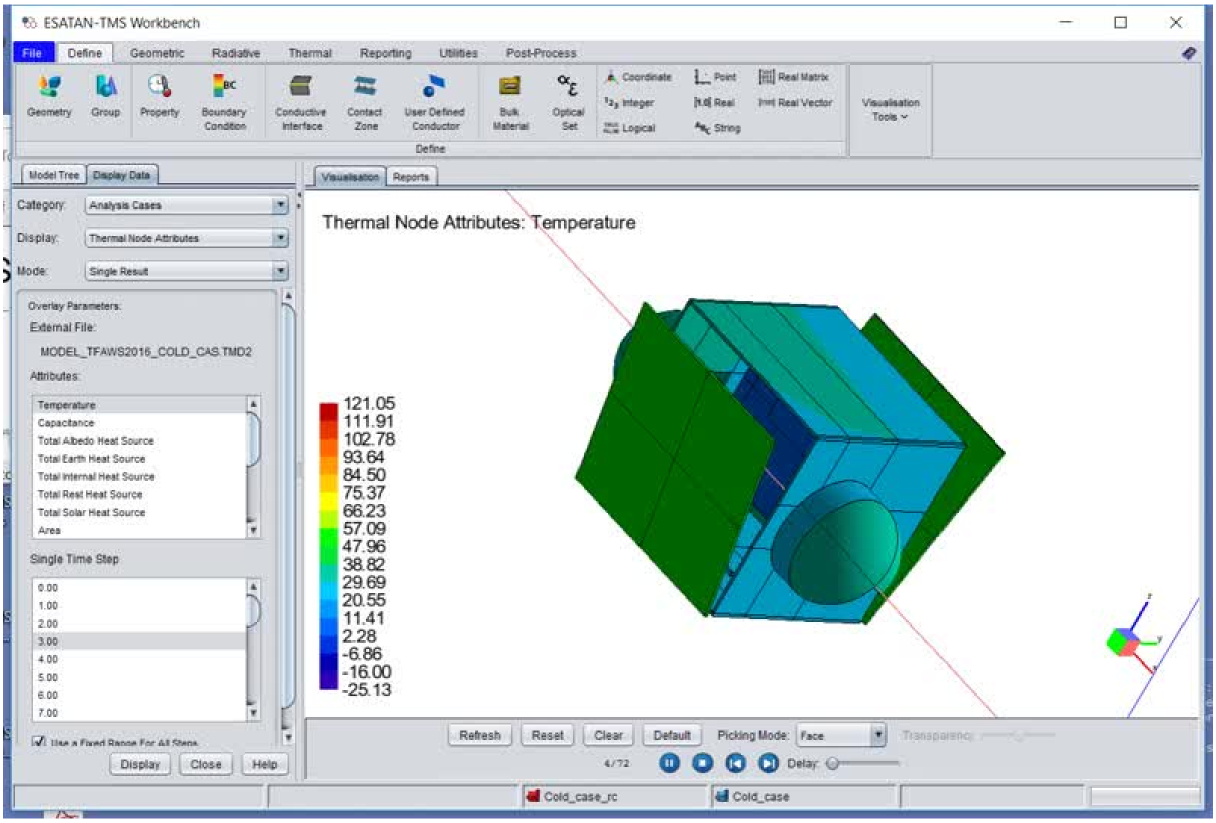
ESATAN-TMS thermal modelling suite

Post-processing

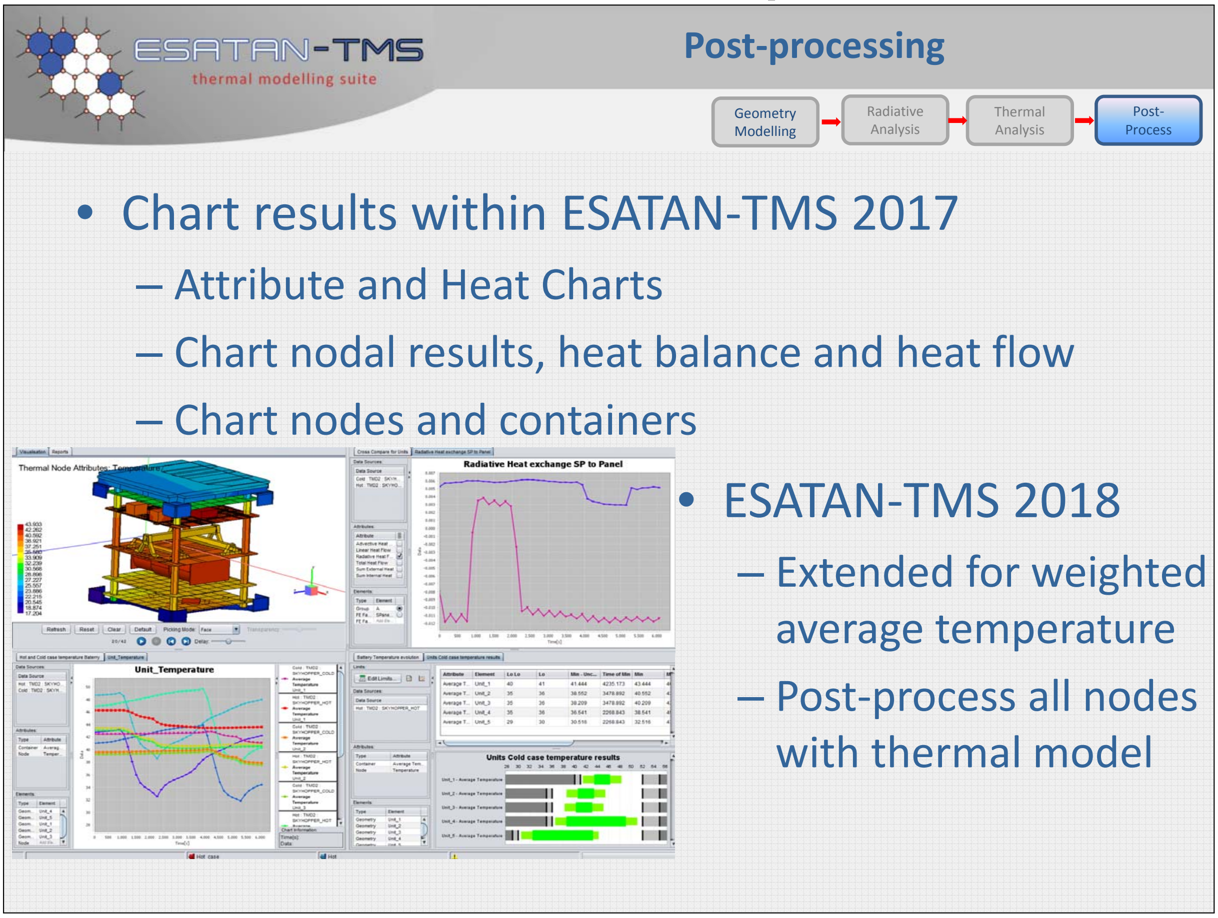
Geometry Modelling → Radiative Analysis → Thermal Analysis → Post-Process

- Flexible post-processing of results within Workbench
  - Animation of results on geometry
  - Animation of assembly movement
  - Control of displayed geometry





Save the attachment to disk or (double) click on the picture to run the movie.

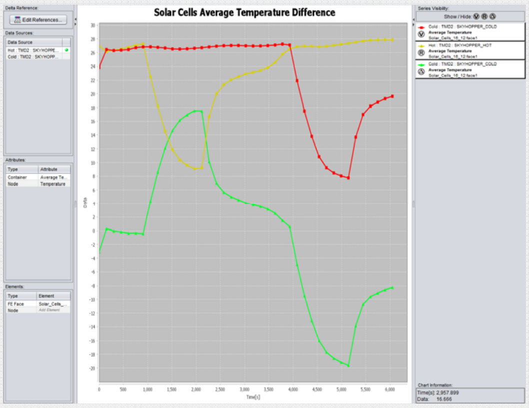


ESATAN-TMS
thermal modelling suite

Post-processing

Geometry Modelling → Radiative Analysis → Thermal Analysis → Post-Process

- Extended for Delta Charts
  - Compare multiple cases against a reference case
  - Compare against fixed or time varying reference
  - Compare any attribute for selected nodes/containers
  - Control series to display
    - Value
    - Reference
    - Delta



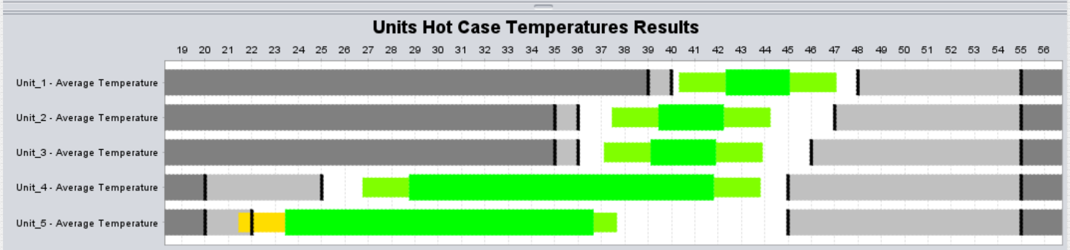
ESATAN-TMS
thermal modelling suite

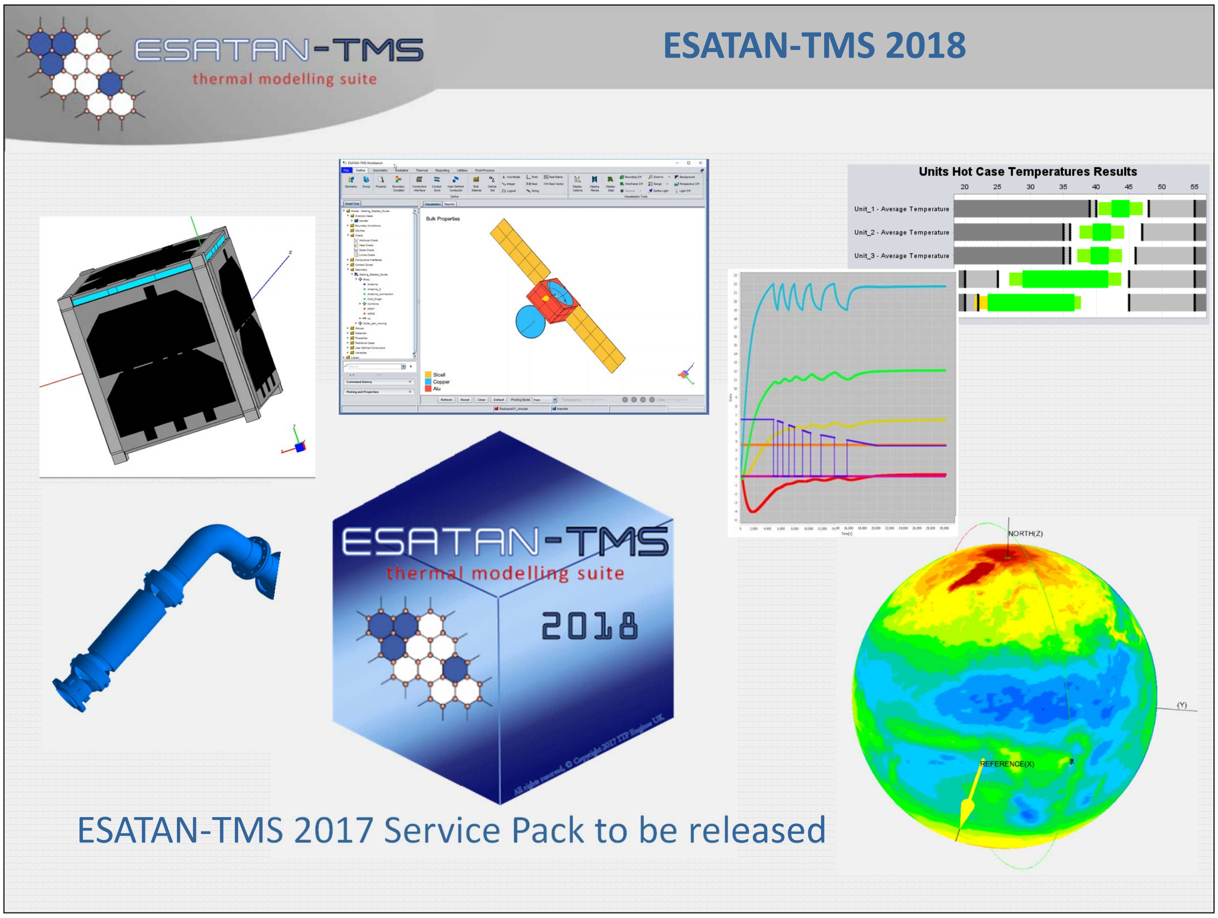
Post-processing

Geometry Modelling → Radiative Analysis → Thermal Analysis → Post-Process

- Extended for Limits Charts
  - Comparison of multiple cases against limit data
  - Graphical and/or tabular display

Attribute	Element	Lo Lo	Lo	Min - Uncert...	Time of Min	Min	Max	Time of Max	Max + Unce...	Hi	Hi Hi
Average Te...	Unit_1	39	40	40.329	4386.429	42.329	45.074	907.537	47.074	48	55
Average Te...	Unit_2	35	36	37.446	3630.148	39.446	42.241	0	44.241	47	55
Average Te...	Unit_3	35	36	37.107	3478.892	39.107	41.907	0	43.907	46	55
Average Te...	Unit_4	20	25	26.751	2117.587	28.751	41.816	907.537	43.816	45	55
Average Te...	Unit_5	20	22	21.433	2117.587	23.433	36.657	907.537	37.657	45	55




ESATAN-TMS
thermal modelling suite
ESATAN-TMS 2018
Units Hot Case Temperatures Results
Unit_1 - Average Temperature
Unit_2 - Average Temperature
Unit_3 - Average Temperature
ESATAN-TMS
thermal modelling suite
2018
NORTH(Z)
REFERENCE(X)
(Y)
ESATAN-TMS 2017 Service Pack to be released

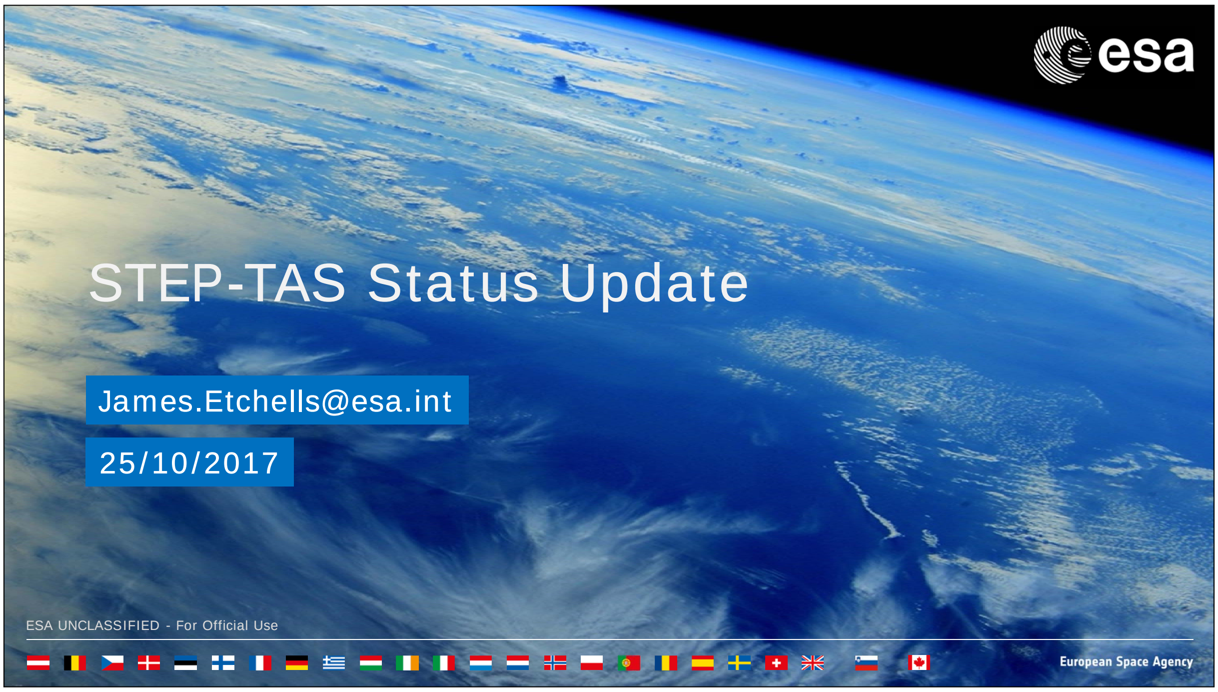
Appendix S

Data exchange for thermal analysis
a status update

James Etchells Duncan Gibson Harrie Rooijackers Matthew Vaughan
(ESA/ESTEC, The Netherlands)

Abstract

This short presentation will give a factual overview of the current status for thermal analysis data exchange.


esa
STEP-TAS Status Update
James.Etchells@esa.int
25/10/2017
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European Space Agency


Review of short term objectives (2017)
esa
ECSS Standard
Dataset validation
TASverter
GMM viewer
ECSS Standard
• ECSS formalisation of STEP-TAS protocol
• Baseline for STEP-TAS compliance in analysis tools
• Protocol openly available online (ECSS portal)
• WG work complete → expected end 2017
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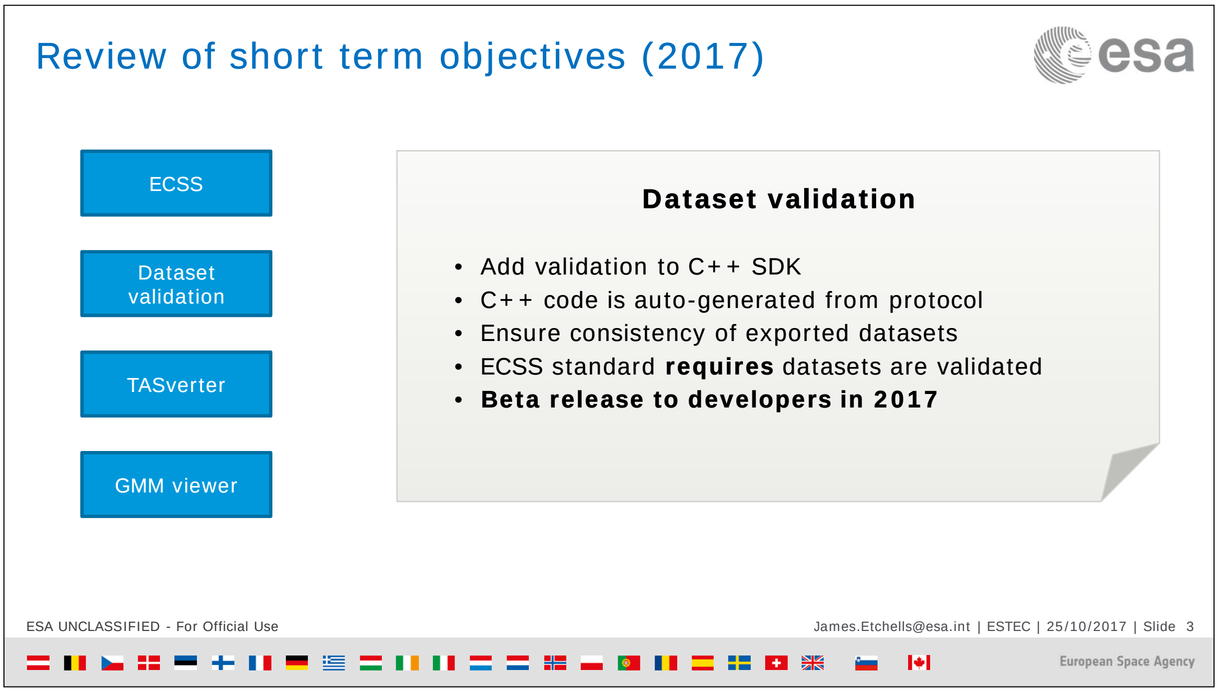
James.Etchells@esa.int | ESTEC | 25/10/2017 | Slide 2
European Space Agency


Review of short term objectives (2017)
esa
ECSS
Dataset validation
TASverter
GMM viewer
Dataset validation
• Add validation to C++ SDK
• C++ code is auto-generated from protocol
• Ensure consistency of exported datasets
• ECSS standard requires datasets are validated
• Beta release to developers in 2017
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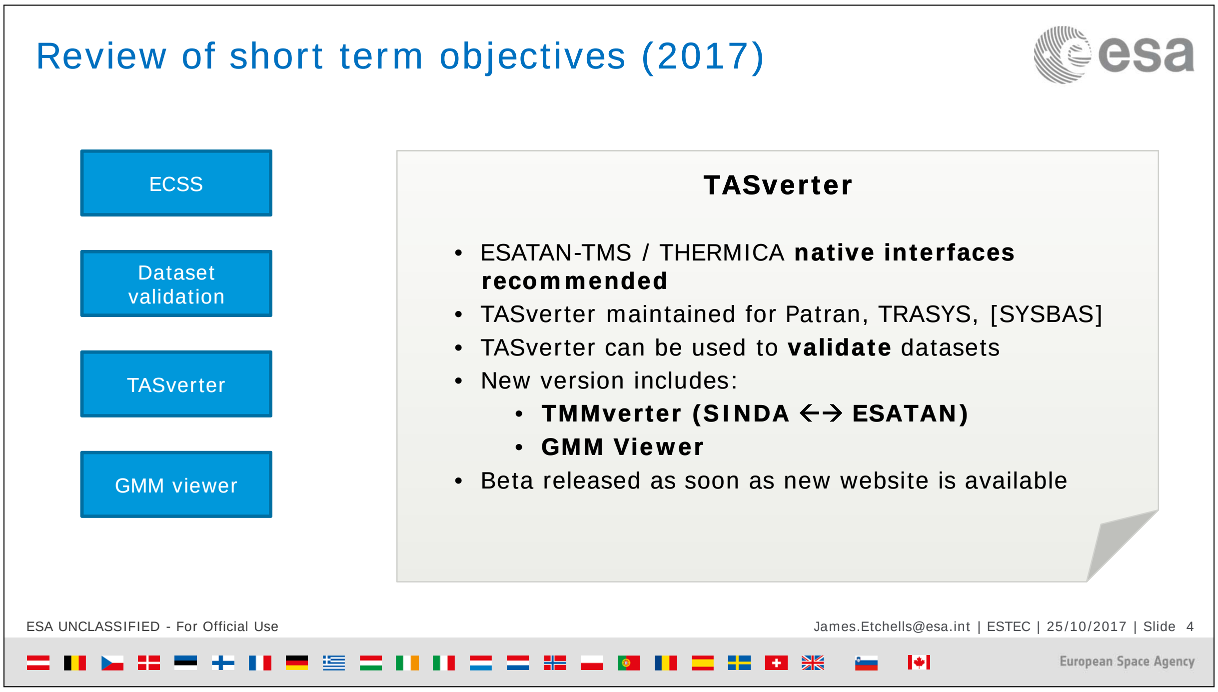
Review of short term objectives (2017)
esa
ECSS
Dataset validation
TASverter
GMM viewer
TASverter
• ESATAN-TMS / THERMICA native interfaces recommended
• TASverter maintained for Patran, TRASYS, [SYSBAS]
• TASverter can be used to validate datasets
• New version includes:
• TMMverter (SINDA <-> ESATAN)
• GMM Viewer
• Beta released as soon as new website is available
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Review of short term objectives (2017)

- ECSS
- Dataset validation
- TASverter
- GMM viewer

GMM viewer

- Replace obsolete BagheraView
- Allow exported STEP-TAS GMMs to be visually checked in neutral tool
- Allow a GMM report to be produced for verification (e.g. nodal area and optical properties)
- **Beta release in 2017 in 2 forms:**
  - **Hosted @ https://exchange.esa.int**
  - **Embedded in TASverter**

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STEP-TAS interfaces in tools

ESATAN-TMS
- No issues outstanding, 1 bug fix in R2017 SP2
- Excellent support for GMM including cutting

THERMICA
- Few issues reported, should be fixed in next release
- Partial support for cutting (cylinders, polygonal prisms)

Thermal Desktop
- STEP-TAS 6.0 interface included in new Thermal Desktop
- *But* not working due to implementation issues...
- ESA in contact with C&R, hope for resolution in next patch

eTherm
- TAS-F internal tool
- Generally functional interface reported

TMG
- Current interface is of limited use → different modelling
- Discussion with Siemens to see what can be done

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Medium term plan (2018 and beyond)

Protocol extensions
- FE and edge nodes for Thermal Desktop and ESATAN-TMS
- Solids requested by launchers → Needed by other users?
- New shapes (e.g. torus) or cutters (e.g. extruded polygon)

Space mission and kinematics
- Mission and kinematics supported in protocol
- Is this real need from users?

Knowledge base
- Online knowledge base for STEP-TAS
- New CMS on exchange should facilitate this

Enhanced TMG support
- GMM and TMM support along with guidelines
- Discussion with Siemens/MAYA → need to identify stakeholder

Future proofing
- Disperse knowledge and development expertise outside ESA
- Simplification of development process

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Closing remarks

- As end users, please:
  - try to **use** the STEP-TAS native interfaces
  - **report** any issues to developers, or ESA if you're not sure
  - ESA are available to **support** where possible
  - **plan** conversions ahead, rules and guidelines to simplify model exchange may be needed
- Links:
  - For **support** and **questions**: step-tas@thermal.esa.int
  - For **downloads** and (hopefully) **viewer**: https://exchange.esa.int
  - For ICES paper: https://ttu-ir.tdl.org/ttu-ir/handle/2346/67718

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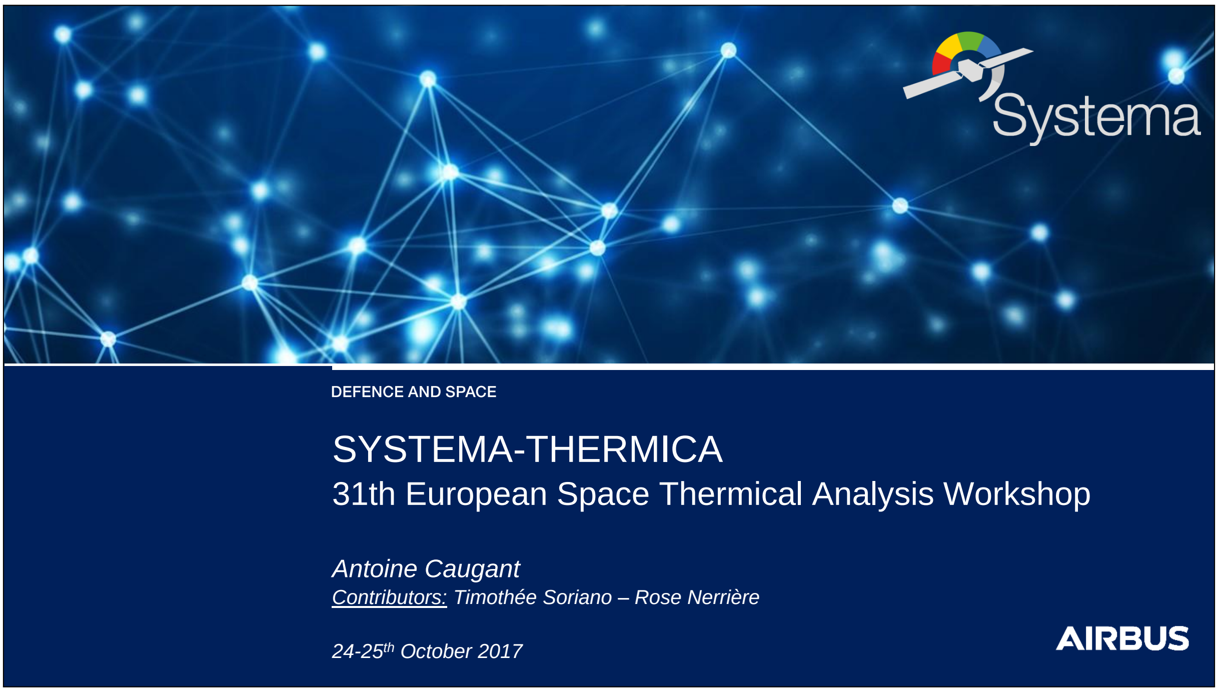
Appendix T

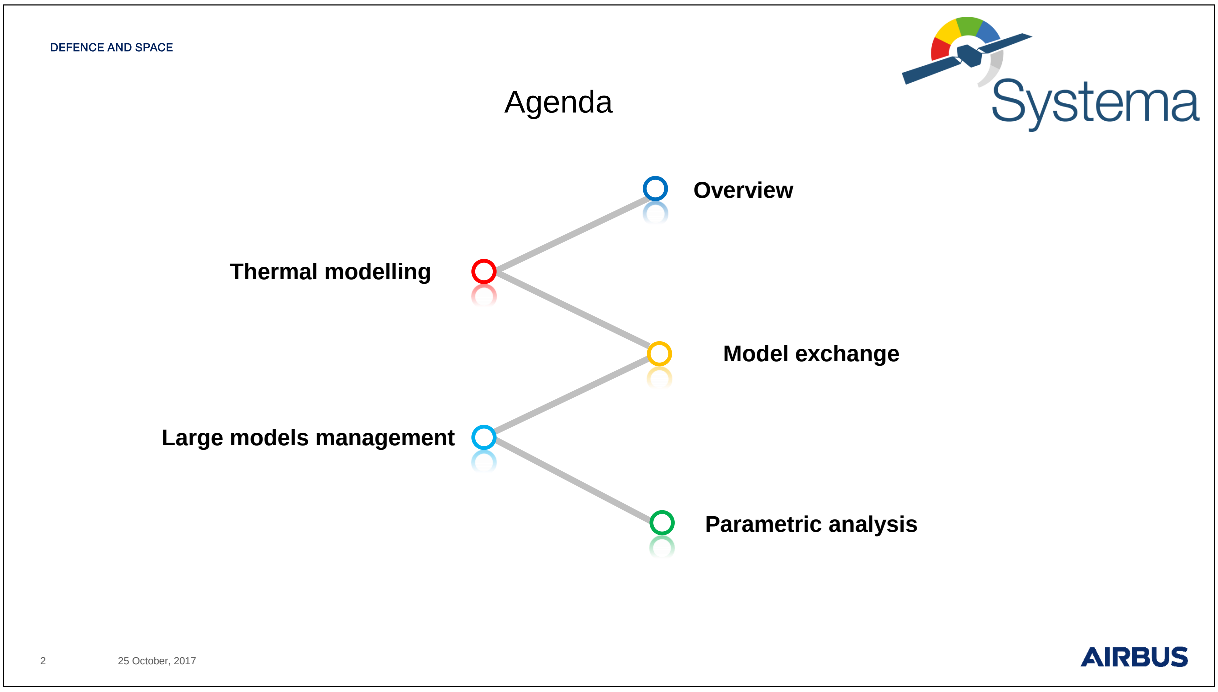
SYSTEMA - THERMICA

Antoine Caugant Rose Nerriere Tomothée Soriano
(Airbus Defence and Space SAS, Toulouse, France)

Abstract

The Systema-Thermica software supports engineers in facing the present and future challenges of space thermal analysis. Several improvements and new features were recently implemented.
First of all, the Systema 3D engine efficiency was raised up to ten times by using an optimized rendering mode. This performance boost enables the modelling of complex thermal behaviors on large models with more than 80 000 meshes.
Simulations with uncertainties on input parameters are made more flexible using advanced parametric analysis. Systema-Thermica provides advanced variables defined with inter- dependencies as well as user-defined GUI to set Python scripts parameters values on the fly.
Besides, a deep rework of cutters management enabled the definition of both finite and infinite cutting shapes including transformations. Users can choose between inside or outside cuttings. These features being Step-TAS-compatible, sharing the resulting geometry with other tools is straightforward.
Enhancements were also performed on various thermal analysis topics such as sensors modelling, infrared camera management and thermal convection, which helps analysists in providing their expertise over a wider set of thermal phenomena.
Finally, a detailed study on a large panel of Systema users, revealed some promising improvement opportunities in the Systema GUI ergonomics. Various improvements are scheduled to facilitate the training of novice users and increase the efficiency of experts.


Systema
DEFENCE AND SPACE
SYSTEMA-THERMICA
31th European Space Thermical Analysis Workshop
Antoine Caugant
Contributors: Timothée Soriano – Rose Nerrière
24-25th October 2017
AIRBUS


DEFENCE AND SPACE
Agenda
Systema
Overview
Thermal modelling
Model exchange
Large models management
Parametric analysis
2
25 October, 2017
AIRBUS

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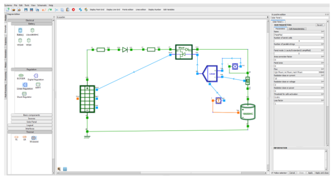
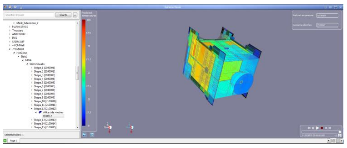
Overview

Systema

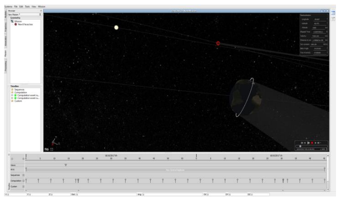
- Support on 3 available products:
  - Systema-Thermica Short Term Support (STS): **v4.8.0P1** (09/2017)
  - Systema-Thermica Long Term Support (LTS): **v4.5.3b** (08/2013)
  - Systema-DynaWorks (DySCo): **v1.0.0** (06/2017)
- Development of next versions:
  - Systema-DynaWorks (DySCo): **v1.1.0** (end of 2017)
  - Next Systema-Thermica STS version: **v4.8.2** (first quarter of 2018)



Systema-4.8.0P1



DySCo 3D-Viewer



Systema-4.5.3b

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Systema

Thermal modelling

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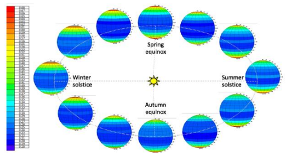
Thermal modelling (1/2) – « Real Detailed Earth Flux »

Systema

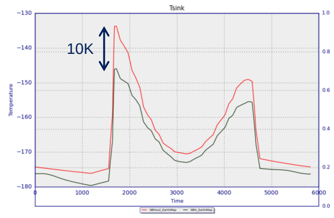
- For simple cases Earth albedo/IR flux can be modelled with constant values:
  - Albedo ~ 35%
  - Earth temperature ~ 264 K
- This modelling becomes problematic in the perspective of design margin reduction
- With Systema-4.5.3, it is possible to model planet albedo/IR with a cartography including:
  - latitude/longitude dependency
  - time dependency (one value per month)
  - editable ascii file with a simple structure (ex: earth.maps)
- A realistic model for Earth albedo/IR flux was put forward by R. Peyrou-Lauga (ESA)
  - using the CERES data
  - providing earth.maps file

→**Significant representativity improvement in temperature computation: up to 10 K difference between realistic and constant modelling on a low orbit satellite project**

earth.maps



Earth albedo realistic modelling based on CERES measurements [1]



Comparison of temperatures between constant albedo/IR and detailed modelling (low orbit satellite)

[1] Romain Peyrou-Lauga, Using real Earth Albedo and Earth IR Flux for Spacecraft Thermal Analysis, ESA, ESTEC, Noordwijk, The Netherlands, July 2017

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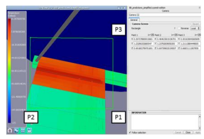
Thermal modelling (2/2) – Ongoing developments

Systema

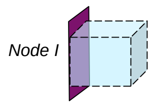
- **Infra-red camera module**: modelling of an IR camera for test facilities
  - A prototype was successfully integrated by users in the context of MITTE (see dedicated presentation)
- **Convection:** measuring thermal exchanges due to contact between a fluid and the model surfaces
  - Simplified thermal modelling (compared to CFD)
  - Coupling with radiation and conductive effects inside a unique model
  - Assisted creation of fluid cavities
  - Surface / Fluid nodes conducto-convective couplings (Mac Adams formulaes available for more accurate computations)
  - Possibility of stratification within fluid cavities
  - → Ongoing work of stabilization

→ **These modules will be included in the next release of Systema (4.8.2)**

- **Perspectives: prepare the next Long Term Support Version (LTS)**
  - Stabilize current functional thermal scope
  - Improve the User Manual coverage



IR Camera positionning



$GL(I,J) = k.S.\Delta T^{\alpha}$

Surface/Air conducto-convective coupling

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Systema

Model exchange

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Model exchange (1/3) - Context

Systema

- Thermal analysists need to share their data within a very complex ecosystems including:
  - Sub-contractors
  - Partners
  - Platform and instruments project teams
  - Mechanical design teams
  - …
- All stakeholders have resort to different methodologies and software tools adapted to their needs:
  - Expertise domain
  - Budget
  - Historical background
- Troubles are encountered to assemble data from every stakeholders

→ **Systema developments head toward a more efficient use of standardized data formats (ex: Step-TAS)**

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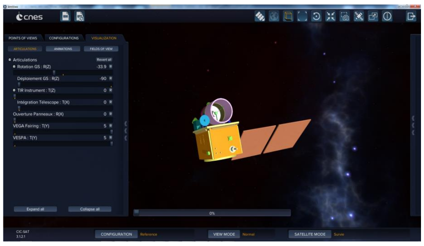
Model exchange (2/3) - IDM-CIC models

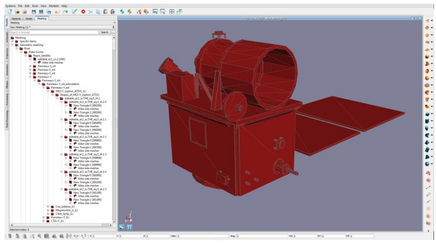
Systema

- IDM-CIC is a concurrent engineering tool developped by CNES to support satellite design phase during pre-phase A studies
- Several synergies with Systema were identified, sharing:
  – solar/planet flux and temperature data using MEM format
  – trajectories and kinematics using OEM/AEM formats
  – **GMM using the Step-TAS format (v6.0)**



Demo Earth observation satellite modelled with IDM-CIC in *.idm format and visualized in IDM-VIEW

Step-TAS



Same model opened in Systema and converted to *.sysmsh format for detailed analysis

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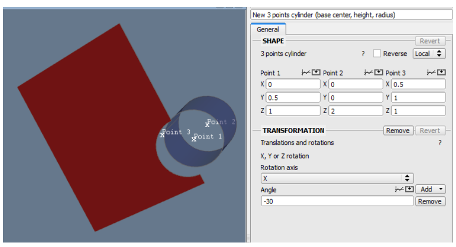
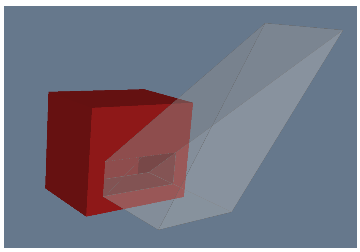
Model exchange (3/3) - Cutters improvements

Systema

- The 3D cutters algorithm is being reworked to improve Step-TAS functions coverage:
  – Cutters positionning using transformations (rotations, translations, etc)
  – Cutters definition with a finite length
  – Reversing cutting operation



Cylinder cutter positionned with transformation



Example of finite length cutter

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Large models management

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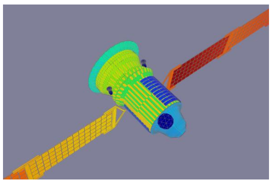
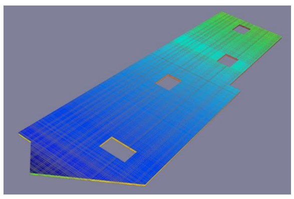
Large models management (1/2) - Context

- Thermal analysists tend to manipulate increasingly large geometries:
  - generated by other software (ex: CATIA, Gmsh, …)
  - modelling complex equipments with precise discretizations (ex: big wall with small condensers, heater and heat pipes)
- These models can be either:
  - simplified into more appropriate simulation models
  - used as such for direct computations
- This complexity is currently hard to handle with legacy software and hardware, especially while doing 3D rendering

→**Systema proposes a boosted 3D rendering algorithm to enable easy manipulations of large models**



Large demo satellite, Step file generated by Blender with one mesh per surface (~15 000 meshes)



Radiator Systema meshing, designed for small condensers/heaters (~67 000 meshes)

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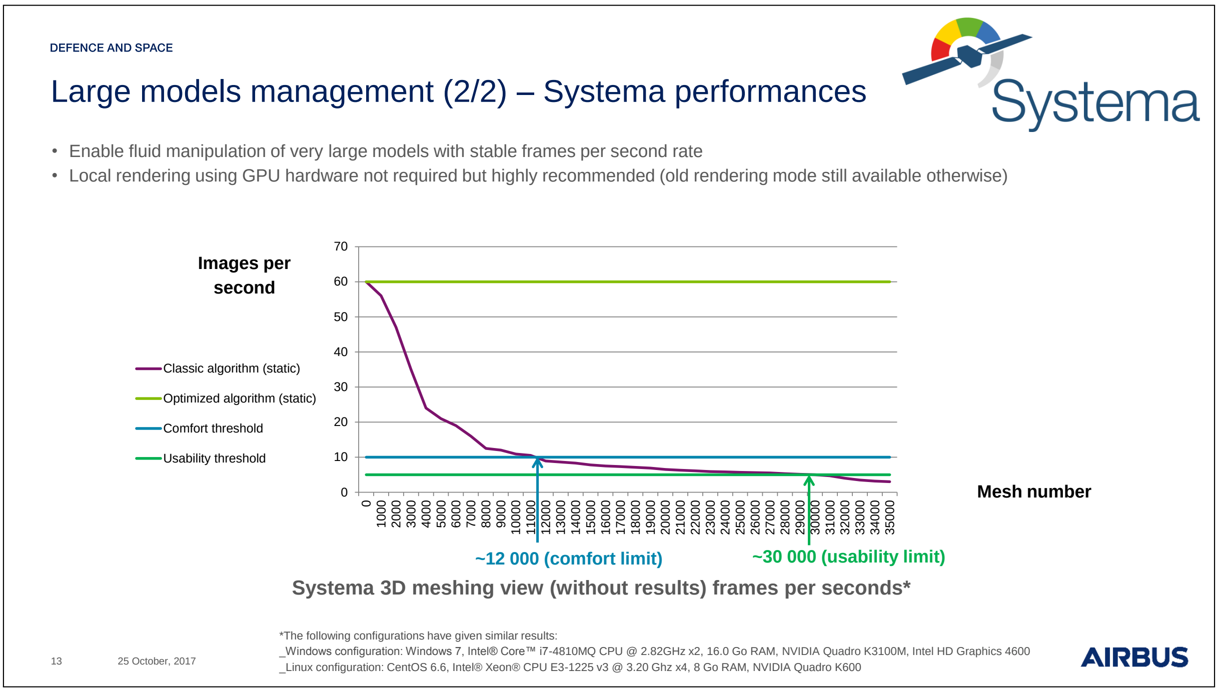
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Large models management (2/2) – Systema performances
Systema
• Enable fluid manipulation of very large models with stable frames per second rate
• Local rendering using GPU hardware not required but highly recommended (old rendering mode still available otherwise)
Images per second
Classic algorithm (static)
Optimized algorithm (static)
Comfort threshold
Usability threshold
70
60
50
40
30
20
10
0
0 1000 2000 3000 4000 5000 6000 7000 8000 9000 10000 11000 12000 13000 14000 15000 16000 17000 18000 19000 20000 21000 22000 23000 24000 25000 26000 27000 28000 29000 30000 31000 32000 33000 34000 35000
Mesh number
~12 000 (comfort limit)
~30 000 (usability limit)
Systema 3D meshing view (without results) frames per seconds*
*The following configurations have given similar results:
_Windows configuration: Windows 7, Intel® Core™ i7-4810MQ CPU @ 2.82GHz x2, 16.0 Go RAM, NVIDIA Quadro K3100M, Intel HD Graphics 4600
_Linux configuration: CentOS 6.6, Intel® Xeon® CPU E3-1225 v3 @ 3.20 Ghz x4, 8 Go RAM, NVIDIA Quadro K600
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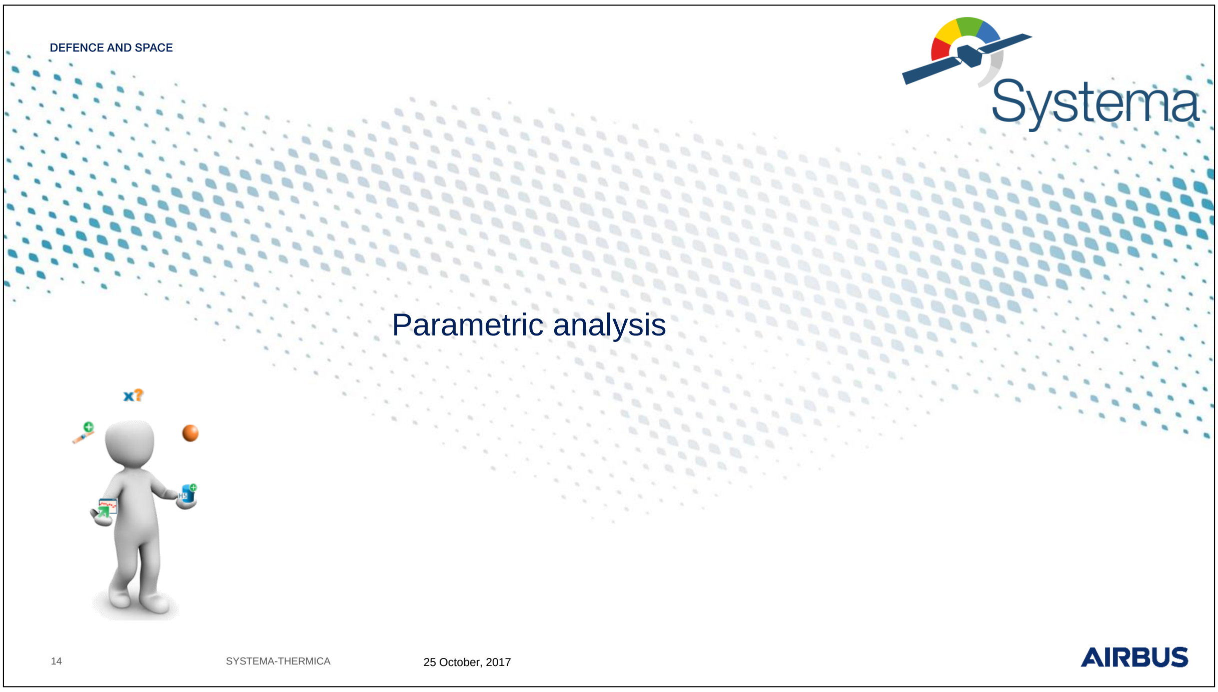
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Parametric analysis
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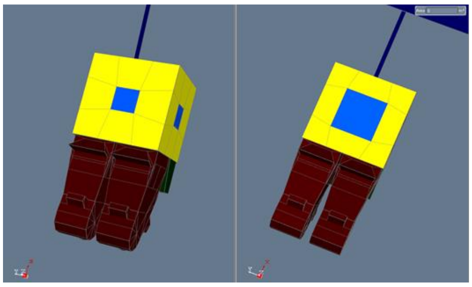
Parametric analysis (1/4) - Context

Systema

- Thermal analysts are constantly challenged to:
  - react more quickly to design/mission modifications
  - identify with certainty the critical thermal aspects of the mission (sensitivity analysis)
- It requires a flexible analysis toolchain that:
  - provides a high level of automation
  - accounts for a great number of input parameters
- Systema already addresses those topics of parametric analysis using:
  - Internal variables overloading + Batch run modes
  - Python scripting



Example of simple parametric model defined using Python

→ **These methods require an advanced mastery of the software (lack of simple solution)**

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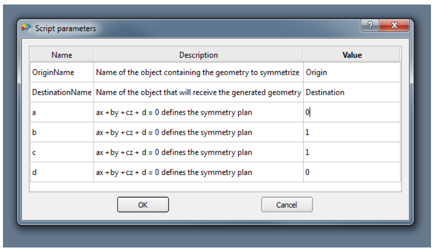
Parametric analysis (2/4) - Python script parameters

Systema

- Systema Python scripts enables input parameters definition through a GUI to:
  - Increase scripts genericity and reusability
  - Facilitate scripts exchanges
  - Help integrating Python script within user process
- Example: Definition of a symmetry plan for geometry construction
  1. Define input parameters inside the Python script
  2. Trigger window generation within the script
  3. User captures its parameters
  4. Run script with user parameters

1. Python script edition

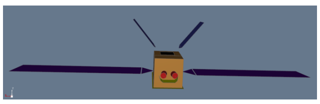


Script parameters

Name	Description	Value
OriginName	Name of the object containing the geometry to symmetrize	Origin
DestinationName	Name of the object that will receive the generated geometry	Destination
a	ax +by +cz + d = 0 defines the symmetry plan	0
b	ax +by +cz + d = 0 defines the symmetry plan	1
c	ax +by +cz + d = 0 defines the symmetry plan	1
d	ax +by +cz + d = 0 defines the symmetry plan	0

OK Cancel

2.3. GUI for symmetry Python script



4. Symmetrized model

Simple model to symmetrize

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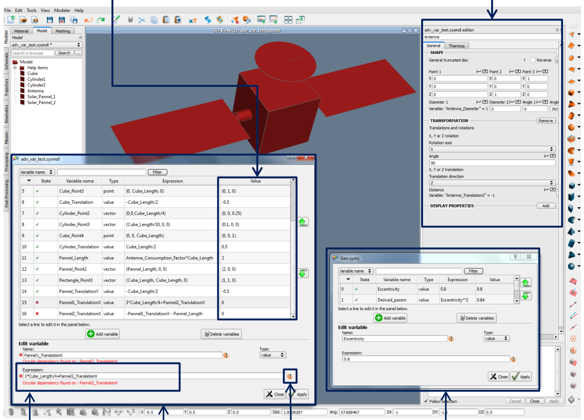
Parametric analysis (3/4) – Advanced variables

- **Principle:** Define Systema variables with inter-dependencies using a mathematical syntax
- Mathematical syntax including:
  - Scalar and vector types
  - Basic operations (+,-,*,/, **, ., ^, .x, etc)
  - Math functions (sqrt, norm, exp, log, cos, sin, …)

myScalar = norm(myVector) + sqrt(2) + log(exp(10)) - cos(x)

- Variables edition through a table window:
  - Display of several variables tables is enabled
  - Possibility to work with multi-windowing (non-blocking)
- Synthetic table view:
  - Including current variables values
  - Integrated access to documentation
  - Detection of syntax errors, circular dependencies, naming errors, etc



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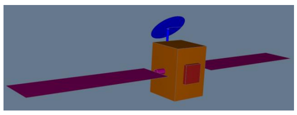
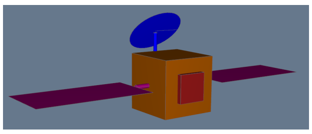
Parametric analysis (4/4) – Geometric example

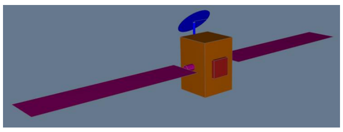
- Parametric definition of geometry with minimalist telecom satellite:
  - A main body (brown) with radiators (red)
  - An antenna (blue)
  - Two solar panels (purple)
- An arbitrary unitless antenna power factor (σ) influences each geometric parts with different sensitivities:
  - Solar panel length in σ^3
  - Main body height in σ^2
  - Main body length in 2 x σ
  - Antenna diameter in 2 x σ



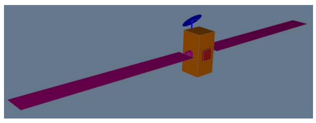
Minimalist telecom satellite



σ = 2



σ = 3



σ = 4

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Conclusion – Upcoming 4.8.2 version

Systema

- **New upcoming features:**
  Next Systema version will bring many improvements and new features such as:
  – Infra-red camera modelling possibilities
  – A new module dedicated to convection computations
  – Finite and reversed geometric cutters
  – A boosted 3D rendering algorithm
  – A flexible Python parameters GUI
  – An integrated user syntax for Systema variables
  – And a lot more…

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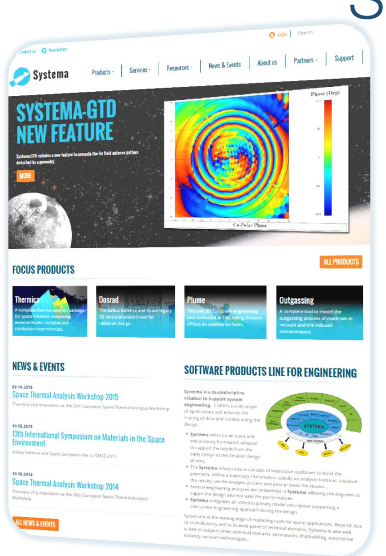
Keep in touch

Systema

- Visit our website: www.systema.airbusdefenceandspace.com



- Contact us by e-mail: engineering.software@airbus.com

- **Use our new hotline service: 05 31 96 80 00**

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...And see you at the coffee break!
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Appendix U

Model correlation of Meteosat Third Generation Platform STM

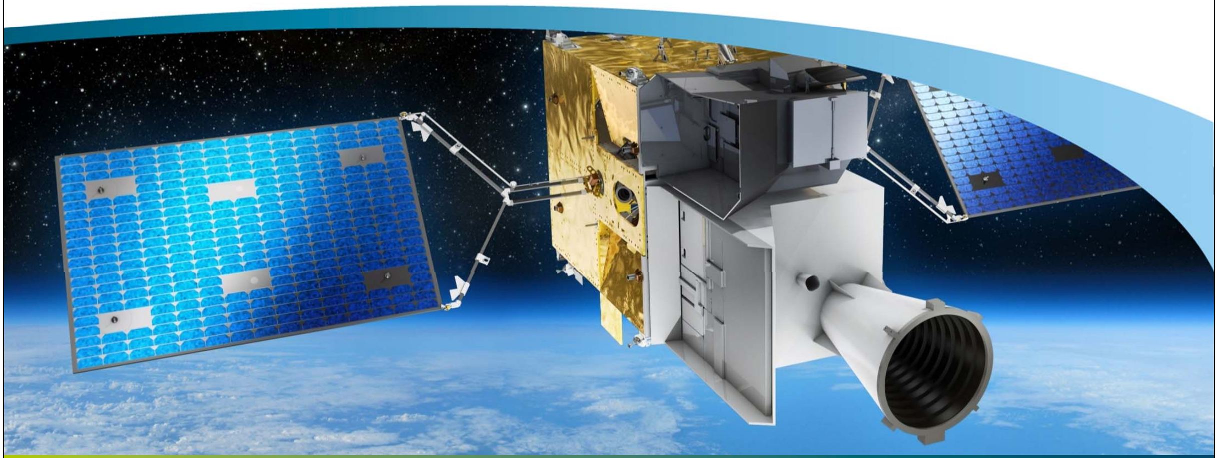
Emmanuelle Fluck
(OHB System AG, Germany)

Abstract

Meteosat Third Generation (MTG) is a series of meteorological satellites, which will take over the service provided currently by MSG. The series consist in 6 satellites: 4 Imagers (MTG-I) and 2 Sounders (MTG-S) having a common platform.

End of 2016, a Thermal Vacuum Test has been performed on a Structural Thermal Model (STM). The test's goal was on one hand to correlate the thermal model and on the other hand to qualify the structure. This presentation describes the process of model correlation from test ending until the results production. First, the thermal balance test is briefly introduced in order to set up the context and define the technical terms. The whole sequence starting with retrieving the data from the test, implementing these data into the thermal model using the ESATAN-TMS software and finally reducing the deviations between predicted and measured temperatures is presented. To illustrate the correlation process, explicit examples will be shown.

OHB System AG
Emmanuelle Fluck
24.10.2017, ESTEC



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MTG-STM Correlation

We. Create. Space.

MTG-STM correlation

Agenda

- Context: presentation of the STM thermal balance test
- Model overview
- Correlation phase:
  - Inputs management
  - TMM configuration
  - Status before correlation
  - Process description
  - Examples
  - Final status
- Conclusion:
  - Advantages of manual correlation
  - Suggestions of ESATAN tools or functions

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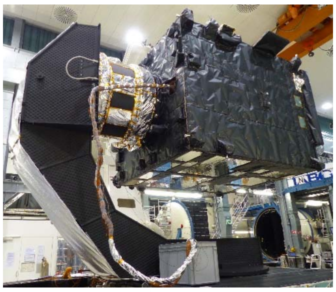
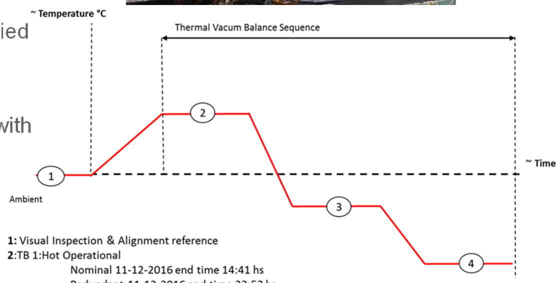
MTG-STM correlation

STM Thermal Balance test



- Objective: thermal model correlation and TCS verification
- 3 phases : hot balance, cold balance, safe mode balance
- STM configuration (platform only):
  - Full structure
  - Units: mechanical and thermal dummies (MTD) supplied with fixed current (EGSE)
  - 1 EM : reaction wheel
  - Heaters controlled in pulse width modulation (PWM) with EGSE
- IABG chamber
- 600 Thermocouples Type T
- Heater control thermistors NTC 15K
- Test heaters supplied with fixed current
- Use of shunt boxes on some power supplies for more accuracy



1: Visual Inspection & Alignment reference
2:TB 1:Hot Operational
Nominal 11-12-2016 end time 14:41 hs
Redundant 11-12-2016 end time 22:52 hs

3:TB 2:Cold Operational
Nominal 13-12-2016 end time 3:30 hs
Change of Set points 13-12-2016 end time 6:05

4:TB 3:Cold Non Operational (Safe balance)
Nominal 14-12-2016 end time 10:30 hs
Change of Set points and VAE HP 14-12-2016 end time 23:59 hs

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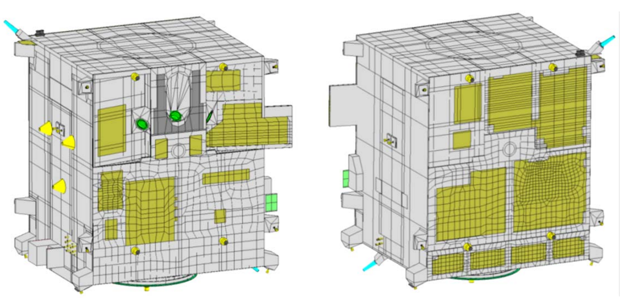
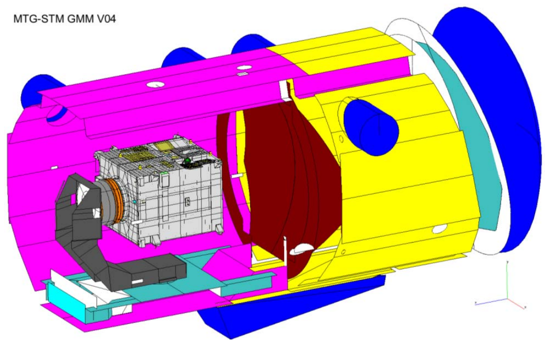
MTG-STM correlation

STM GMM overview

- Hybrid model MTG S/I
- Thermal Chamber model (provided by IABG)



STM



STM + chamber

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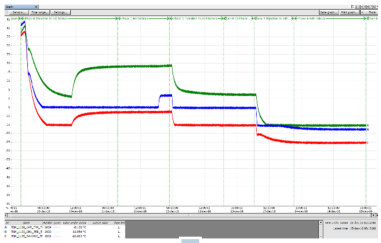
MTG-STM correlation

Correlation – Inputs management

- Test data to be processed for the correlation:
  - Temperatures for all TCs and thermistors
  - Input currents of the MTD: i_{MTD}
  - Input currents of the heaters: i_{heater}
  - Flight heater duty cycles in seconds (PWM): DC_{PWM}

  To convert into power
  - Measured resistances of MTD and heater circuits: R_{MTD} and R_{heater}
- Export of data at the end of **each balance phase**: the **average of the last 30 min** is calculated for each measurement above



Measurement data results for test 'MTG ' between 12-dec-16 19:30:00 and 13-dec-						
	TC_STR_1	TC_ACS_5	TC_EPS_4	TC_DHS_1	TC_EPS_3	TC_TTC_2
	#1	#2	#3	#4	#5	#6
Time	°C	°C	°C	°C	°C	°C
12.12.16 19:30	-0.75	12.89	13.38	8.93	8.99	4.72
12.12.16 19:31	-0.78	12.94	13.37	8.91	9.02	4.74
12.12.16 19:32	-0.78	12.93	13.39	8.9	9.02	4.73
12.12.16 19:33	-0.78	12.92	13.37	8.9	9.02	4.73
12.12.16 19:34	-0.82	12.98	13.37	8.83	9.06	4.74
12.12.16 19:35	-0.79	13	13.38	8.89	9.11	4.75
12.12.16 19:36	-0.87	12.89	13.44	8.85	8.97	4.89
12.12.16 19:37	-0.79	12.92	13.37	8.88	9.01	4.72
12.12.16 19:38	-0.78	12.83	13.41	8.91	8.93	4.77
12.12.16 19:39	-0.75	12.88	13.37	8.89	8.99	4.71
12.12.16 19:40	-0.79	12.84	13.42	8.89	8.94	4.8
12.12.16 19:41	-0.84	12.95	13.38	8.83	9.05	4.76
12.12.16 19:42	-0.81	12.92	13.36	8.87	8.99	4.72
12.12.16 19:43	-0.79	12.82	13.41	8.88	8.93	4.8
12.12.16 19:44	-0.82	12.83	13.44	8.87	8.9	4.8
12.12.16 19:45	-0.71	12.85	13.38	8.96	8.95	4.74
12.12.16 19:46	-0.88	12.93	13.36	8.82	9.01	4.74

Example of raw data as exported during test

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MTG-STM correlation

Correlation – Inputs management

- Temperature: not a model input, but used for results comparison (see post-processing)
- Dissipation, test and flight heater power need to be calculated from the data:
  - *Dissipation of MTD:* $D_{MTD} = R_{MTD} * i_{MTD}^2$
  - *Power of test heaters:* $P_{test\_heater} = R_{heater} * i_{heater}^2$
  - *Power of flight heaters:*
    - The standard duty cycle in % is obtained by dividing the PWM duty cycle by 10 (DC_{PWM} = number of seconds where the heater is on within 10s)
    - The "installed power" of the heater is obtained with the constant current in the circuit.
    - $P_{flight\_heater} = R_{heater} * i_{heater}^2 * (DC_{PWM} / 10)$

Data implemented as arrays in the TMM (extract)

```
##################################################################
#                        |  Power Max  |  Power Max  |  Power Min
#                        | HOT BALANCE | HOT BALANCE | COLD BALANCE
#                        |   (CASE 2)  | RED(CASE 2) |   (CASE 3)
##################################################################
#
#
A_QI_MTD_WDE_05(6)   =      6.34   ,     6.34    ,     5.78    ,
A_QI_MTD_RW_5(6)     =      7.07   ,     7.07    ,     4.30    ,
#
##################################################################
# AOCS MTD HEATER LINES
A_QI_MTD_STR_01(6)   =      4.87   ,     4.87    ,     4.35    ,
A_QI_MTD_STR_02(6)   =      6.85   ,     6.85    ,     6.22    ,
A_QI_MTD_STR_03(6)   =      6.42   ,     6.42    ,     5.82    ,
A_QI_MTD_GYR(6)      =      0.50   ,     0.50    ,     2.35    ,
A_QI_MTD_GYRE(6)     =     34.91   ,    34.91    ,    23.24    ,
A_QI_MTD_WDE_01(6)   =     12.69   ,    12.69    ,     6.38    ,
A_QI_MTD_WDE_02(6)   =     12.22   ,    12.21    ,     5.96    ,
A_QI_MTD_WDE_03(6)   =     12.84   ,    12.84    ,     6.37    ,
```

```
##################################################################
#                    |     Hot      |     Hot      |    Cold     |
#                    |   Balance    |   Balance    |   Balance   |
#                    |  Consum      |   Consum     |  Consum     |
#                    |  (case 2)    | RED (case 2) |  (case 3)   |
##################################################################
#
# AOCS HEATER
CONS_STR_01(6)    =      6.7,          6.8,          8.7,
CONS_STR_02(6)    =      6.7,          6.7,          8.6,
CONS_STR_03(6)    =      6.8,          6.8,          8.5,
CONS_STR_01_Bfle(6)=     2.9,          2.9,          2.9,
CONS_STR_02_Bfle(6)=     4.6,          4.7,          4.8,
CONS_STR_03_Bfle(6)=     3.6,          3.6,          3.8,
CONS_WDE_01(6)    =      0.0,          0.0,         11.8,
CONS_WDE_02(6)    =      0.0,          0.0,          0.0,
CONS_WDE_05(6)    =      0.0,          0.0,          5.8,
```

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MTG-STM correlation

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Correlation – TMM configuration

- Step 1: TMM with steady-state solver
  - Fixed dissipation and heater power for each case
  - Successive steady state runs

+ Fast (multiple iterations possible) and easier to manipulate

− Local heat balance wrong as long as correlation progress is low

```
# HOT BALANCE
      ISW_OUT = 0
      CALL SET_TMTA_HOT
      CALL SET_MTD_POW(1)      } Define and place
      CALL MTD_POW_PLACEM      } MTD dissipation
      CALL TCS_HTR_PF_CONS(1)  }
      CALL TCS_HTR_PL_CONS(1)  } Define and
      CALL TCS_HTR_PF_PLACEM   } place flight
      CALL TCS_HTR_PL_PLACEM   } heater power
      CALL TEST_HTR_CONS(1)    } Define and place
      CALL TEST_HTR_PLACEM     } test heater power
    CALL SOLVFM
```

Extract of the $execution block

- Step 2: TMM with transient solver
  - Fixed dissipation for MTDs
  - Temperature set points introduced for flight and test heaters: values as-run
  - Simulation duration: 40 hours per phase

+ Necessary to correlate the heater duty cycle

− Long to run

Extract of the $variables2 block

```
#====================================#
#    HOT BALANCE (CASE 2)            #
#====================================#
#
    IF(TIMEN.LT.136800.0)THEN
#
Define and place       { CALL SET_MTD_POW(1)
MTD dissipation        { CALL MTD_POW_PLACEM
Define flight          { CALL TCS_HTR_PF_SETP(1)
heater set points      { CALL TCS_HTR_PL_SETP(1)
activate heater        { CALL TCS_HTR_PF_ACTIV
and place power        { CALL TCS_HTR_PL_ACTIV
                       { CALL TCS_HTR_PF_PLACEM
                       { CALL TCS_HTR_PL_PLACEM
...same for test       { CALL TEST_HTR_SETP(1)
heaters                { CALL TEST_HTR_ACTIV
                       { CALL TEST_HTR_PLACEM
#
    ENDIF
```

MTG-STM correlation / 24.10.2017 Page 7 OHB System AG

MTG-STM correlation

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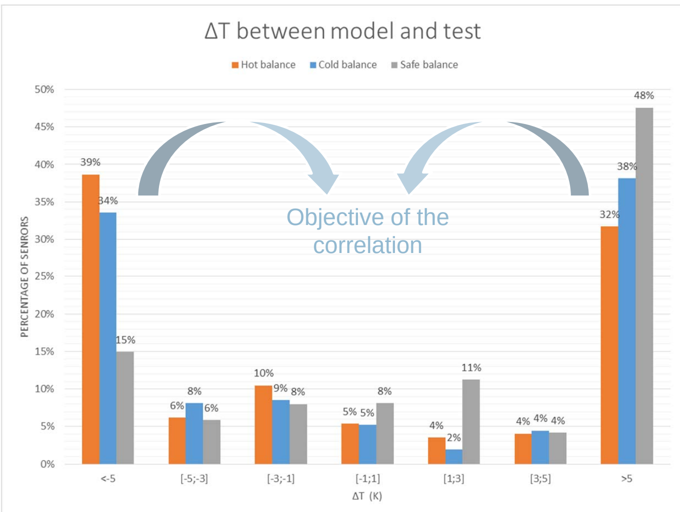
Correlation - Status before correlation

- Status before correlation on all sensors:
  - Deviation between sensor measurement and associated node temperature is calculated
  - Deviations sorted by ranges
  - ~40% of nodes within 5°C deviation

- Agreed success criteria:
- **Temperature:** 100% of TRPs ΔT to test results shall be lower than 5K.
- **Heater lines duty cycle:**
  - For each line, duty cycle deviation to test results shall be within 20%.
  - The overall power consumption deviation to test shall be within 10%.



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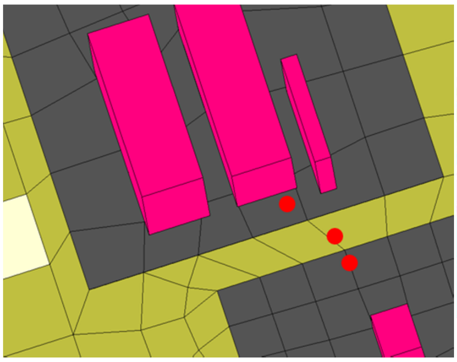
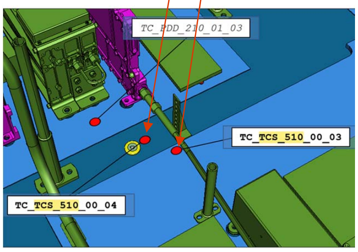
MTG-STM correlation

Correlation process

- Post-processing strategy
  - Compare temperatures between test and model
  - Compare duty cycles between test and model (for transient runs)
- Correspondence Sensors (thermistors/thermocouples) and nodes: linear interpolation

	Interpolation parameters						Mod_hot_bal			
Sensor	Node1	weigh	Node2	weigh	Node3	weigh	T_1	T_2	T_3	Averag
TC_TCS_510_00_03	C_DOU_TWT:81227110	1	C_DOU_TWT:81227124	1	0	0	7.0789	6.7252	0	6.90205
TC_TCS_510_00_04	C_PF_PY_RAD:71217178	1	C_PF_PY_RAD:71217146	1	0	0	-3.7253	-3.5697	0	-3.6475
TC_TCS_510_00_05	C_PF_PY_RAD:71227004	1	C_PF_PY_RAD:71217227	0	0	0	2.3093	-1.3524	0	2.3093
TC_TCS_520_00_01	S_DOU_GYRE:83817131	2	S_DOU_GYRE:83817126	1	0	0	20.0725	26.0898	0	22.0783





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MTG-STM correlation

Correlation process

- Correlation process: **from the most global to the most local**
  - Correlate the OSR emissivity to reach a correct average T on radiators
    - Emissivity variation from 0.8 to 0.89
    - Typical correlated value around **0.83**
  - Correlate MLI performance
    - Effective emissivity defined by a temperature dependent array
    - Eff. Emissivity multiplied by a **performance factor** for each blanket
    - Correlated performance factor for external MLI: 1.25
  - Panels in plane/out of plane conductivity (aluminum and CFRP): low sensitivity of the model
  - Adjust the unit conductive I/F
  - Local correlation issues implying remodeling

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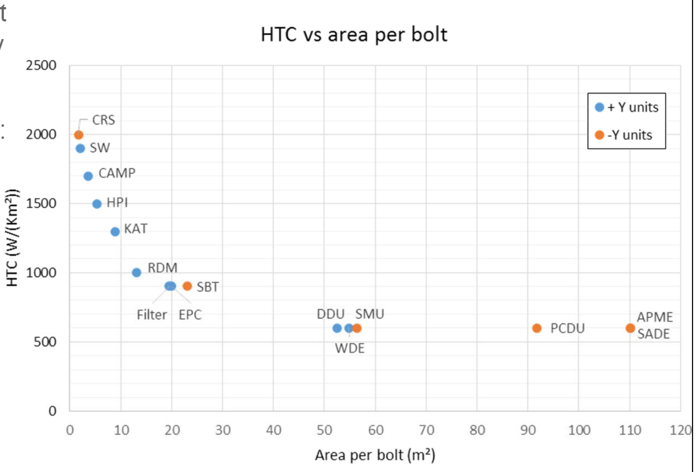
MTG-STM correlation

OHB

Correlation example 1: Standard unit conductive I/F

- I/F conductance is modelled via a heat transfer coefficient (HTC) multiplied by footprint area
- First approximation at correlation start:

  HTC = dissipation / (ΔT * area)
- HTC adjusted to take into account distance between the sensors
- Compromise between:
  - Deviations test/model
  - Reality (hardware): area, bolts, interfiller,…



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MTG-STM correlation

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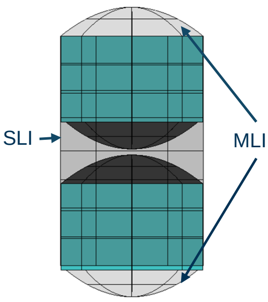
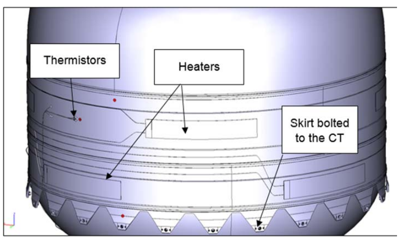
Correlation example 2: Propellant tanks

- Observations right after test:
- Heater power consumption higher than predicted by the model
- Impact in steady state analysis: calculated temperatures much higher than in test
- Deduction: tanks are too isolated in the model
- 2 major contributors to the coupling between tanks and platform:
- SLI on the internal side of the central tube
- I/F conductive conductors





LOAD DATA	S/S	Hot balance T /°C			Cold balance T /°C			Safe balance T /°C		
		Mod_hot_bal			Mod_cold_bal			Mod_safe_bal		
Unit		Test	Mod	Delt	Test	Mod	Delt	Test	Mod	Delt
CT - Tanks			#N/A			#N/A			#N/A	
MMH bottom	UPS	20.01	29.27	9.26	14.83	25.99	11.17	9.69	23.04	13.35
MMH center	UPS	19.15	34.13	14.98	14.19	30.14	15.96	8.91	28.89	19.98
MMH tank	UPS	19.57	31.89	12.32	13.94	27.77	13.83	9.34	25.87	16.53
MMH tank bottom	UPS	20.50	29.27	8.77	15.25	25.99	10.75	10.24	23.04	12.80
MMH tank center	UPS	19.38	34.13	14.75	14.44	30.14	15.70	9.10	28.89	19.79
MMH top	UPS	20.02	31.89	11.87	14.94	27.77	12.83	9.87	25.87	15.99
MON bottom	UPS	20.52	29.58	9.06	14.91	27.95	13.04	9.53	23.77	14.24
MON center	UPS	19.55	28.88	9.33	14.09	26.01	11.92	8.17	20.22	12.04
MON tank	UPS	19.73	28.71	8.98	14.39	25.68	11.28	9.13	22.56	13.43
MON tank bottom	UPS	20.63	29.58	8.95	15.19	27.95	12.76	9.83	23.77	13.94
MON tank center	UPS	19.44	#N/A	#N/A	14.12	#N/A	#N/A	8.49	#N/A	#N/A
MON tank center	UPS	19.63	28.88	9.25	14.13	26.01	11.88	8.14	20.22	12.07
MON top	UPS	20.19	28.71	8.52	14.85	25.68	10.82	9.60	22.56	12.96

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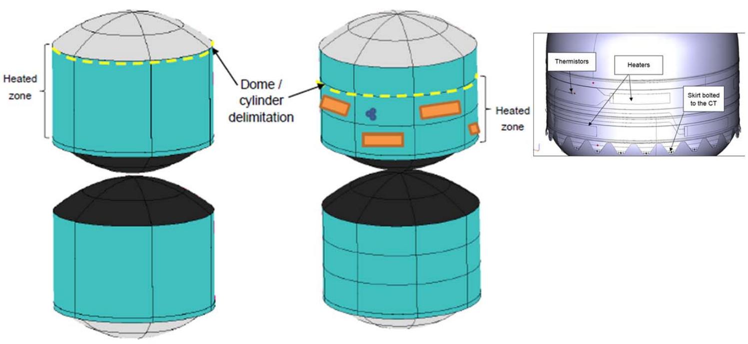
MTG-STM correlation

OHB

Correlation example 2: Propellant tanks (2)

- Necessity to remesh the tanks to have more accurate results
- I/F conductive conductance increased by a factor 5
- SLI emissivity (VDA coating) increased from 0.05 to 0.1 => **significant impact**



LOAD DATA	S/S	Hot balance T /°C			Hot balance red T /°C			Cold balance T /°C			Safe balance T /°C		
		Mod_hot_bal			Mod_hot_bal_r			Mod_cold_bal			Mod_safe_bal		
Unit		Tes	Mod	Delt	Tes	Mod	Delt	Tes	Mod	Delt	Tes	Mod	Delt
CT - Tanks			#N/A			#N/A			#N/A			#N/A	
MMH top	UPS	20.02	19.26	-0.76	20.01	18.34	-1.68	14.94	14.28	-0.66	9.87	9.49	-0.39
MMH tank top	UPS	19.57	19.08	-0.48	19.48	18.23	-1.25	13.94	14.57	0.64	9.34	9.40	0.06
MMH tank top	UPS	19.61	19.08	-0.52	19.54	18.23	-1.32	14.45	14.57	0.12	9.38	9.40	0.02
MMH tank top	UPS	19.46	19.59	0.14	19.42	18.84	-0.59	14.27	15.36	1.09	9.09	10.20	1.11
MMH tank top	UPS	19.93	20.07	0.14	19.89	19.01	-0.88	14.69	14.73	0.04	9.61	9.74	0.13
MMH tank top	UPS	19.70	20.07	0.37	19.69	19.01	-0.68	14.50	14.73	0.23	9.45	9.74	0.29
MMH tank top	UPS	20.62	20.98	0.36	20.54	19.87	-0.67	15.43	15.27	-0.15	10.65	10.41	-0.25
MMH center	UPS	19.15	20.15	1.00	19.16	19.37	0.21	14.19	15.61	1.43	8.91	11.09	2.18
MMH tank center	UPS	19.38	22.20	2.82	19.40	21.58	2.18	14.44	18.28	3.84	9.10	13.40	4.30
MMH tank center	UPS	18.56	19.88	1.32	18.61	19.19	0.58	13.57	15.77	2.20	8.18	10.71	2.53
MMH tank center	UPS	11.61	8.72	-2.89	11.65	8.33	-3.32	7.77	5.42	-2.36	-1.35	-5.18	-3.83
MMH tank center	UPS	21.74	22.97	1.23	21.67	21.85	0.18	16.21	17.07	0.86	12.23	12.27	0.04
MMH tank center	UPS	18.98	17.46	-1.52	19.03	16.56	-2.48	12.31	10.20	-2.11	6.19	1.50	-4.69
MMH bottom	UPS	20.01	23.52	3.51	20.03	22.64	2.61	14.83	17.64	2.81	9.69	11.81	2.12
MMH tank bottom	UPS	20.50	17.84	-2.66	20.48	17.27	-3.22	15.25	13.88	-1.37	10.24	7.86	-2.38
MMH tank bottom	UPS	19.95	17.36	-2.59	20.01	16.82	-3.20	14.75	13.83	-0.92	9.40	7.47	-1.94
MMH tank bottom	UPS	20.04	17.12	-2.91	20.04	16.57	-3.47	14.90	13.59	-1.32	9.72	7.20	-2.51
MMH tank bottom	UPS	21.05	19.11	-1.93	21.05	18.49	-2.56	15.48	14.72	-0.76	10.49	8.91	-1.57
MMH tank bottom	UPS	20.87	18.22	-2.66	20.85	17.63	-3.22	15.49	14.16	-1.34	10.55	8.13	-2.43
MMH tank bottom	UPS	20.59	18.22	-2.37	20.64	17.63	-3.01	15.31	14.16	-1.16	10.26	8.13	-2.13
MON top	UPS	20.19	17.39	-2.80	20.20	16.83	-3.37	14.85	13.63	-1.22	9.60	7.60	-1.99
MON tank top	UPS	19.73	17.06	-2.67	19.73	16.51	-3.22	14.39	13.49	-0.90	9.13	7.30	-1.83
MON tank top	UPS	19.61	17.06	-2.55	19.56	16.51	-3.05	14.33	13.49	-0.84	8.99	7.30	-1.69
MON tank top	UPS	#N/A	16.92	#N/A	#N/A	16.38	#N/A	#N/A	13.38	#N/A	#N/A	6.92	#N/A
MON tank top	UPS	#N/A	18.22	#N/A	#N/A	17.63	#N/A	#N/A	14.22	#N/A	#N/A	8.14	#N/A
MON tank top	UPS	20.28	18.22	-2.06	20.35	17.63	-2.72	14.80	14.22	-0.58	9.80	8.14	-1.67
MON tank top	UPS	20.15	18.63	-1.53	20.23	18.06	-2.17	14.35	14.44	0.09	9.00	8.20	-0.81
MON center	UPS	19.55	16.92	-2.62	19.57	16.38	-3.19	14.09	13.38	-0.71	8.17	6.92	-1.25
MON tank center	UPS	19.63	19.24	-0.39	19.66	18.91	-0.75	14.13	16.11	1.98	8.14	7.94	-0.21
MON tank center	UPS	19.15	17.41	-1.74	19.16	16.99	-2.17	13.58	14.06	0.48	7.46	6.18	-1.28
MON tank center	UPS	13.83	12.34	-1.49	13.95	12.19	-1.76	6.55	4.89	-1.66	-1.43	-3.41	-1.97
MON tank center	UPS	21.98	21.53	-0.45	21.91	21.07	-0.84	15.99	16.43	0.44	10.41	9.37	-1.04
MON tank center	UPS	22.17	20.52	-1.65	22.20	20.21	-1.99	12.13	10.26	-1.87	5.47	2.76	-2.71
MON bottom	UPS	20.52	23.86	3.34	20.53	23.52	2.99	14.91	17.68	2.77	9.53	10.24	0.71
MON tank bottom	UPS	20.63	21.97	1.34	20.65	21.66	1.01	15.19	21.05	5.87	9.83	15.70	5.87
MON tank bottom	UPS	20.23	20.67	0.44	20.23	20.40	0.17	14.79	18.67	3.88	9.09	11.96	2.86
MON tank bottom	UPS	20.20	20.73	0.53	20.19	20.45	0.25	14.96	20.35	5.40	9.39	14.69	5.30
MON tank bottom	UPS	21.05	20.73	-0.32	21.08	20.45	-0.63	15.67	20.35	4.68	10.27	14.69	4.42
MON tank bottom	UPS	21.16	24.31	3.14	21.16	23.98	2.82	15.44	20.94	5.50	9.97	14.82	4.85
MON tank bottom	UPS	21.19	22.64	1.44	21.24	22.32	1.09	15.80	21.55	5.75	10.49	16.19	5.71

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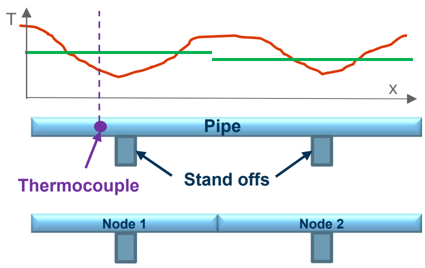
MTG-STM correlation

OHB

Correlation example 3 : Pipework

- Not sufficient correlation at the start
- Observations:
- Higher heater consumption in test than in model (steady state temperature higher)
- Most TCs placed close to stand-offs, while model contains large nodes which are not representative of the local temperature
- Model not detailed enough for good correlation

LOAD DATA	Sensor	Hot balance T /°C			Cold balance T /°C			Safe balance T /°C		
		Mod_hot_bal			Mod_cold_bal			Mod_safe_bal		
Unit		Te	Mo	De	Te	Mo	De	Te	Mo	De
Piping			#N/A			#N/A			#N/A	
piping heaterline 1	TSM_1089_PLINES_TRP_TEMP_A1	23.59	52.38	28.79	18.56	47.41	28.85	13.51	41.13	27.62
	TC_UPS_000_01_01	47.58	46.40	-1.18	47.85	43.35	-4.50	45.88	36.04	-9.84
	TC_UPS_000_01_02	19.31	40.28	20.98	17.26	37.89	20.63	11.90	30.77	18.87
	TC_UPS_000_02_01	34.02	47.97	13.95	31.98	44.18	12.20	27.84	36.97	9.13
	TC_UPS_000_03_01	33.14	58.17	25.03	28.57	53.43	24.86	24.76	47.70	22.95
	TC_UPS_000_03_02	26.76	46.50	19.74	21.14	40.38	19.24	16.93	33.62	16.69
	TC_UPS_000_04_01	#N/A	52.89	#N/A	#N/A	47.72	#N/A	#N/A	41.26	#N/A
	TC_UPS_000_05_01	#N/A	57.05	#N/A	#N/A	52.79	#N/A	#N/A	46.88	#N/A
	TC_UPS_000_05_02	25.73	47.09	21.36	20.65	42.71	22.06	14.69	36.06	21.37
	TC_UPS_000_06_01	35.15	45.88	10.73	33.12	44.15	11.03	29.84	39.66	9.82
	TC_UPS_000_06_02	27.42	44.03	16.61	24.07	41.57	17.49	19.73	36.46	16.73
	TC_UPS_000_25_01	34.22	47.93	13.71	32.96	42.98	10.02	28.38	35.16	6.78
	TC_UPS_000_25_02	37.22	52.15	14.93	35.65	48.55	12.91	32.10	41.85	9.76
	TC_UPS_000_25_03	23.44	54.04	30.59	19.35	51.07	31.72	14.48	46.93	32.45
piping heaterline 2	TSM_1090_PLINES_TRP_TEMP_A2	21.10	52.14	31.03	16.06	48.66	32.60	10.75	50.40	39.65
	TC_UPS_000_11_01	15.40	39.70	24.30	18.63	41.05	22.43	13.37	38.73	25.36
	TC_UPS_000_12_01	26.15	49.53	23.38	25.30	47.55	22.25	24.57	49.34	24.77
	TC_UPS_000_12_02	30.65	45.07	14.41	33.11	44.78	11.67	36.50	44.96	8.46
	TC_UPS_000_13_01	21.77	44.40	22.63	16.01	40.16	24.15	10.84	38.89	28.05
	TC_UPS_000_14_01	35.41	63.16	27.75	32.14	60.23	28.09	35.19	65.82	30.63
	TC_UPS_000_15_01	28.41	50.21	21.80	26.05	47.88	21.83	25.15	49.19	24.04
	TC_UPS_000_16_01	31.51	54.56	23.05	28.81	55.26	26.45	25.79	55.67	29.88
	TC_UPS_000_16_02	31.89	55.54	23.65	27.65	51.57	23.92	26.57	53.55	26.98
	TC_UPS_000_17_01	26.21	36.18	9.97	26.20	36.38	10.18	27.03	34.85	7.82
	TC_UPS_000_17_02	11.34	30.79	19.45	8.92	30.16	21.24	3.06	29.52	26.46
	TC_UPS_000_18_01	25.75	40.44	14.70	20.86	38.62	17.76	19.88	38.19	18.31
piping heaterline 3	TSM_1091_PLINES_TRP_TEMP_A3	24.46	43.78	19.32	18.75	60.50	41.76	13.77	55.41	41.63
	TC_UPS_000_07_01	30.06	34.23	4.17	30.27	33.29	3.02	25.78	26.56	0.78
	TC_UPS_000_07_02	10.81	26.91	16.10	9.49	25.94	16.45	0.51	21.66	21.15
	TC_UPS_000_08_01	22.40	38.00	15.60	15.70	33.73	18.03	10.43	28.96	18.53
	TC_UPS_000_09_01	29.96	40.57	10.61	26.19	40.46	14.27	22.45	35.58	13.12
	TC_UPS_000_09_02	23.78	33.99	10.21	19.22	30.08	10.86	14.19	24.79	10.60
piping heaterline 4	TSM_1101_PLINES_TRP_TEMP_A5	23.01	37.20	14.19	17.79	34.82	17.03	12.73	29.77	17.04
	TC_UPS_000_19_01	30.36	45.16	14.79	27.25	47.26	20.01	25.05	45.38	20.33
	TC_UPS_000_27_01	10.70	12.46	1.76	2.22	4.78	2.56	-5.77	-4.36	1.41
	TC_UPS_000_27_02	10.61	14.98	4.37	1.99	8.06	6.07	-8.15	-0.13	8.02
piping heaterline 5	TSM_1102_PLINES_TRP_TEMP_A6	23.32	40.97	17.65	18.08	39.77	21.69	12.93	36.68	23.75
	TC_UPS_000_20_01	34.69	49.34	14.65	55.10	73.03	17.92	47.35	65.25	17.91
	TC_UPS_000_20_02	28.98	47.17	18.19	38.15	65.61	27.46	32.09	59.07	26.97
	TC_UPS_000_21_01	24.69	43.96	19.26	40.95	70.00	29.05	33.02	62.54	29.53
	TC_UPS_000_21_02	27.54	35.69	8.15	44.46	51.22	6.77	37.03	43.76	6.73
	TC_UPS_000_22_01	22.03	41.67	19.64	27.76	65.13	37.37	20.52	57.43	36.91
	TC_UPS_000_22_02	29.23	40.91	11.68	42.75	59.11	16.36	35.91	52.38	16.47
	TC_UPS_000_23_01	25.61	43.65	18.04	31.90	63.94	32.04	25.38	57.84	32.46
	TC_UPS_000_28_01	10.94	11.81	0.87	2.84	4.80	1.96	-5.77	-4.05	1.72
	TC_UPS_000_28_02	12.00	19.10	7.11	2.84	11.94	9.10	-5.71	4.42	10.13
	TC_UPS_000_29_AA	24.49	47.14	22.65	18.89	68.55	49.66	13.77	62.93	49.16
	TC_UPS_000_29_01	24.97	44.64	19.67	22.06	62.79	40.73	16.94	57.28	40.34
	TC_UPS_000_30_01	28.92	44.95	16.03	31.62	62.94	31.32	26.17	57.38	31.21
	TC_UPS_000_30_02	26.30	45.38	19.07	21.49	62.82	41.33	16.55	57.67	41.11



Real temperature: low close to standoff, high between 2 standoffs

Calculated temperature by model: averaged value on each node

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MTG-STM correlation

Correlation example 3 : Pipework (2)

- To decrease the general temperature level (in steady state analysis), radiative leaks have to be increased by correlating the **chofoil properties**.
- The final correlated values are:
- Radiative area increased by 50%. This is justified by integration reasons: overlapping chofoil layers, inclusion of the propulsion tubing heater, wrinkles
- Piping longitudinal conductivity increased assuming 2 layers of chofoil instead of 1 (+60%)

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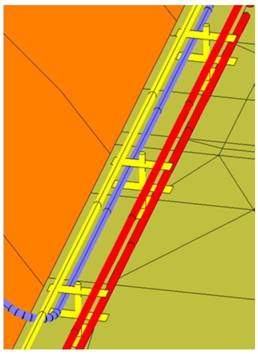
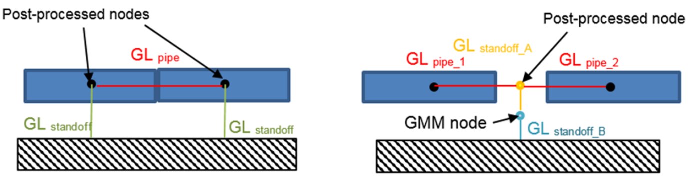
MTG-STM correlation

Correlation example 3 : Pipework (3)

- Model improvement:
- Stand off modelling (GMM and TMM)
- Split of large nodes into 2 types of nodes: nodes close to standoff (cold spot) and nodes between 2 standoffs (hot spot)

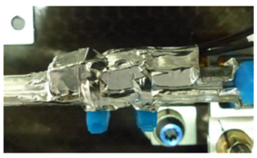


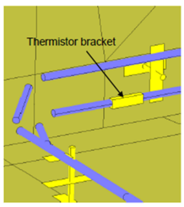
GMM of stand off



Before After

- Modelling of thermistor bracket including chofoil wrapping





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MTG-STM correlation

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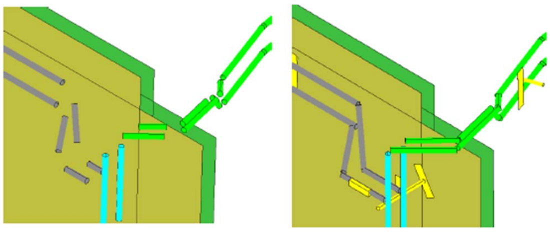
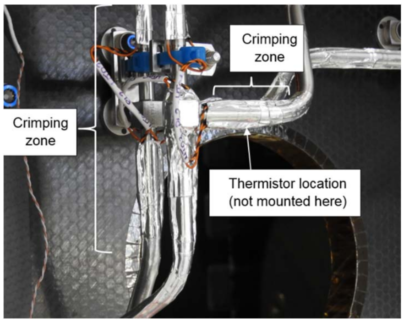
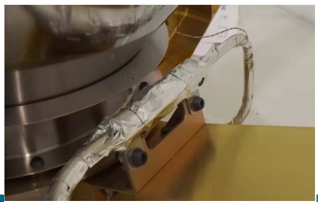
Correlation example 3 : Pipework (4)

- Local correlation on specific areas
- Areas close to thermistors have to be correlated carefully (impact on heater power consumption for a large bunch of pipe sections)
- Crimping zones: locally no heating (on STM only, this is reviewed for PFM as an outcome of the test)
- LAE bracket:
  - Adjustement conductive coupling
  - Consideration of chofoil wrapping







MTG-STM correlation / 24.10.2017 Page 17 OHB System AG

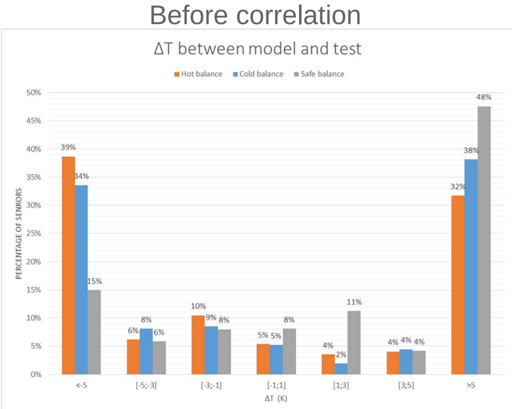
MTG-STM correlation

OHB

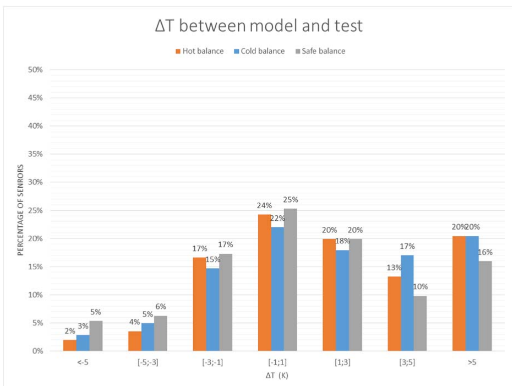
Correlation – Final status

- Status of the temperature deviations after correlation in **Steady State**:

Before correlation



After correlation



- High deviations (> 5K) are due to the fixed heater power (steady state)
- TRPs are correlated well, while graphs include the 600 TCs

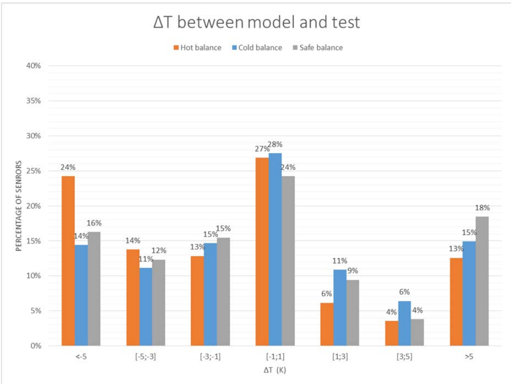
MTG-STM correlation / 24.10.2017 Page 18 OHB System AG

MTG-STM correlation

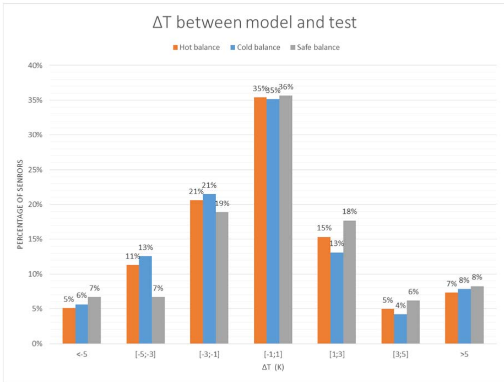
Correlation – Final status

- Status of temperature deviations after correlation in **Transient**:

Before correlation



After correlation



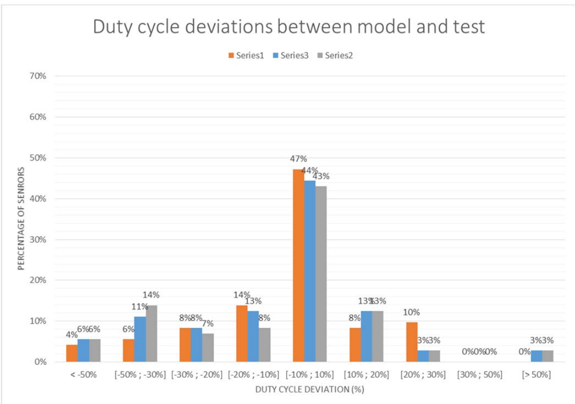
- TRPs are correlated well, while graphs include the 600 TCs

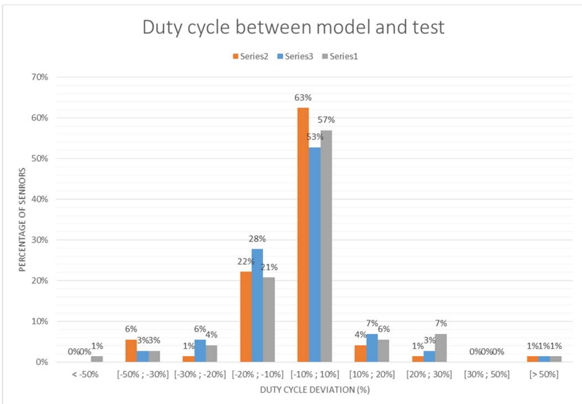
MTG-STM correlation / 24.10.2017 Page 19 OHB System AG

MTG-STM correlation

Correlation – Final status

- Status of duty cycles deviations after correlation in **Transient**:





MTG-STM correlation / 24.10.2017 Page 20 OHB System AG

MTG-STM correlation

Lessons learnt

- Test LL:
  - Instrumentation: piping, panels outer side, doubler I/F, panels
  - Online Data verification: deviation between shunt boxes and power supply raw data
- Correlation LL:
  - Underestimation of some parameters: Star tracker conductivity, Tanks I/F conductivity, piping model
  - Sensitivity analysis is impacted by correlation: tanks were not sensitive to platform parameter variation before correlation ; this changed after improvement of the model
- Design LL implemented on Flight Models
  - Crimping points of the propulsion tubing heater to be reviewed
  - Design changes needed for mission critical issues (tanks heaters)
  - Heat pipe start-up heaters to be implemented

MTG-STM correlation / 24.10.2017 Page 21 OHB System AG

MTG-STM correlation

Conclusion

- Manual correlation quite heavy, but “hands-on” work allows:
  - Consolidating the knowledge of sensitivity to various parameters
  - Keeping parameters within control and understanding (realistic approach of the values’ adjustment, investigation on hardware, etc.)
  - Identification of design improvements and reviewing the model in deep details
- Suggestions for ESATAN functions or improvement to help correlation:
  - Interpolation tool with sensor coordinates as an input
  - Visualization of the sensors temperatures and deltas to model predictions on the GMM (by creating a TMD from test data)

MTG-STM correlation / 24.10.2017 Page 22 OHB System AG

Appendix V

Development of a Modularized and Scalable Thermal Model for Small Satellites

Alexander Zwiebler Oliver Kluge Claudius Birkefeld Dr. Tino Schmiel
Prof. Dr. Martin Tajmar
(Dresden University of Technology, Germany)

Abstract

Thermal analysis of pico- and nano satellites is a underestimated field, judged from our own experience and feedback from other small satellite developers around the world. Sophisticated thermal engineering during all project phases is a difficult task and is often only done late in phases C and D.
Therefore it is our goal to provide small satellite developers with a modular and scalable thermal model that will simplify building new models step by step with quick and reliable results.
We did research on various small satellite design schemes and came up with a preliminary modularized thermal model, which is using building blocks (e.g. for PCBs and structure). These modules can have various levels of detail, so you can start thermal analysing from the beginning. The model is written in MatLab, using ESATAN- syntax and is scalable from 1U to 4U CubeSat size.
First results of our interim model prove that a modularized and scalable thermal model works in principle. The development is still ongoing. We will add more levels of detail to our modules to cover various design approaches for an assembly. Currently we are evaluating costs and licensing concepts of different commercial thermal modelling solutions to use at university. The evaluation of our modelling approach by thermal- vacuum test is also still open. The results of our concept will be presented and the restrictions and doubts will be discussed.

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Faculty of Mechanical Science and Engineering, Institute of Aerospace Engineering, Chair of Space Systems

Development of a Modularized and Scalable Thermal Model for Small Satellites

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Noordwijk, 25.10.2017

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Institute of Aerospace Engineering

Director: Prof. Dr. Martin Tajmar

Aircraft Engineering
Prof. Dr. Klaus Wolf

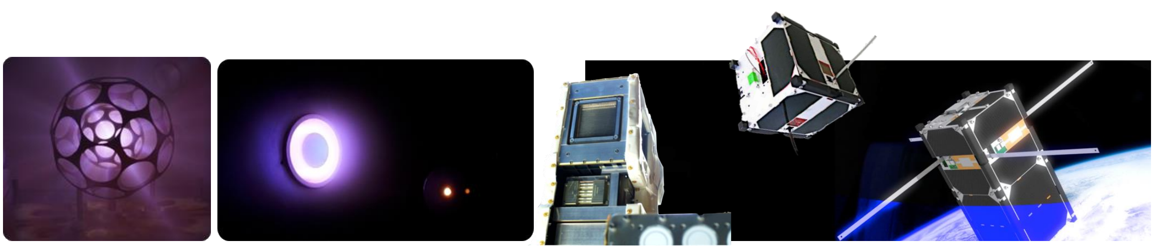
Space Systems
Prof. Dr. Martin Tajmar

Research Groups

Space Propulsion & Future Concepts
(Prof. Dr. Martin Tajmar)

Small Satellites & Spin-off Technologies
(Dr.-Ing. Tino Schmiel)

Space Power Systems & Mobile Applications
(Dr.-Ing. Tino Schmiel)



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Outline

- Our Aim
- Small Satellites – Thermal Simulaton
  – Construction Types
- Our Approach
- Software Architecture
- GUI
- Further Development

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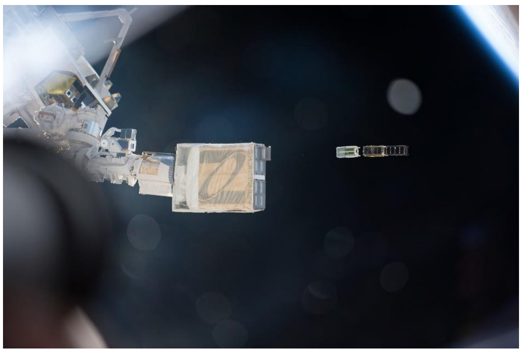
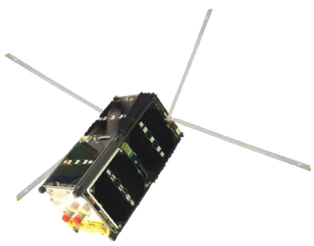
Small Satellites – Our Aim

- Small Satellites / Cubesats
  - Broad user base
  - Underestimated field
  - Mostly university
  - Willing to share data
  - We‘ve build our own
  - Sophisticated thermal engineering only done late in phases C and D
- Our Aim
  - Providing small satellite developers
  - **Modular** and **scalable** thermal model
  - Simplify building of "small" thermal models
  - Play around with different configurations → students
- Survey
  - Selection of 50 (flown) Cubesats up to 3U
  - Contacted 30 (so far)
  - Feedback → map



1st airlock cycle , May 16-17, 2017 © NASA



SOMP-2

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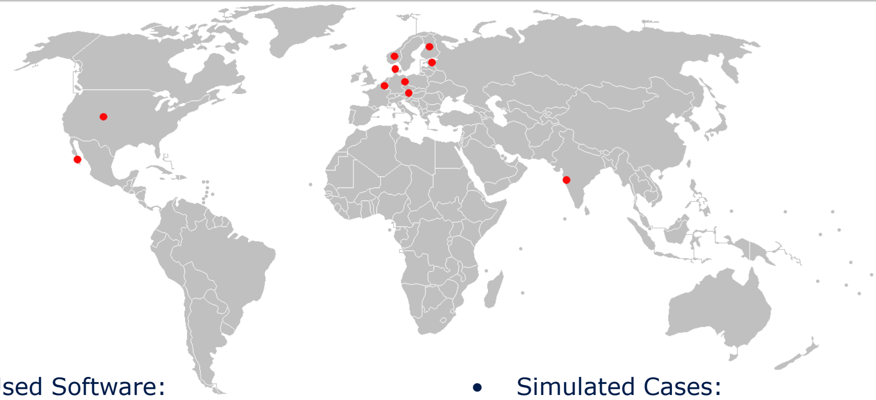
Small Satellites – Thermal Simulation I



- Used Software:
  - ESATAN
  - Thermal Desktop
  - Siemens NX TMG
  - ANSYS WB (only stationary)
  - Excel
- Simulated Cases:
  - Hot / cold case
  - Stationary / transient
- Simulated Geometries:
  - Structure (Shell)
  - Solar panels (Shell)
  - PCBs (Shells)
  - Battery (Solids)
  - Payload (if present) (Solids)

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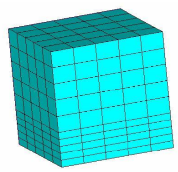
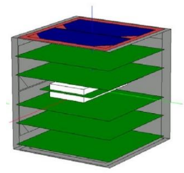
Small Satellites – Thermal Simulation II

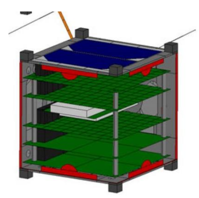
- Discretization of geometries
  - Coarse gird with refinements at connections of the assemblies
  - 300 nodes on average
  - Detailed geometry less important for simulation results
  - Major importance: boundaries and heat transfer
- Material properties: mostly Database values,
  seldom experimental verification
- Boundaries:
  - Heatloads manually derived from electronics efficiency for: PCB, battery
  - Heaters: partially implemented, only cyclical operation
  - Seldom heatloads from solar cells used (BOL-, EOL- efficiency)
  - Thermal conductance (GL) manually calculated for Frame-(Side)Panel; Frame-Card Cage; inter-PCB, PCB-Battery



First step (Compass-1)



Second step (OUFTI-1)



Last step (OUFTI-1)

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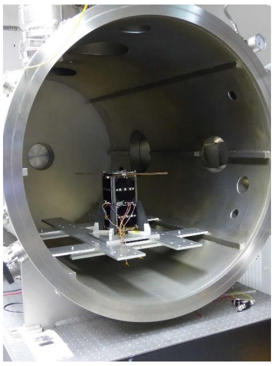
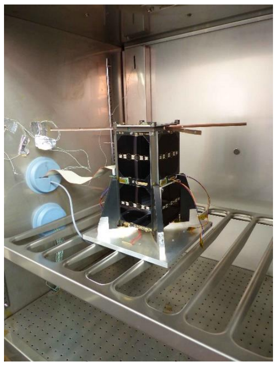
Small Satellites – Thermal Simulation III

- Post processing
  - Mostly via GUI of the simulation software
  - Seldom via Matlab/Excel (temperature-, heatflux-plots)
- Correlation of models
  - No correlation (lack of test facilities)
  - Experiments to determine chosen GLs
  - Via TBAL and TVAC





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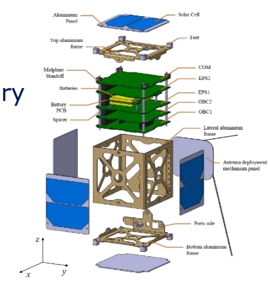
Small Satellites – Construction Types

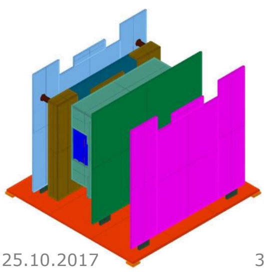
General findings:

- Design of the Frame → cube lattice
- Main building blocks: Frame, Side Panels, PCBs and Battery
- Panels attached to structure via screws
- Solar cells glued to panels
- **Main differences** in the structure of the card cage
- Arrangement and connections of PCBs and batteries
- In general 3 types of card cages:
  - Spacer
  - Motherboard
  - Direct structure contact



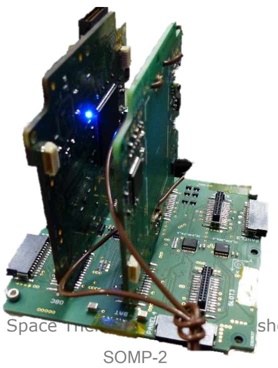
© : OUFTI-1, University of Liege

Spacer-Type



© : Compass-1, FH Aachen

Motherboard-Type



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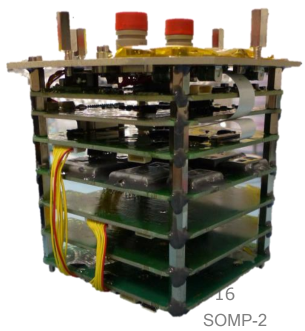

SOMP-2

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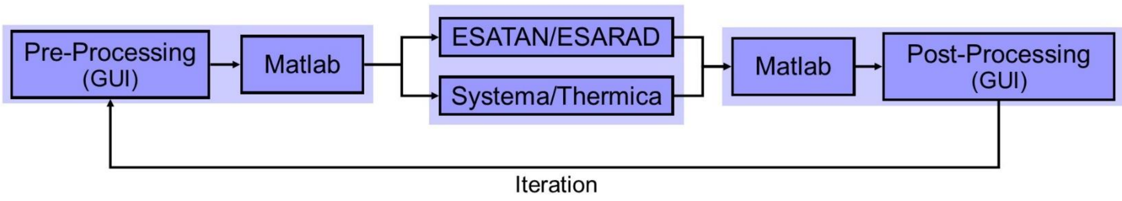
Our Approch

- Preprocessing: Model generation in Matlab
- Slover: ESATAN/ Systema
- Postprocessing: Matlab and ESATAN/ Systema

- Model generation in Matlab via GUI
- Building blocks for frame, solar panel, card cage and battery
- Scalable form 1 to 4U Cubesat-size
- Modell-files generated in ESATAN/ Systema-Syntax
- → Models can be refined manually with advancing project



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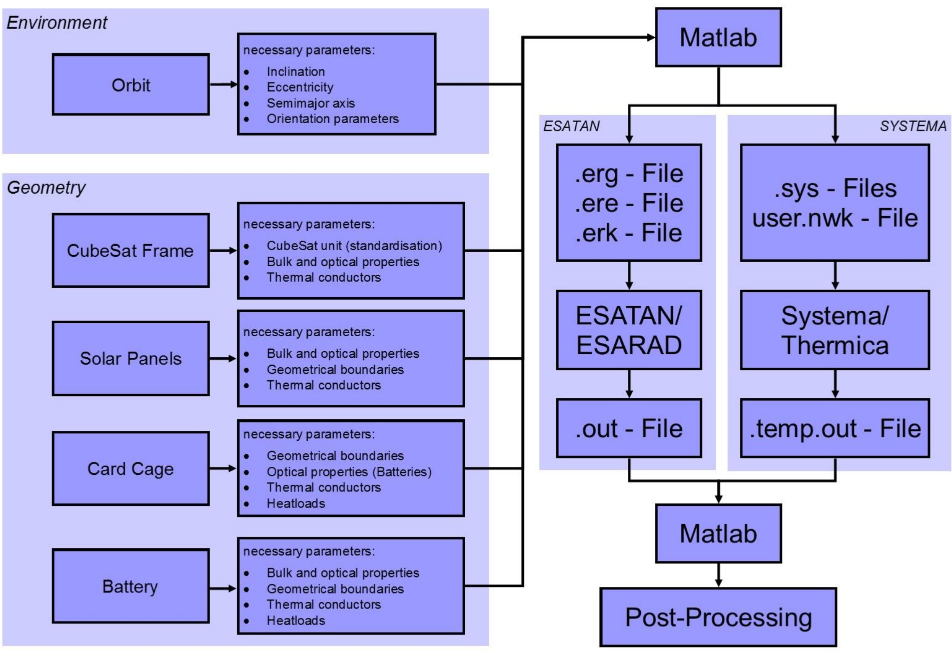
Software architecture



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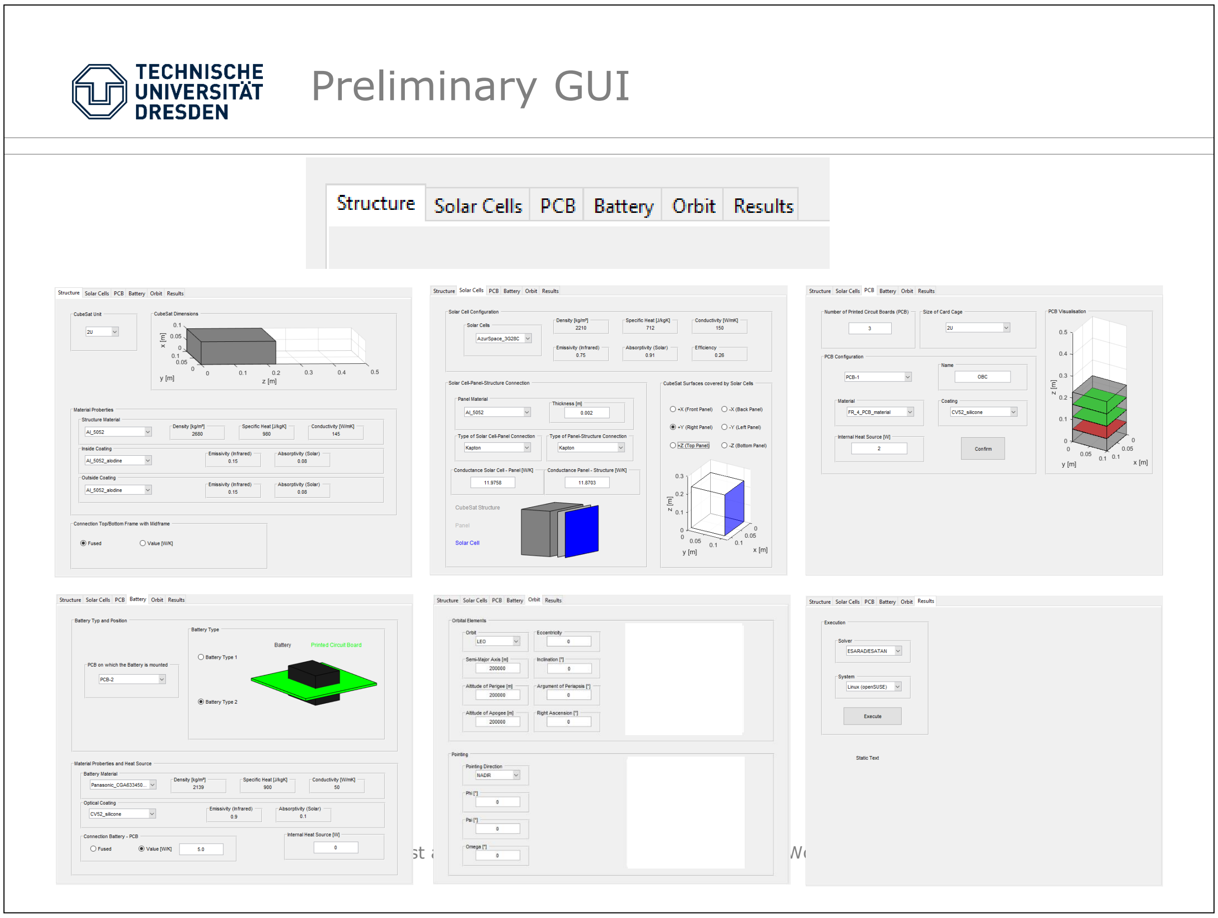
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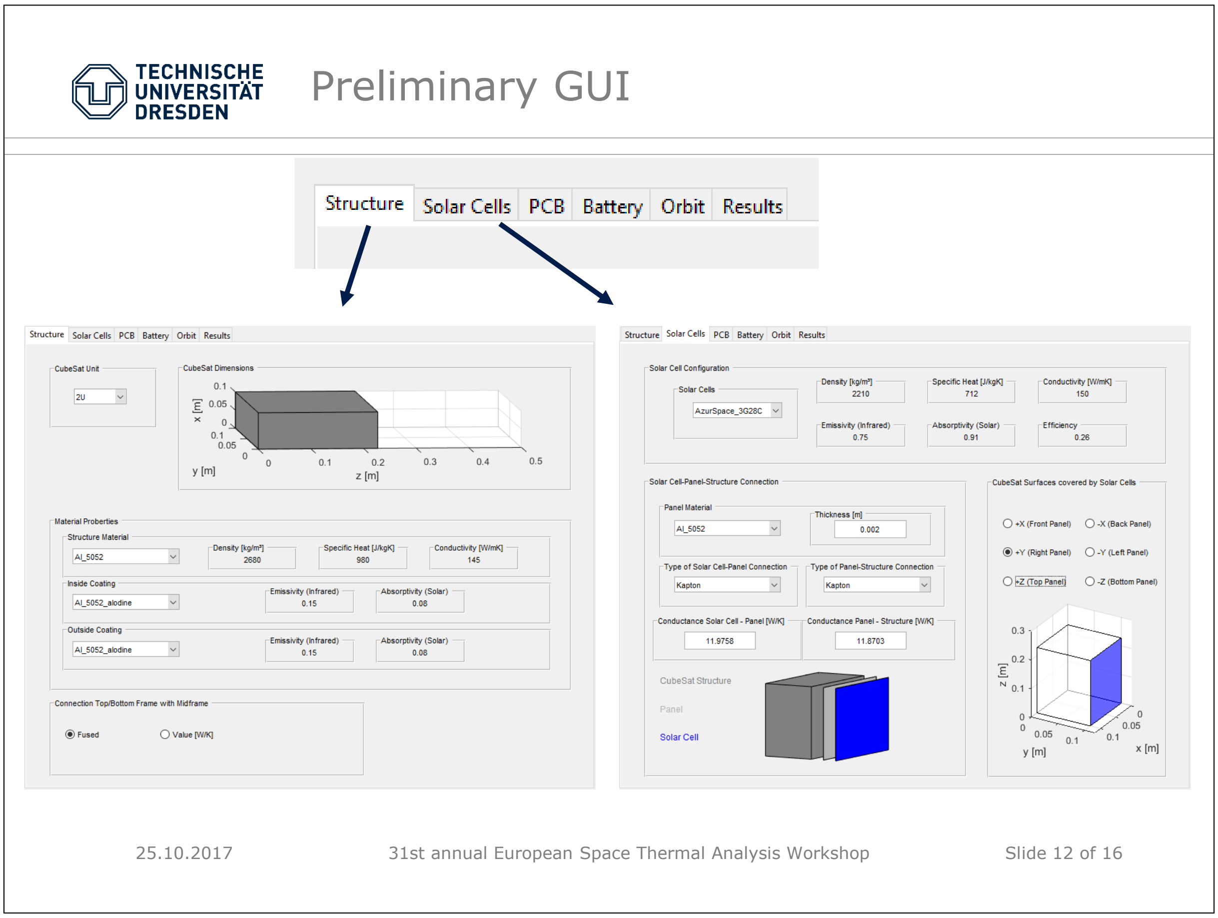
Preliminary GUI
Structure
Solar Cells
PCB
Battery
Orbit
Results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Preliminary GUI
Structure
Solar Cells
PCB
Battery
Orbit
Results
CubeSat Unit
2U
CubeSat Dimensions
Material Properties
Structure Material
AL_5052
Density [kg/m³]
2680
Specific Heat [J/kgK]
980
Conductivity [W/mK]
145
Inside Coating
AL_5052_alodine
Emissivity (Infrared)
0.15
Absorptivity (Solar)
0.08
Outside Coating
AL_5052_alodine
Emissivity (Infrared)
0.15
Absorptivity (Solar)
0.08
Connection Top/Bottom Frame with Midframe
Fused
Value [W/K]
Solar Cell Configuration
Solar Cells
AzurSpace_3G28C
Density [kg/m³]
2210
Specific Heat [J/kgK]
712
Conductivity [W/mK]
150
Emissivity (Infrared)
0.75
Absorptivity (Solar)
0.91
Efficiency
0.26
Solar Cell-Panel-Structure Connection
Panel Material
AL_5052
Thickness [m]
0.002
Type of Solar Cell-Panel Connection
Kapton
Type of Panel-Structure Connection
Kapton
Conductance Solar Cell - Panel [W/K]
11.9758
Conductance Panel - Structure [W/K]
11.8703
CubeSat Structure
Panel
Solar Cell
CubeSat Surfaces covered by Solar Cells
+X (Front Panel)
-X (Back Panel)
+Y (Right Panel)
-Y (Left Panel)
+Z (Top Panel)
-Z (Bottom Panel)
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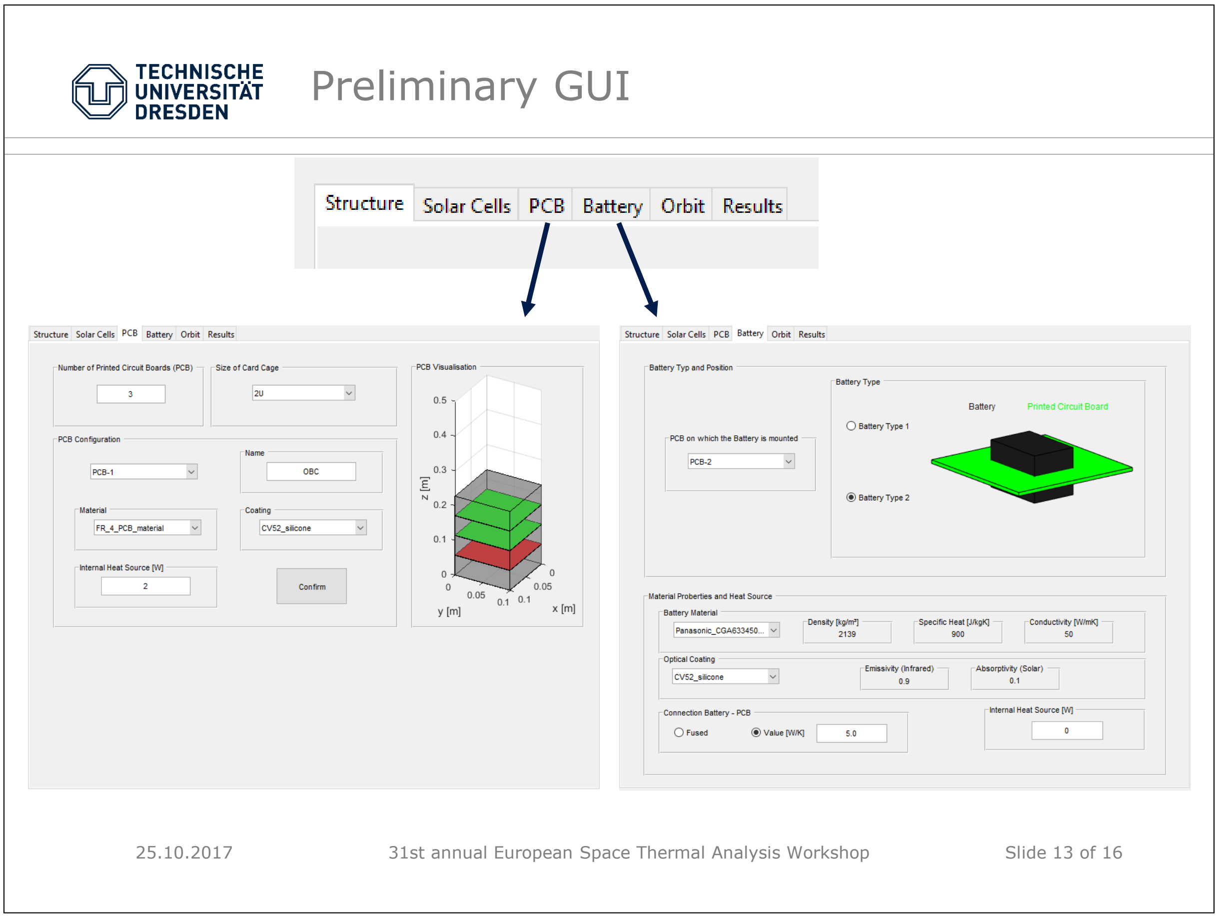
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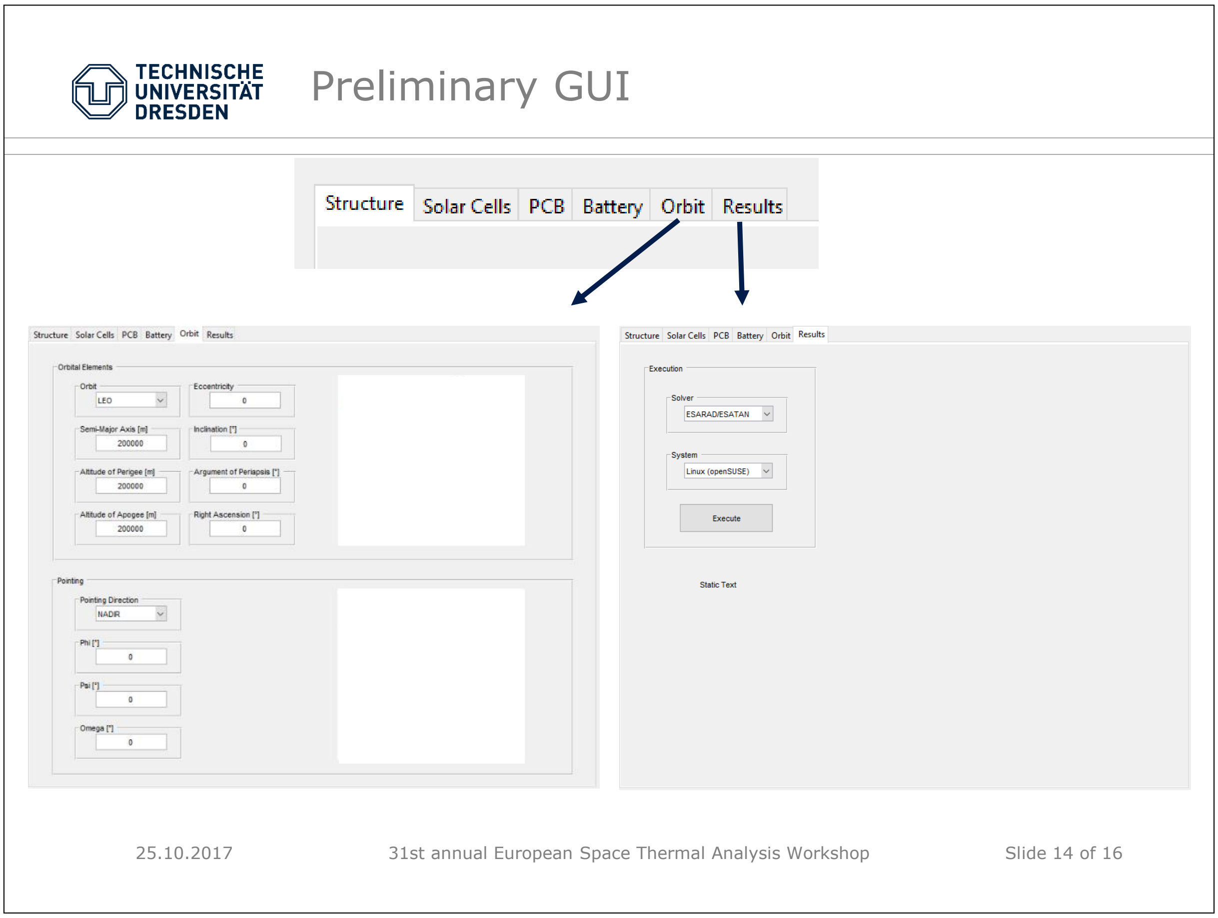
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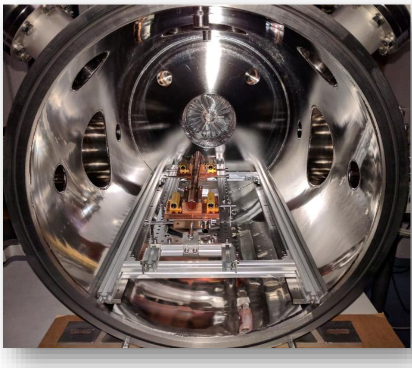
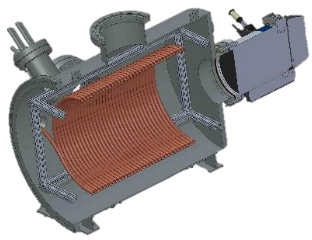
Further Development

- Currently adapting code to Systema
- Implementing further design varieties to the existing building blocks
- Redesigning GUI
- Expand postprocessing in Matlab
- Turn „playing around" with configurations to sensitivity analysis
- Experimental determination of GLs in our own TV-chamber





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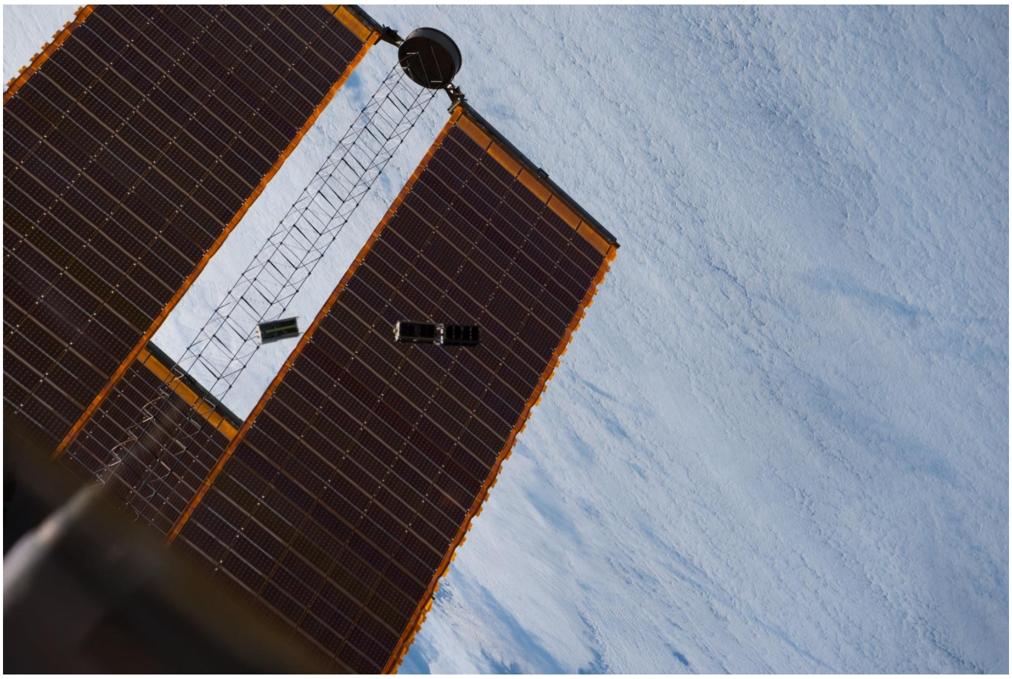
Thanks for your patience



1st airlock cycle , May 16-17, 2017 © NASA

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Faculty of Mechanical Science and Engineering, Institute of Aerospace Engineering, Chair of Space Systems

Development of a Modularized and Scalable Thermal Model for Small Satellites

Alexander Zwiebler *), Oliver Kluge, C. Birkefeld, T. Schmiel, Martin Tajmar

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Noordwijk, 25.10.2017

TECHNISCHE UNIVERSITÄT DRESDEN

Abstract

Development of a Modularized and Scalable Thermal Model for Small Satellites

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alexander.zwiebler@tu-dresden.de; oliver.kluge@tu-dresden.de

Thermal analysis of pico- and nano satellites is a underestimated field, judged from our own experience and feedback from other small satellite developers around the world. Sophisticated thermal engineering during all project phases is a difficult task and is often only done late in phases C and D.

Therefore it is our goal to provide small satellite developers with a modular and scalable thermal model that will simplify building new models step by step with quick and reliable results.

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Appendix W

DySCo
improvement of thermal vacuum test monitoring and exploitation in real time

Guillaume Pelissier
(Airbus Toulouse, France)

Abstract

Airbus Defence and Space develops DySCo, an application for satellite thermal vacuum test monitoring and exploitation in real time, which brings together within the same environment measurement data acquisition, data display on the numerical model, comparison to simulation and model updating.
DySCo, acronym for "DynaWorks - Systema Collaboration", is based on two software packages dedicated to test and simulation domains. The first one is an integrated solution for test data storage and analysis; the second one quantifies the interactions between a satellite and its environment.
The goal of this collaboration is to improve satellite thermal vacuum test process by displaying real time temperatures and powers on the satellite 3D model, extrapolating test results on non-instrumented nodes and comparing test to simulation.


DySCo
DEFENCE AND SPACE
DySCo
31th European Space Thermal Analysis Workshop
Presenter: G. Pélissier
Contributors: H. Dussurget, A. Caugant, G. Capblancq, T. Soriano, D. Cayrol-Midan, R. Nerrière
25/10/2017
AIRBUS


DEFENCE AND SPACE
Table of content
1. Context and objectives
2. DySCo functionalities
3. Upcoming versions
4. Conclusion
2
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31th European Space Thermal Analysis Workshop
DySCo
AIRBUS

DEFENCE AND SPACE

Context and objectives

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DySCo AIRBUS

DEFENCE AND SPACE

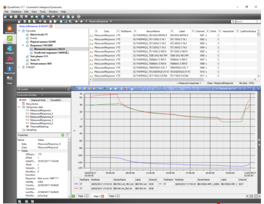
Context and objectives

Context:

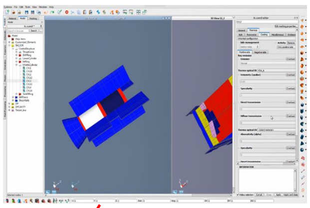
- Satellite thermal testing is time and money consuming
- High number of thermocouples and telemetries
- No global view of the satellite during the test
- Lack of information on areas without sensors
- No direct link between test and simulation

Objectives of DySCo project:

- DySCo: **Dyn**aWorks – **S**ystema **Co**llaboration
- Common database and environment for test and simulation results
- Real time* display of measured temperatures on satellite 3D model
- Comparison to simulation → enhancement of model updating
- Extrapolation to non-instrumented nodes
- Integration of MITTE project methods (IR camera, temporal extrapolation, etc.)

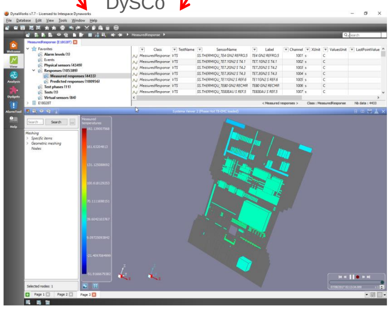


DynaWorks



Systema

DySCo



(*) Real time : the temperatures are updated at each acquisition time step

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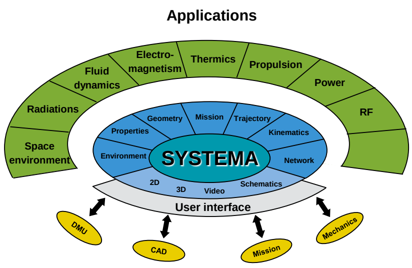
DySCo AIRBUS

DEFENCE AND SPACE

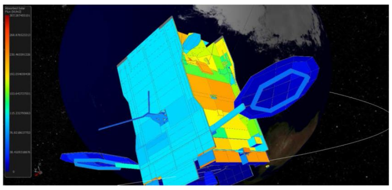
Context and objectives

Systema, in a few words:

- Systema is a **multidiscipline** solution to support space systems engineering offering a wide scope of applications and ensuring the sharing of data and models along the design
- Enables the **prediction of interactions** between the satellite and the mission environment
- The **Thermica** suite provides a complete package to perform thermal design using Thermisol solver



Systema overview



Systema-Thermica solar fluxes

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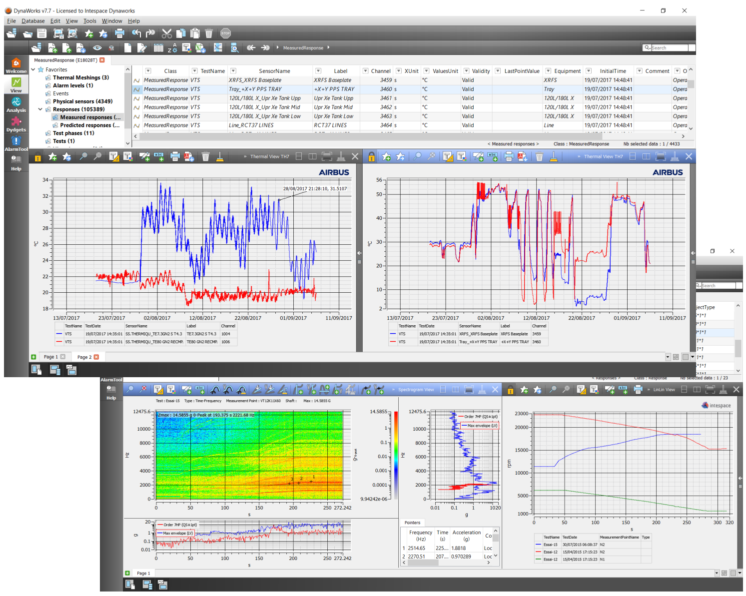
DySCo AIRBUS

DEFENCE AND SPACE

Context and objectives

DynaWorks, in a few words:

- An **integrated** solution for **data** storage, management, visualization, analysis and reporting
- Compliant with **mixed** data formats (meta-data, time series, frequency responses, pictures, documents) from multiple sources
- **Open solution** to provide a platform to host all the corporate application (API Python, user functions, scripts, plug-ins)



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DySCo AIRBUS

DEFENCE AND SPACE

DySCo functionalities

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DEFENCE AND SPACE

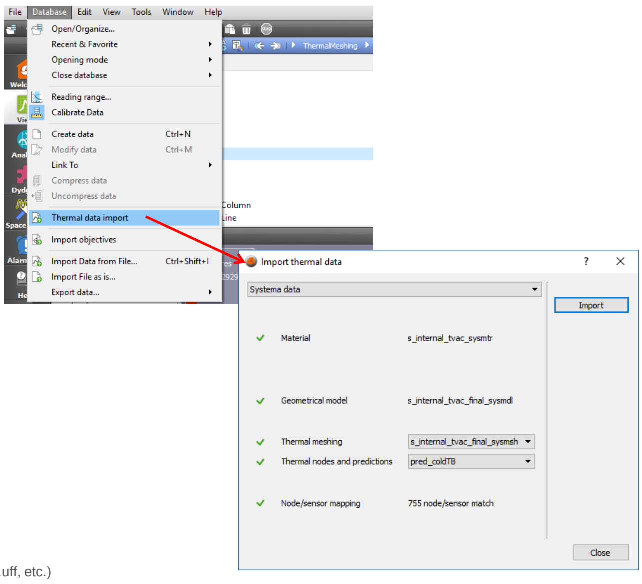
DySCo functionalities

Real time acquisition of test data into DynaWorks V7 database:

- Operational on 3 ADS vacuum thermal chambers
- Acquisition of thermocouples and telemetries results

Import wizard for simulation data:

- Compliant with Systema and Step-TAS formats*
- Guided step-by-step import
  - Materials (*.sysmtr or *.step)
  - Geometrical model (*.sysmdl or *.step)
  - Thermal meshing (*.sysmsh or *.step)
  - Predictions (*.h5)
  - Node / sensor mapping (*.xlsx)
- Check of compliance regarding to test data



(*) Also compliant with DynaWorks standard formats outside wizard (*,xlsx, *.nt, *.uff, etc.)

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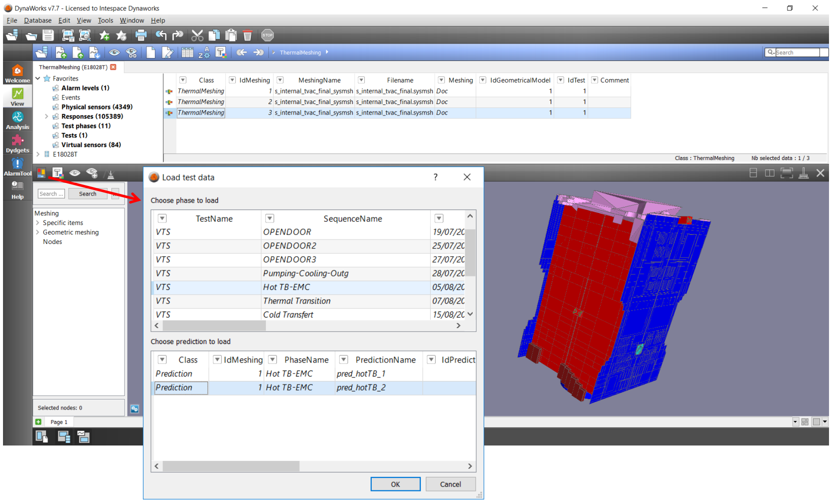
DySCo functionalities

Test results display for a given phase:
- Completed phase
- Current phase (real time) → detection of phase modification

Management of different predictions for a given phase :
- Initial prediction
- Predictions after model updating



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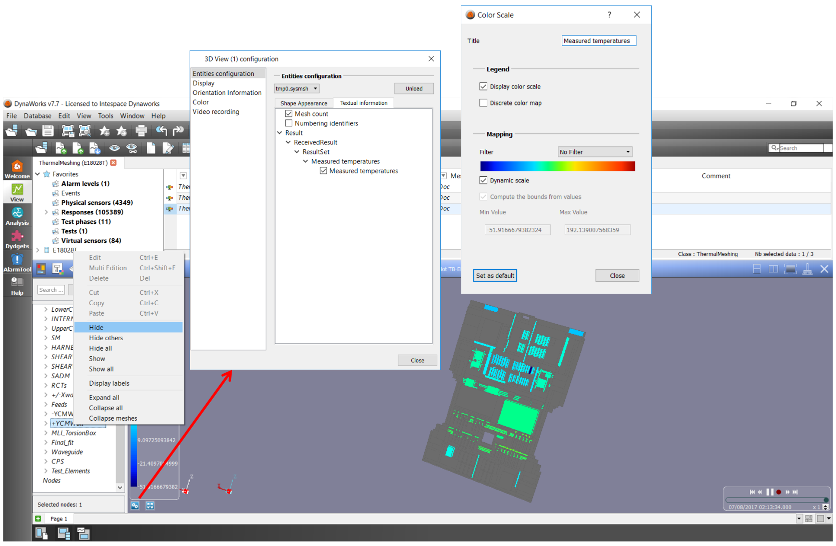
DySCo functionalities

Systema tree view:
- Possible to show / hide some selected elements
- Search bar
- Etc.

Systema options:
- Colour scale configuration
- Textual information display (nodes, temperatures)
- Etc.

Systema player:
- Play / pause
- Real time or replay
- Test acceleration



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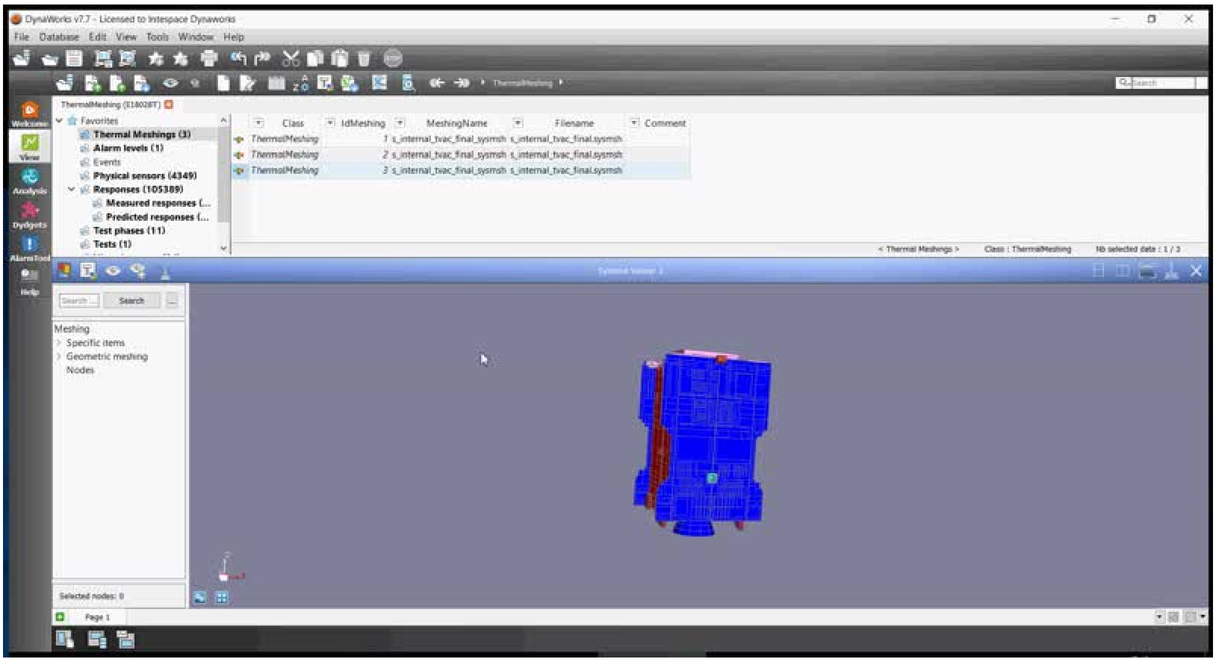

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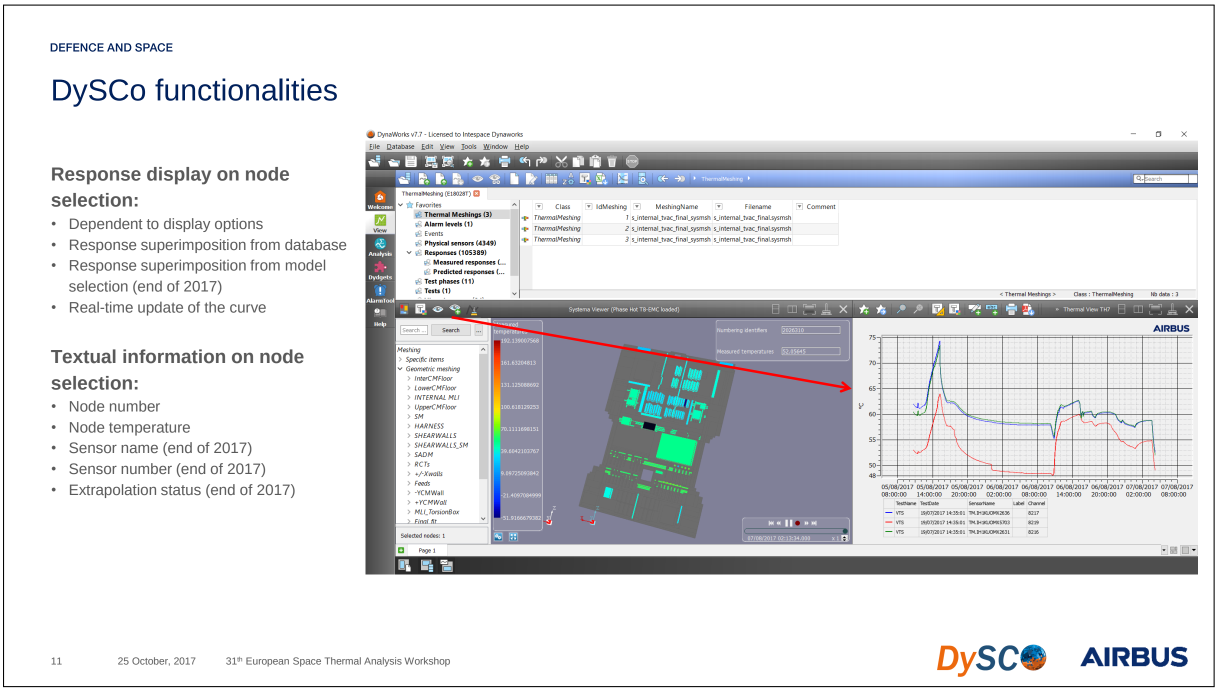
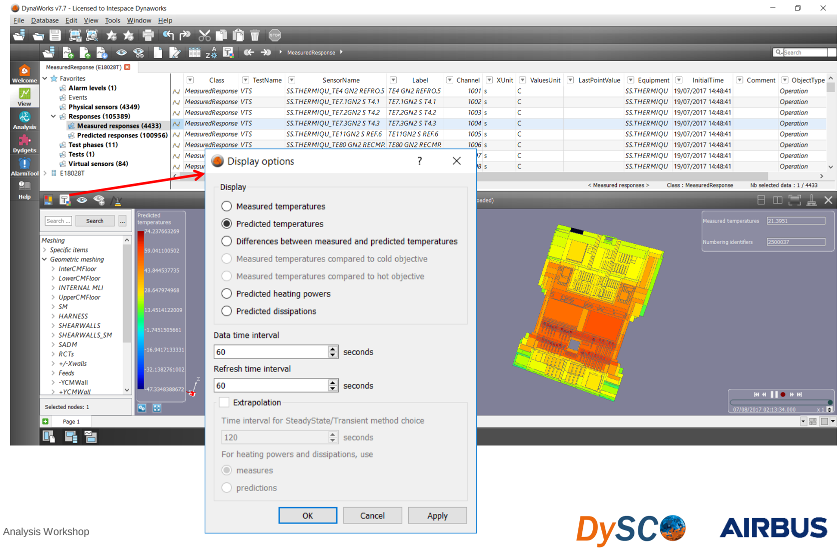


DEFENCE AND SPACE

DySCo functionalities

Display options:

- Measured temperatures
- Predicted temperatures (mean value)
- Difference between measurement and prediction
- Distance to objective
- Predicted heating powers
- Predicted dissipations



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DySCo AIRBUS

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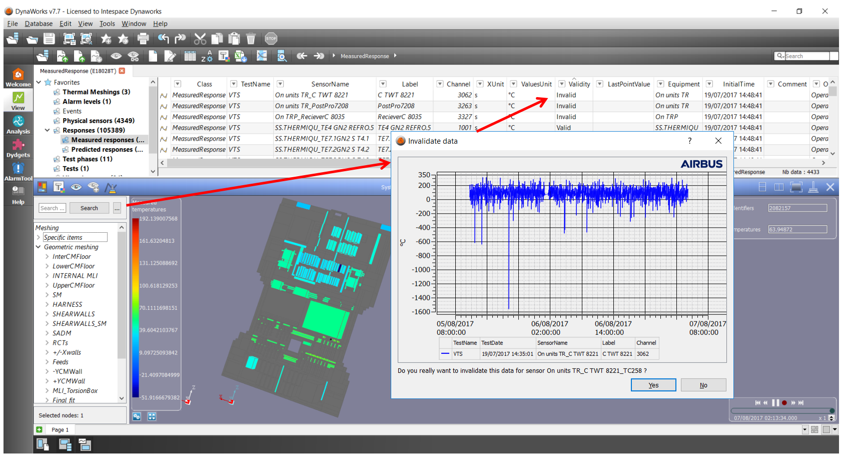
DySCo functionalities

Sensor invalidation on node selection:

- Display of sensor name and response before confirmation
- Modification of sensor validity into the database
- Real-time update of the color map
- Possible to re-validate a sensor from the data base view



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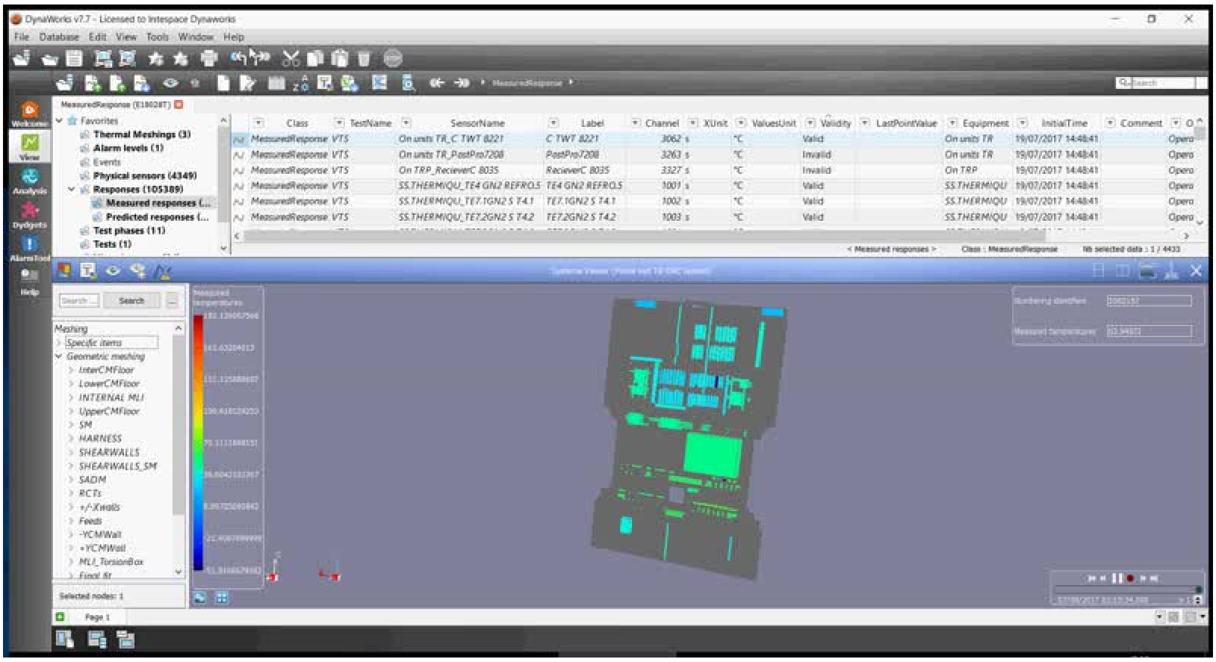
DySCo AIRBUS



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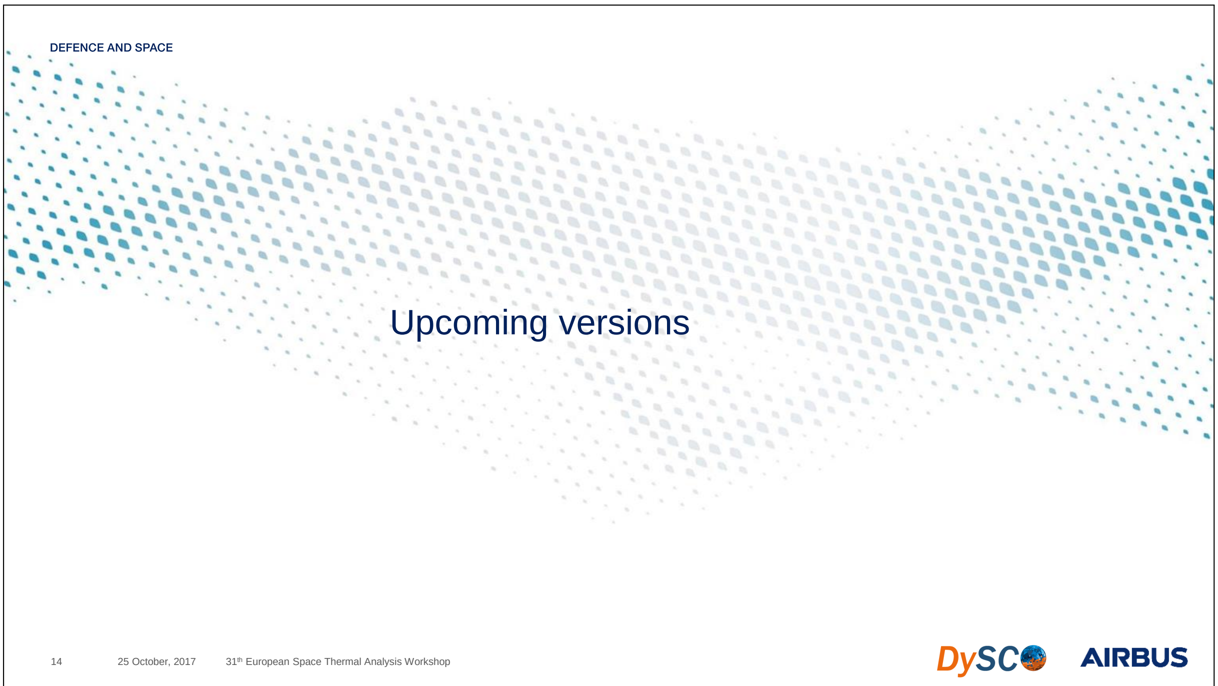

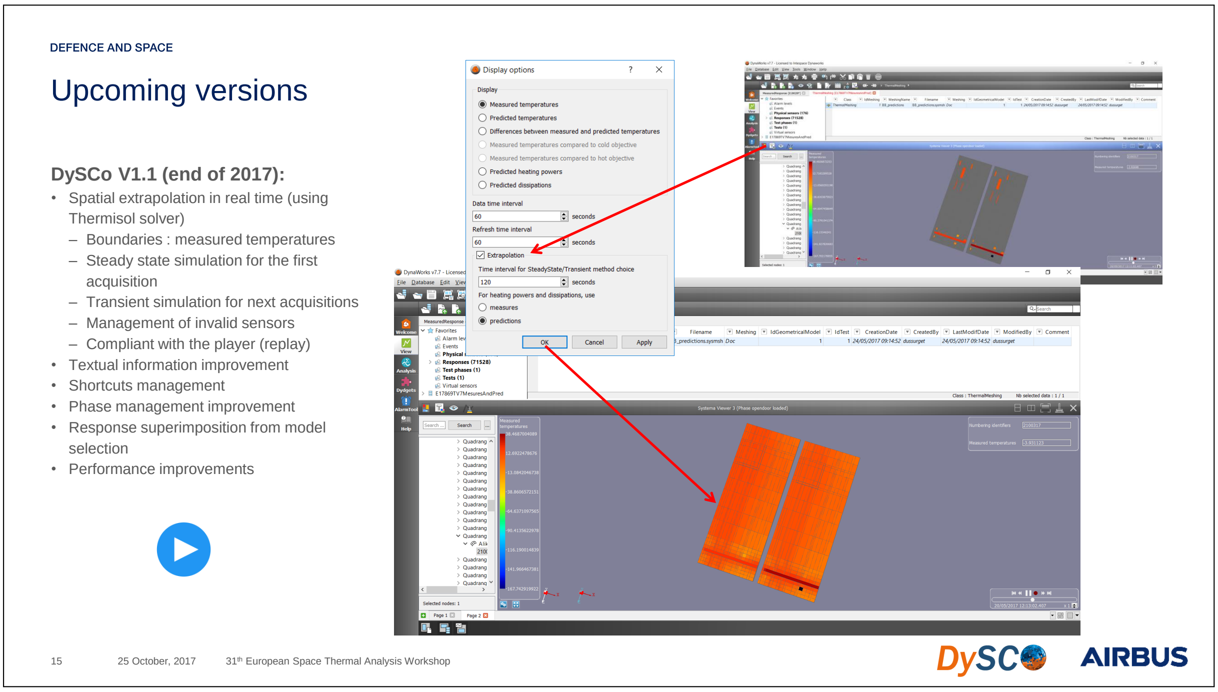

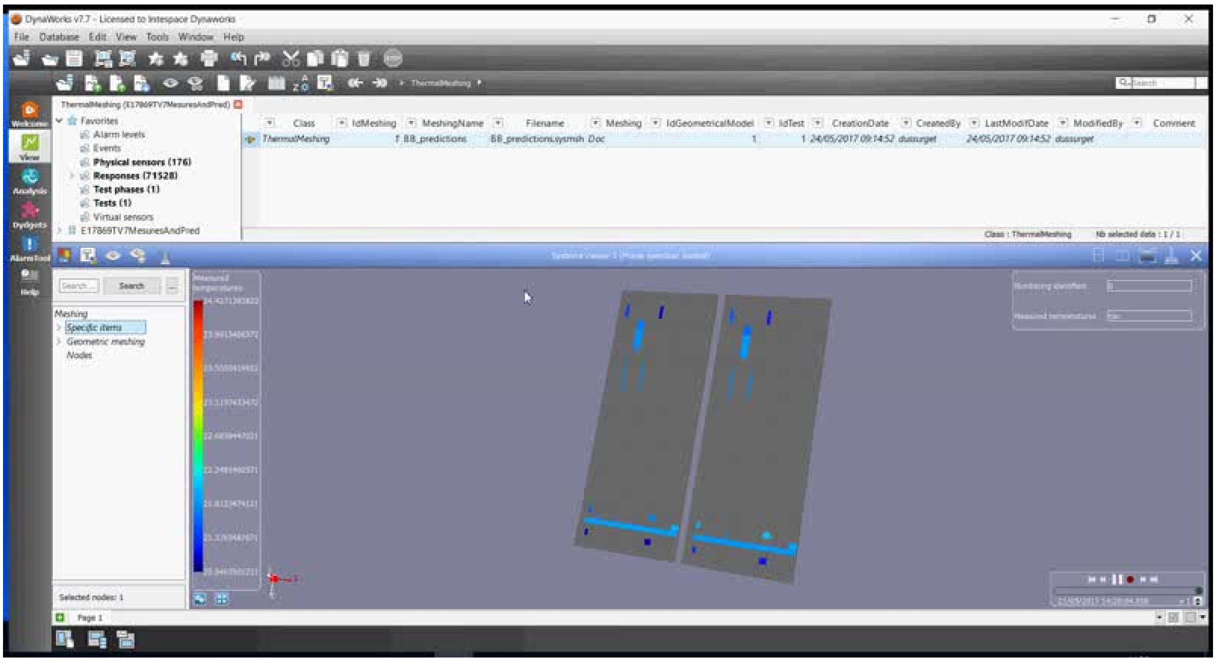

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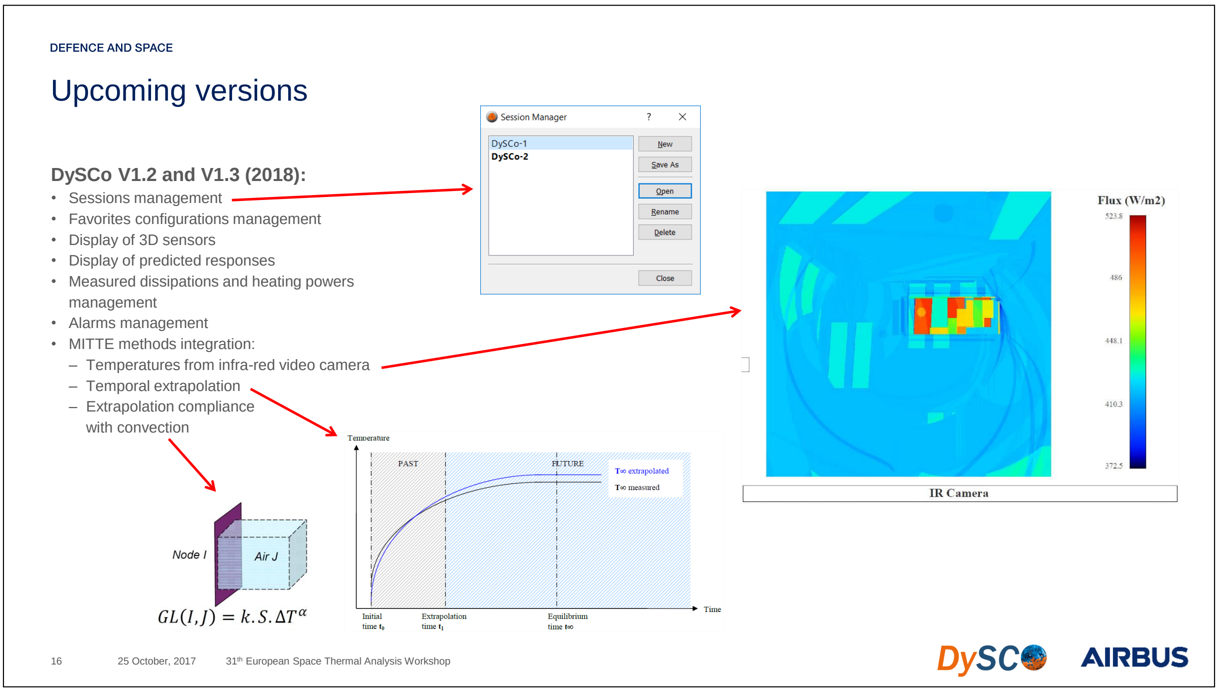
DEFENCE AND SPACE
Upcoming versions
DySCo V1.2 and V1.3 (2018):
• Sessions management
• Favorites configurations management
• Display of 3D sensors
• Display of predicted responses
• Measured dissipations and heating powers management
• Alarms management
• MITTE methods integration:
– Temperatures from infra-red video camera
– Temporal extrapolation
– Extrapolation compliance with convection
Session Manager
DySCo-1
DySCo-2
New
Save As
Open
Rename
Delete
Close
Flux (W/m2)
523.8
486
448.1
410.3
372.5
IR Camera
Temperature
PAST
FUTURE
T∞ extrapolated
T∞ measured
Time
Initial time t0
Extrapolation time t1
Equilibrium time t∞
Node I
Air J
$GL(I,J) = k.S.\Delta T^{\alpha}$
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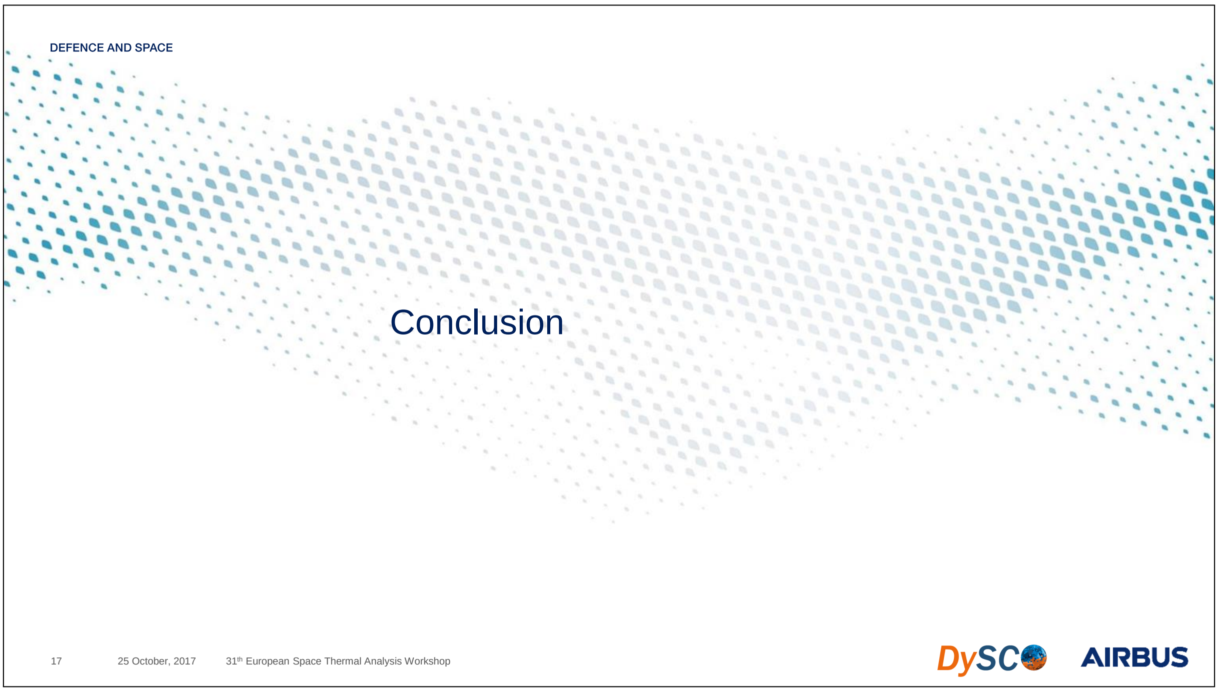
DySCo
AIRBUS


DEFENCE AND SPACE
Conclusion
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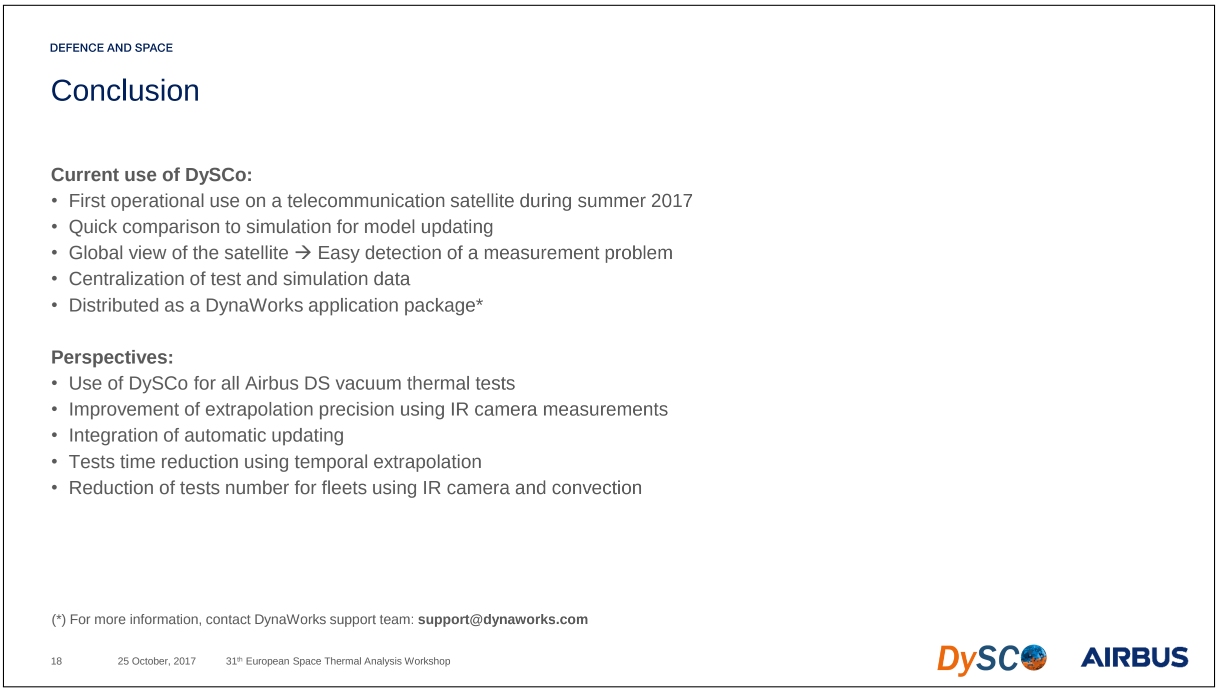
AIRBUS


DEFENCE AND SPACE
Conclusion
Current use of DySCo:
• First operational use on a telecommunication satellite during summer 2017
• Quick comparison to simulation for model updating
• Global view of the satellite → Easy detection of a measurement problem
• Centralization of test and simulation data
• Distributed as a DynaWorks application package*
Perspectives:
• Use of DySCo for all Airbus DS vacuum thermal tests
• Improvement of extrapolation precision using IR camera measurements
• Integration of automatic updating
• Tests time reduction using temporal extrapolation
• Reduction of tests number for fleets using IR camera and convection
(*) For more information, contact DynaWorks support team: support@dynaworks.com
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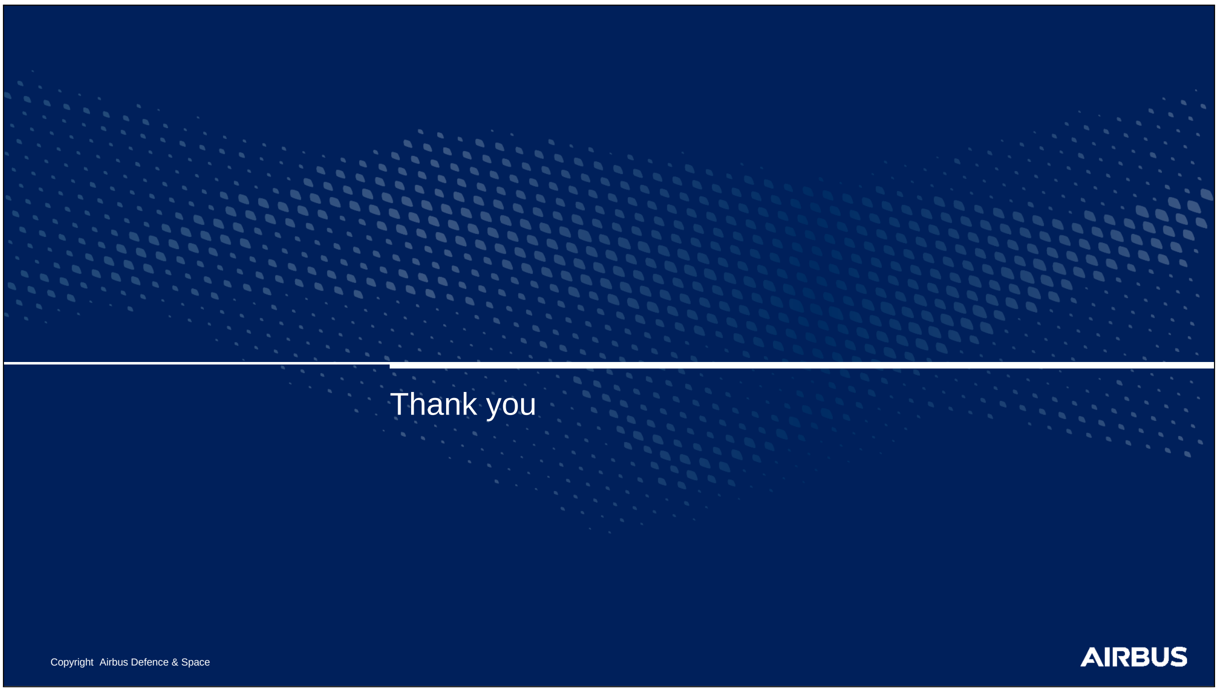
DySCo
AIRBUS


Thank you
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AIRBUS

Appendix X

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