Appendix M

THERMICA-THERMISOL 4.5.0

Timothée Soriano
(EADS Astrium, France)

Abstract

Non-Grey Body Implementation

Under an ESA contract, Astrium has enhanced THERMICA-THERMISOL functionalities by implementing multi-spectral analysis. This new functionality is presented and the interest of using non-grey bodies will be demonstrated on a simple example.

Edges management in THERMISOL

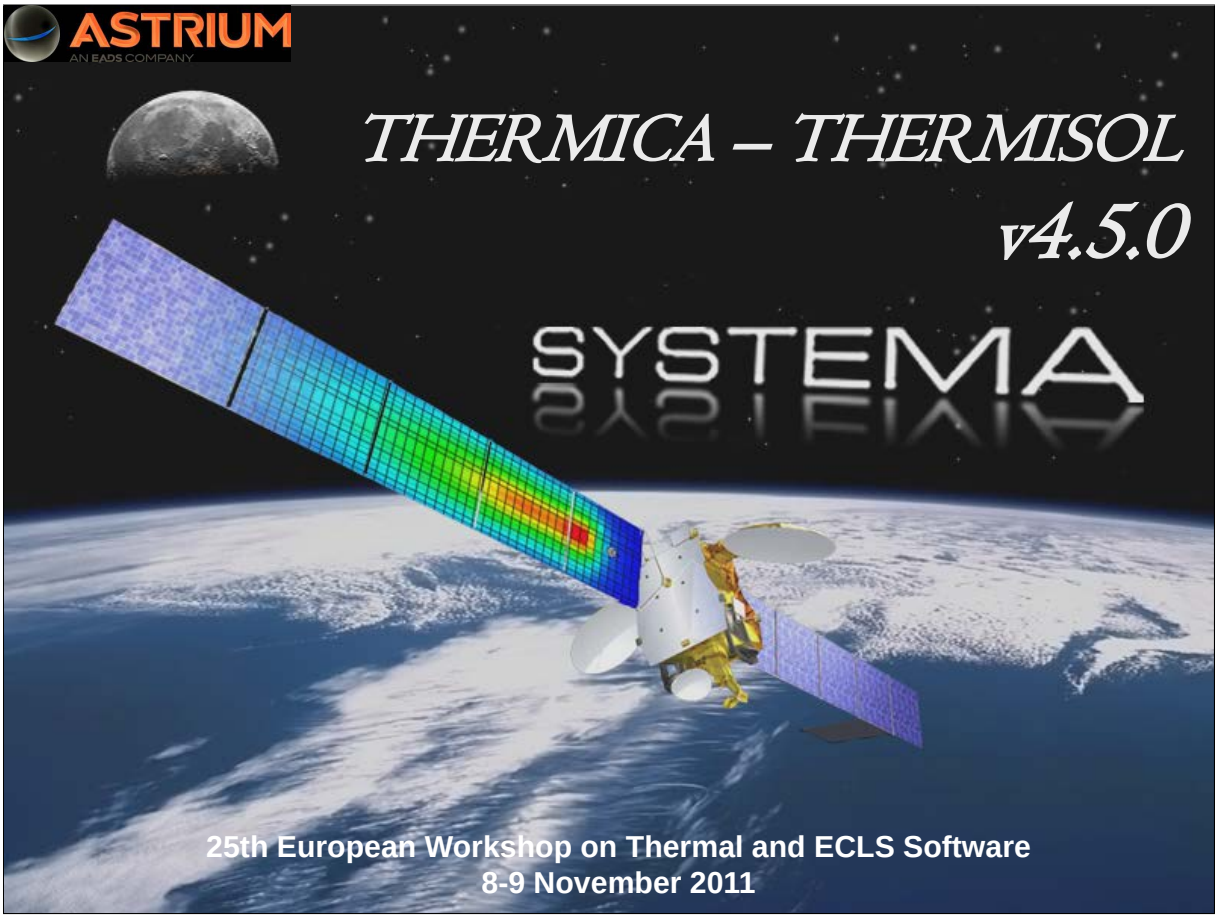
In order to allow easy handling of edges, a new notion of EDGES has been implemented in THERMISOL in order to have a definition of edges corresponding to their purpose and usage, not to increase the number of thermal nodes and especially to compute automatically the conductive flux between thermal nodes.

Simplified conductive method

An extension of the RCN method leading to shape-to-shape couplings has been developed. It solves the conductive flux crossing the frontiers by using a spatial extrapolation of a linearized temperature profile between the edge and the shape's center. This method is less accurate than the RCN method itself because it assumes linear temperature and the real direction of the conductive flux is lost. However, on many cases this approximation may be sufficient and THERMICA now proposes this possibility in order to get an approximated conductive method using the classical shape-to-shape topology of couplings.

Other THERMICA Improvements

The other implemented features of the v4.5.0 concerns **Incident Angle Dependencies**, **Parametric Outputs from THERMICA** and the **Management of Coplanar Shapes** in ray-tracing computations.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AN EADS COMPANY
THERMICA – THERMISOL
v4.5.0
SYSTEMA
25th European Workshop on Thermal and ECLS Software
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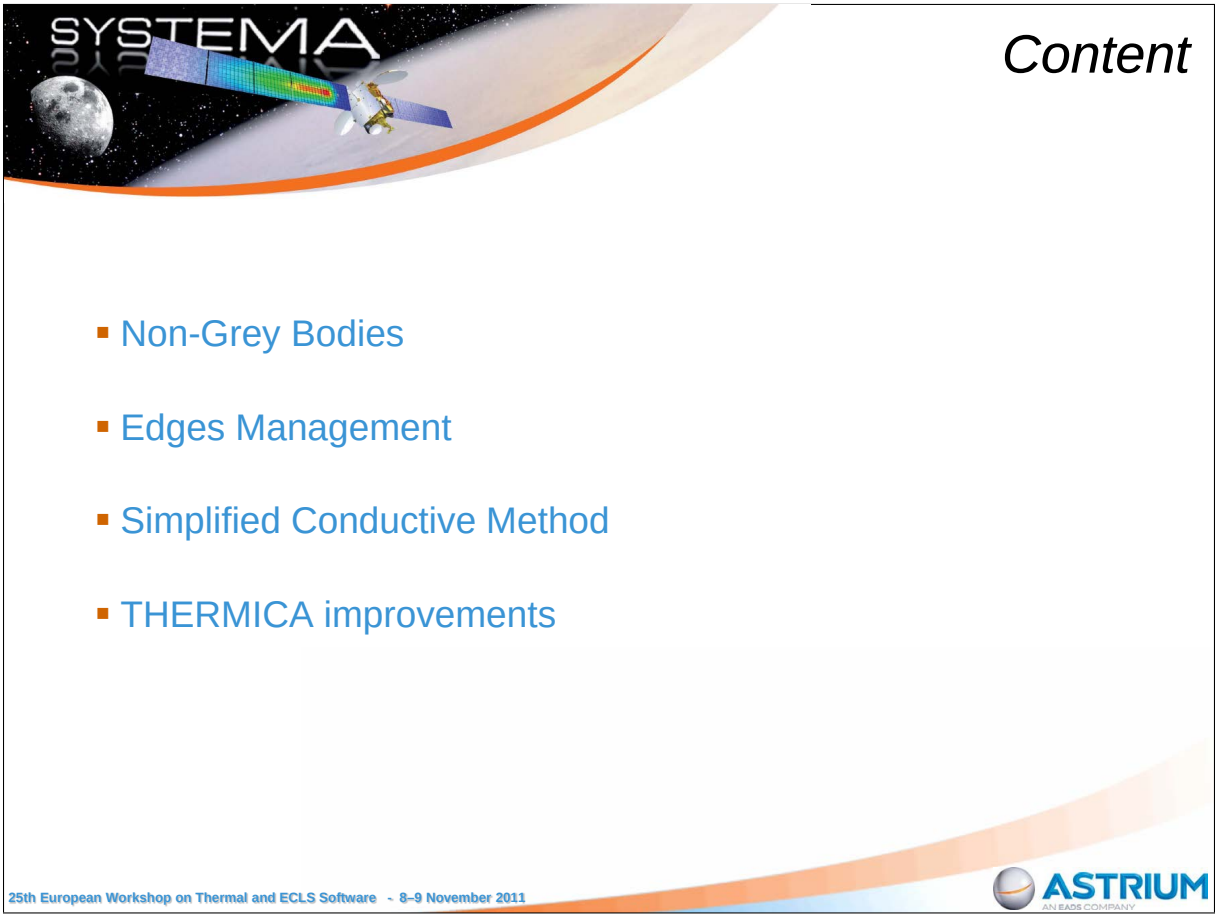
SYSTEMA
Content
Non-Grey Bodies
Edges Management
Simplified Conductive Method
THERMICA improvements
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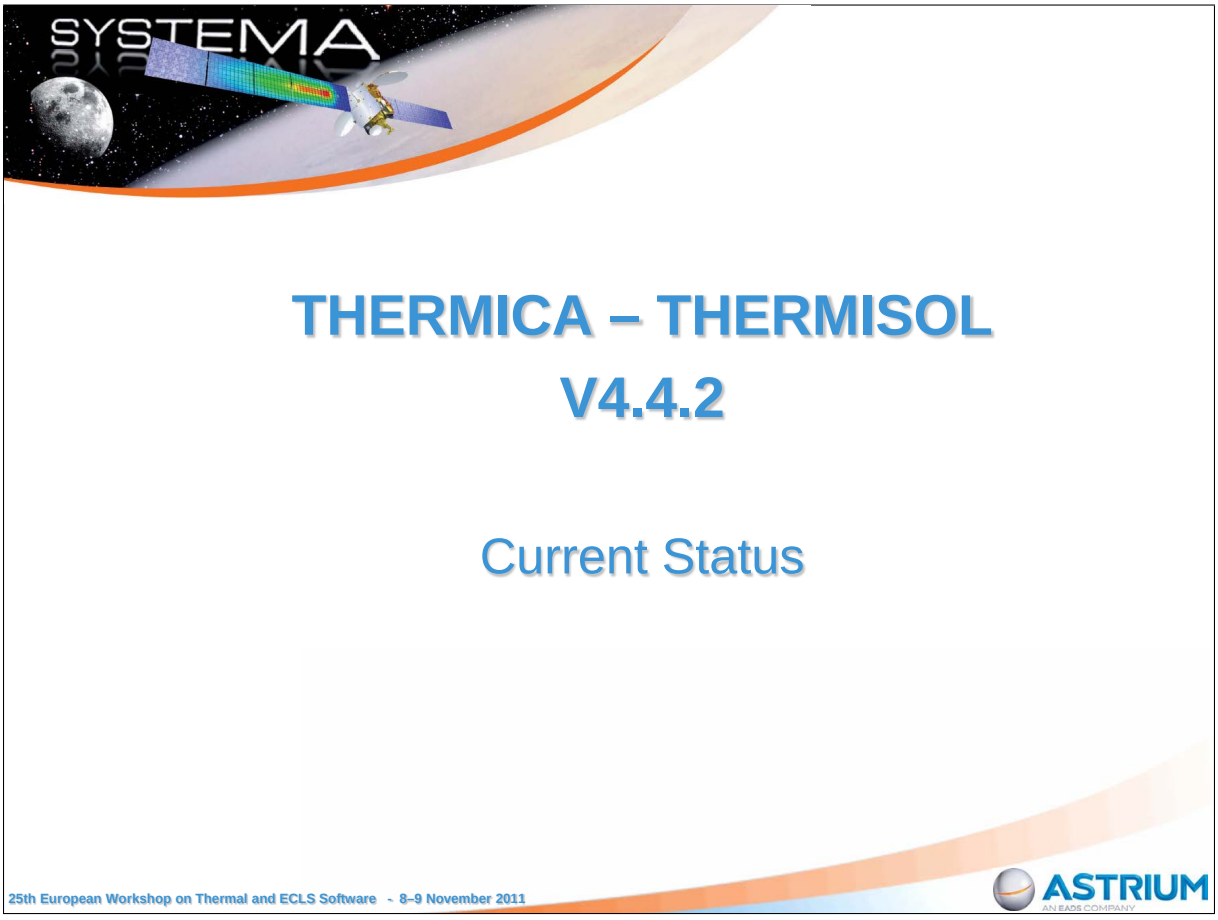
SYSTEMA
THERMICA – THERMISOL
V4.4.2
Current Status
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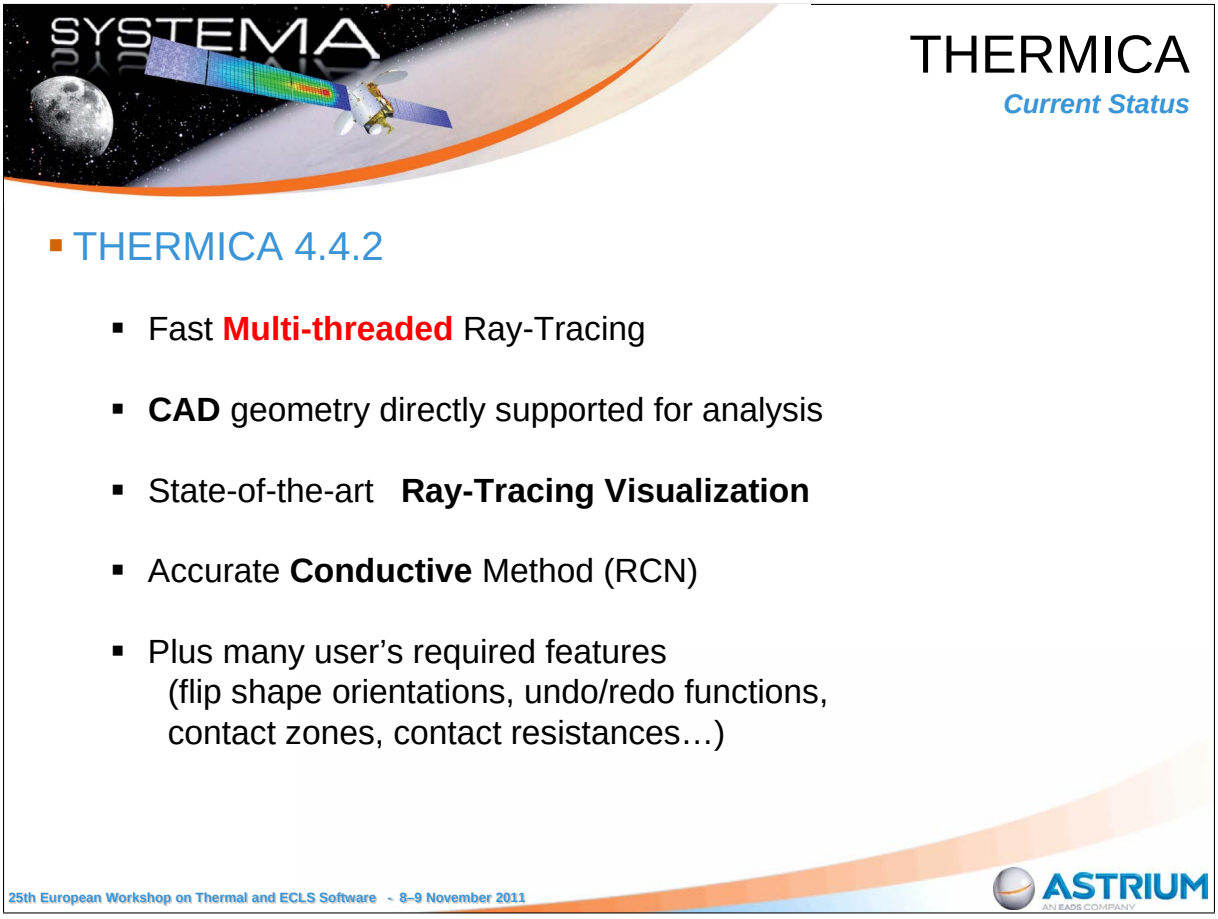
SYSTEMA
THERMICA
Current Status
THERMICA 4.4.2
Fast Multi-threaded Ray-Tracing
CAD geometry directly supported for analysis
State-of-the-art Ray-Tracing Visualization
Accurate Conductive Method (RCN)
Plus many user's required features
(flip shape orientations, undo/redo functions,
contact zones, contact resistances…)
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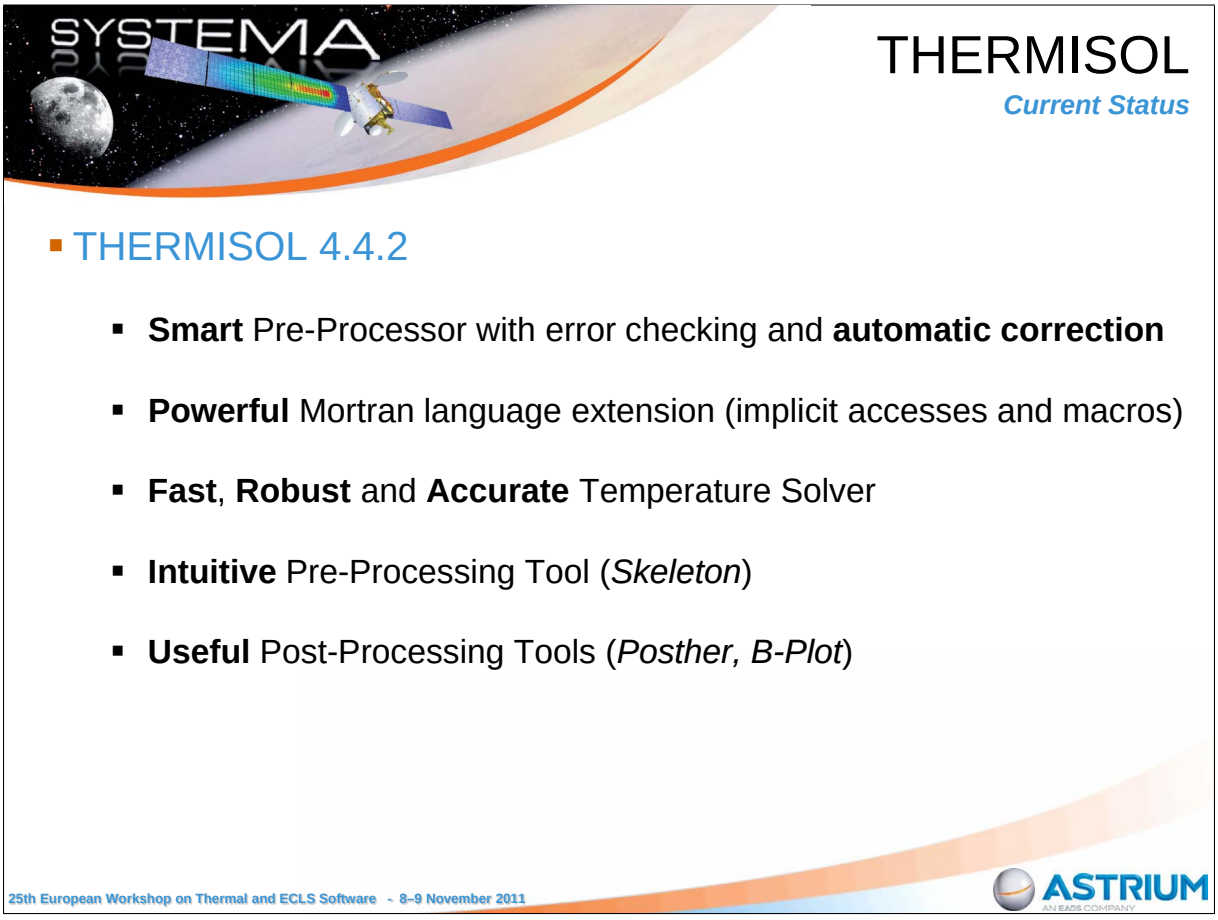
SYSTEMA
THERMISOL
Current Status
THERMISOL 4.4.2
Smart Pre-Processor with error checking and automatic correction
Powerful Mortran language extension (implicit accesses and macros)
Fast, Robust and Accurate Temperature Solver
Intuitive Pre-Processing Tool (Skeleton)
Useful Post-Processing Tools (Posther, B-Plot)
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SYSTEMA
THERMICA – THERMISOL
v4.5.0
Non-Grey Bodies
(under ESA contract)
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SYSTEMA

THERMICA

Non-Grey Bodies

Non-Grey Body

- **Objective:** Implementation of wavelength dependent IR properties
  Preservation of CPU time Performances

- **Development Performed:**
  Wavelength dependence setting in SYSTEMA
  Multi-Spectral Radiative couplings computation
  Multi-Spectral Planet IR flux computation
  THERMISOL language extension for wavelength dependent data
  Multi-Spectral Temperature computation

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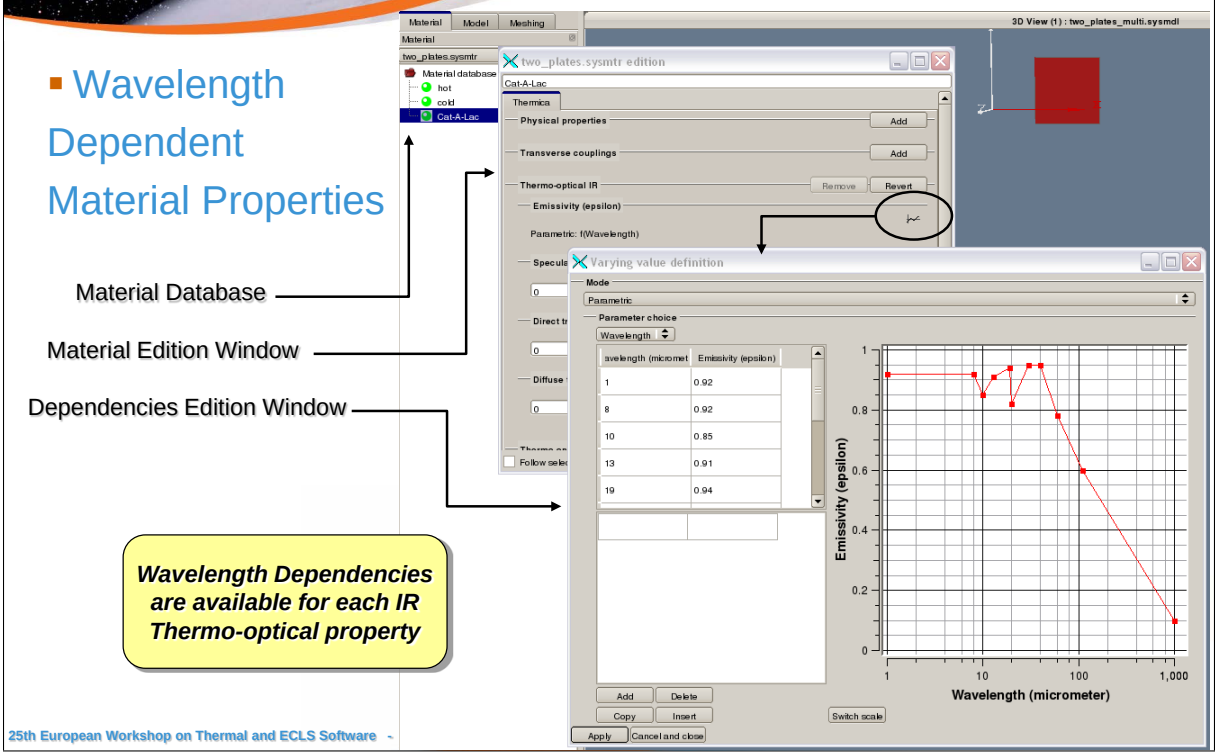
Non-Grey Bodies

Wavelength Dependent Material Properties



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SYSTEMA

THERMICA

Non-Grey Bodies

Non-Grey Body in THERMICA

- **Automatic filtering of multi-spectral / mono-spectral couplings**
- **Preserved CPU performances:**

Industrial PDR Case of 1600 mesh and 76 orbital positions

Modules	Computation Time (seconds)		
	Mono-Spectral	*4 Bands*	*5 Bands*
GR Radiative Couplings	47	92	112
QE-QA Planet Fluxes	148	176	236
QS Solar Fluxes	261	263	277
Total	456	531	625

Computation Time Increase contained to a minimum thanks to efficient multi-spectral Ray-Tracing

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SYSTEMA

THERMISOL

Non-Grey Bodies

Non-Grey Body in THERMISOL

- New Entities **EPSWLB** and **GRWLB** for wavelength dependent properties
  Those are valued as arrays for an easy reading and a better understanding of the data
- New function **EPSWLBEF()** to automatically update the equivalent EPS at the node's temperature
- CPU Time for temperature integration contained to a minimum raise

Industrial PDR Case with 1939 nodes, more than 92000 radiative couplings including more than 42000 wavelength dependent couplings (multi-spectral case)

Modules	Computation Time (seconds)		
	Mono-Spectral	*4 Bands*	*5 Bands*
THERMISOL SS + TR	51	-	376

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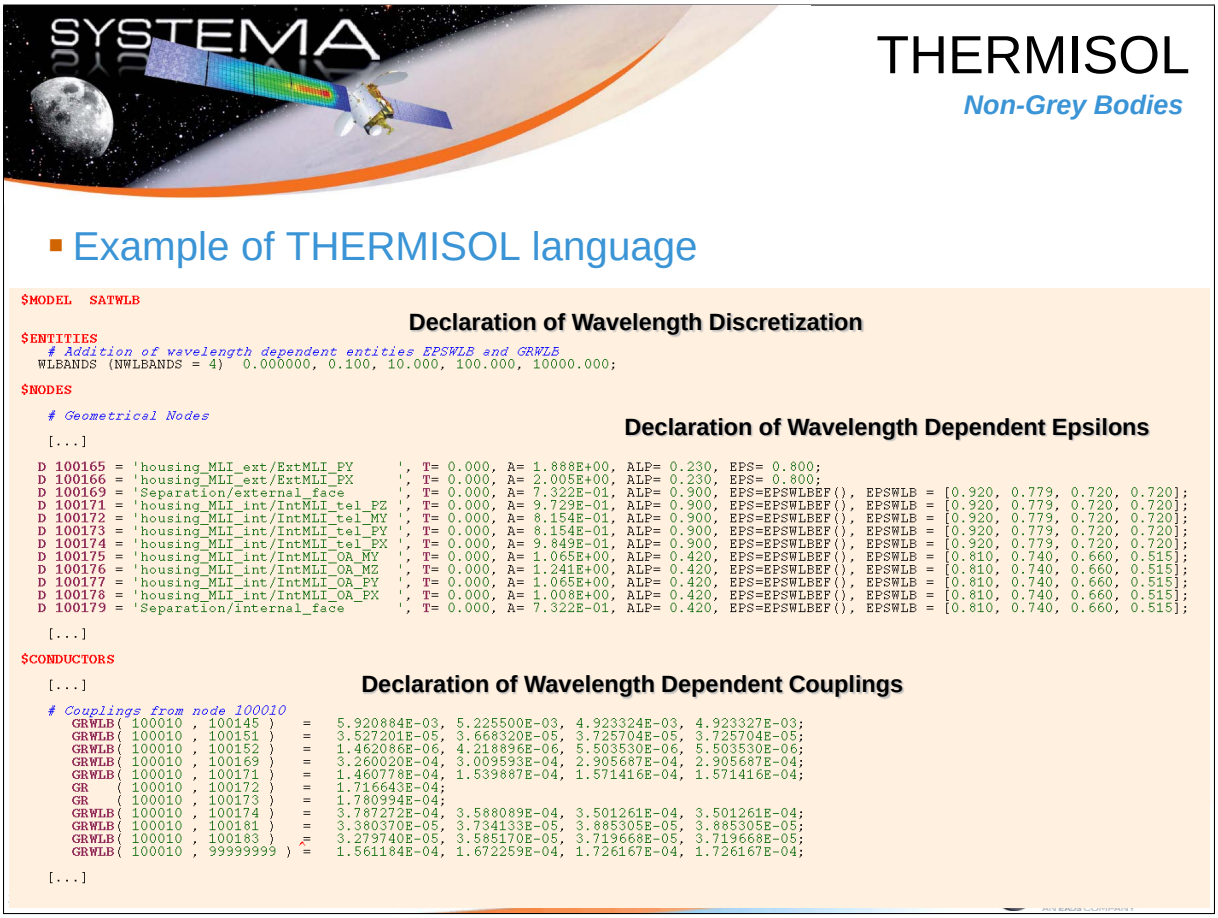
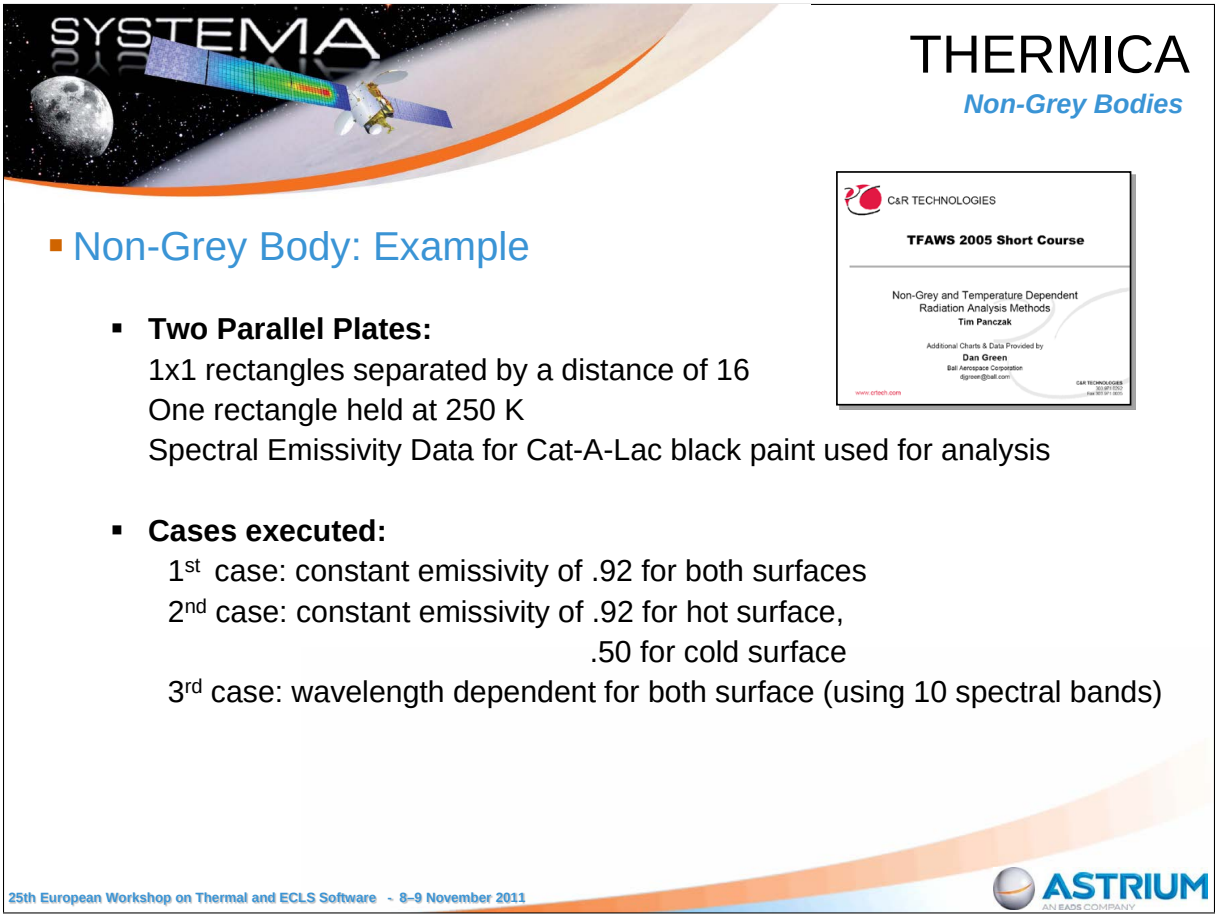

SYSTEMA
THERMISOL
Non-Grey Bodies
Example of THERMISOL language
$MODEL SATWLB
Declaration of Wavelength Discretization
$ENTITIES
Addition of wavelength dependent entities EPSWLB and GRWLB
WLBANDS (NWLBANDS = 4) 0.000000, 0.100, 10.000, 100.000, 10000.000;
$NODES
Geometrical Nodes
[...]
Declaration of Wavelength Dependent Epsilons
D 100165 = 'housing_MLI_ext/ExtMLI_PY ', T= 0.000, A= 1.888E+00, ALP= 0.230, EPS= 0.800;
D 100166 = 'housing_MLI_ext/ExtMLI_PX ', T= 0.000, A= 2.005E+00, ALP= 0.230, EPS= 0.800;
D 100169 = 'Separation/external_face ', T= 0.000, A= 7.322E-01, ALP= 0.900, EPS=EPSWLBEF(), EPSWLB = [0.920, 0.779, 0.720, 0.720];
D 100171 = 'housing_MLI_int/IntMLI_tel_PZ ', T= 0.000, A= 9.729E-01, ALP= 0.900, EPS=EPSWLBEF(), EPSWLB = [0.920, 0.779, 0.720, 0.720];
D 100172 = 'housing_MLI_int/IntMLI_tel_MY ', T= 0.000, A= 8.154E-01, ALP= 0.900, EPS=EPSWLBEF(), EPSWLB = [0.920, 0.779, 0.720, 0.720];
D 100173 = 'housing_MLI_int/IntMLI_tel_PY ', T= 0.000, A= 8.154E-01, ALP= 0.900, EPS=EPSWLBEF(), EPSWLB = [0.920, 0.779, 0.720, 0.720];
D 100174 = 'housing_MLI_int/IntMLI_tel_PX ', T= 0.000, A= 9.849E-01, ALP= 0.900, EPS=EPSWLBEF(), EPSWLB = [0.920, 0.779, 0.720, 0.720];
D 100175 = 'housing_MLI_int/IntMLI_OA_MY ', T= 0.000, A= 1.065E+00, ALP= 0.420, EPS=EPSWLBEF(), EPSWLB = [0.810, 0.740, 0.660, 0.515];
D 100176 = 'housing_MLI_int/IntMLI_OA_MZ ', T= 0.000, A= 1.241E+00, ALP= 0.420, EPS=EPSWLBEF(), EPSWLB = [0.810, 0.740, 0.660, 0.515];
D 100177 = 'housing_MLI_int/IntMLI_OA_PY ', T= 0.000, A= 1.065E+00, ALP= 0.420, EPS=EPSWLBEF(), EPSWLB = [0.810, 0.740, 0.660, 0.515];
D 100178 = 'housing_MLI_int/IntMLI_OA_PX ', T= 0.000, A= 1.008E+00, ALP= 0.420, EPS=EPSWLBEF(), EPSWLB = [0.810, 0.740, 0.660, 0.515];
D 100179 = 'Separation/internal_face ', T= 0.000, A= 7.322E-01, ALP= 0.420, EPS=EPSWLBEF(), EPSWLB = [0.810, 0.740, 0.660, 0.515];
[...]
$CONDUCTORS
[...]
Declaration of Wavelength Dependent Couplings
Couplings from node 100010
GRWLB(100010 , 100145) = 5.920884E-03, 5.225500E-03, 4.923324E-03, 4.923327E-03;
GRWLB(100010 , 100151) = 3.527201E-05, 3.668320E-05, 3.725704E-05, 3.725704E-05;
GRWLB(100010 , 100152) = 1.462086E-06, 4.218896E-06, 5.503530E-06, 5.503530E-06;
GRWLB(100010 , 100169) = 3.260020E-04, 3.009593E-04, 2.905687E-04, 2.905687E-04;
GRWLB(100010 , 100171) = 1.460778E-04, 1.539887E-04, 1.571416E-04, 1.571416E-04;
GR (100010 , 100172) = 1.716643E-04;
GR (100010 , 100173) = 1.780994E-04;
GRWLB(100010 , 100174) = 3.787272E-04, 3.588089E-04, 3.501261E-04, 3.501261E-04;
GRWLB(100010 , 100181) = 3.380370E-05, 3.734133E-05, 3.885305E-05, 3.885305E-05;
GRWLB(100010 , 100183) = 3.279740E-05, 3.585170E-05, 3.719668E-05, 3.719668E-05;
GRWLB(100010 , 99999999) = 1.561184E-04, 1.672259E-04, 1.726167E-04, 1.726167E-04;
[...]


SYSTEMA
THERMICA
Non-Grey Bodies
Non-Grey Body: Example
C&R TECHNOLOGIES
TFAWS 2005 Short Course
Non-Grey and Temperature Dependent Radiation Analysis Methods
Tim Panczak
Additional Charts & Data Provided by
Dan Green
Ball Aerospace Corporation
Two Parallel Plates:
1x1 rectangles separated by a distance of 16
One rectangle held at 250 K
Spectral Emissivity Data for Cat-A-Lac black paint used for analysis
Cases executed:
1st case: constant emissivity of .92 for both surfaces
2nd case: constant emissivity of .92 for hot surface,
.50 for cold surface
3rd case: wavelength dependent for both surface (using 10 spectral bands)
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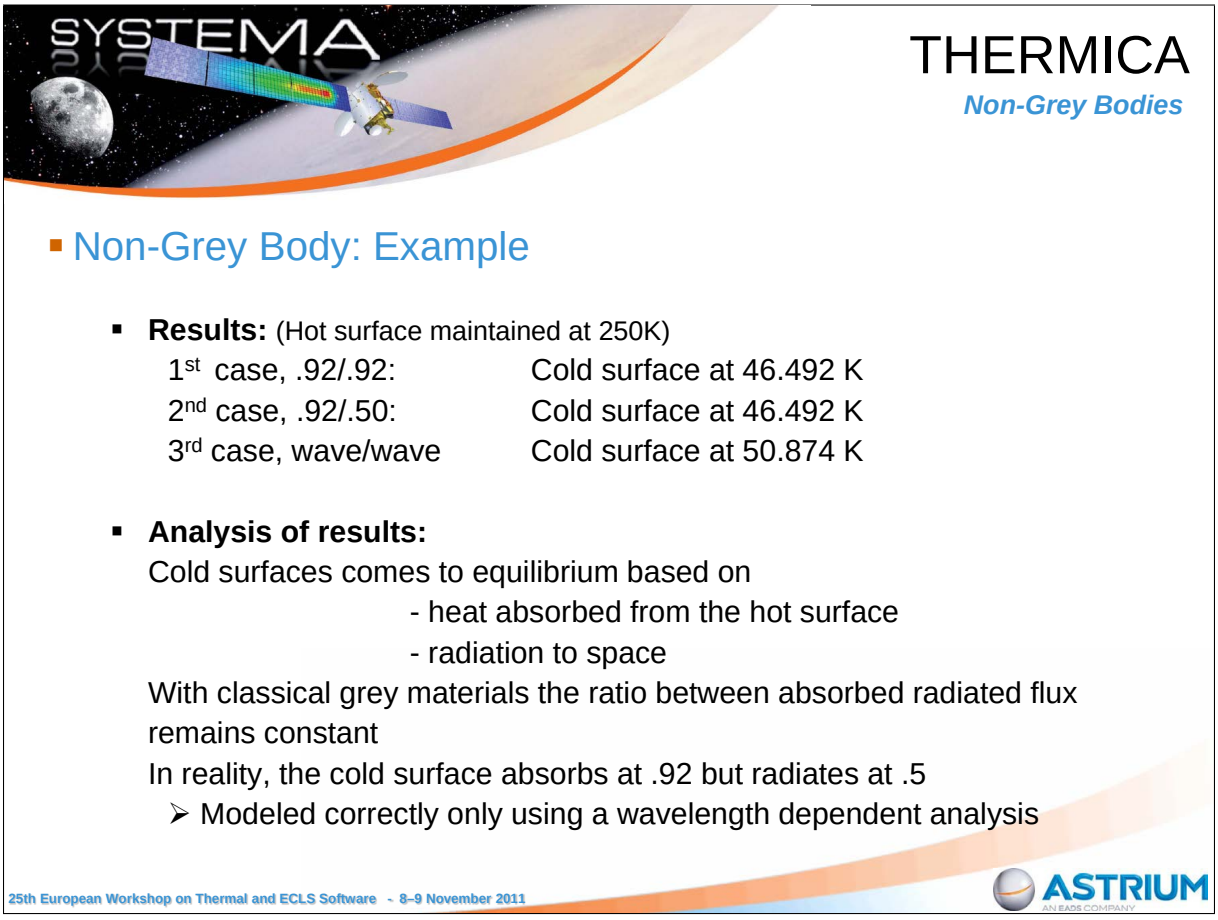
SYSTEMA
THERMICA
Non-Grey Bodies
Non-Grey Body: Example
Results: (Hot surface maintained at 250K)
1st case, .92/.92: Cold surface at 46.492 K
2nd case, .92/.50: Cold surface at 46.492 K
3rd case, wave/wave Cold surface at 50.874 K
Analysis of results:
Cold surfaces comes to equilibrium based on
- heat absorbed from the hot surface
- radiation to space
With classical grey materials the ratio between absorbed radiated flux remains constant
In reality, the cold surface absorbs at .92 but radiates at .5
Modeled correctly only using a wavelength dependent analysis
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THERMICA-THERMISOL
v4.5.0
Edge Management
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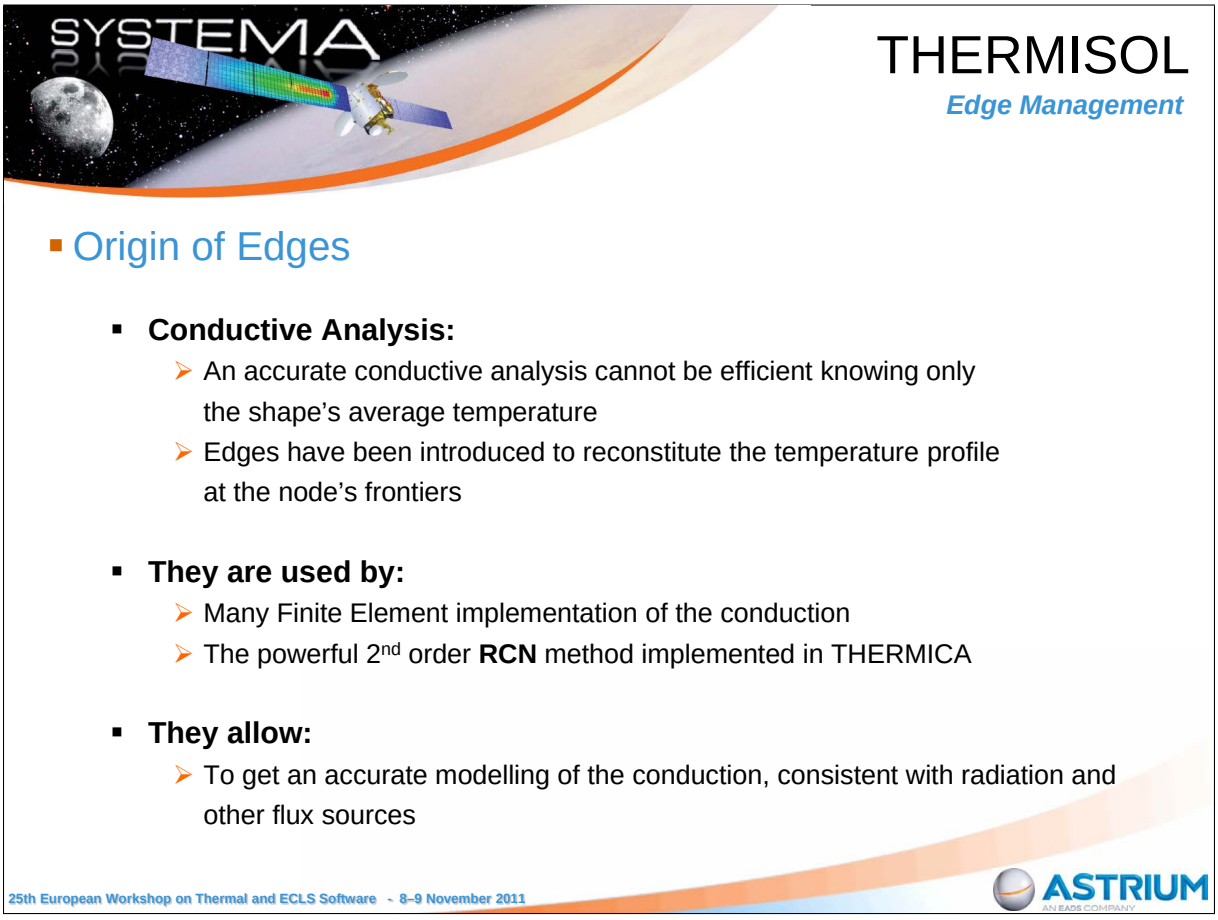
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THERMISOL
Edge Management
Origin of Edges
Conductive Analysis:
An accurate conductive analysis cannot be efficient knowing only the shape's average temperature
Edges have been introduced to reconstitute the temperature profile at the node's frontiers
They are used by:
Many Finite Element implementation of the conduction
The powerful 2nd order RCN method implemented in THERMICA
They allow:
To get an accurate modelling of the conduction, consistent with radiation and other flux sources
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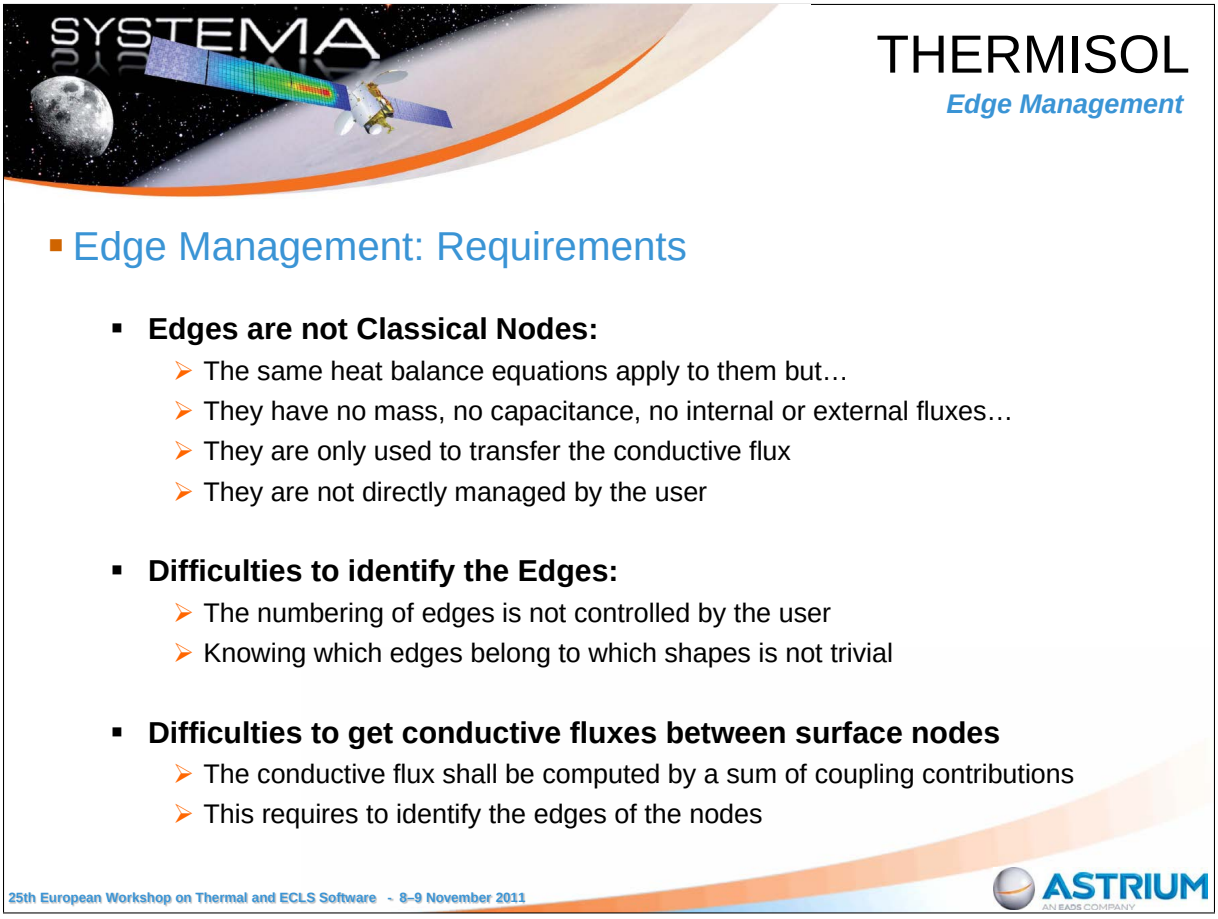
SYSTEMA
THERMISOL
Edge Management
Edge Management: Requirements
Edges are not Classical Nodes:
The same heat balance equations apply to them but…
They have no mass, no capacitance, no internal or external fluxes…
They are only used to transfer the conductive flux
They are not directly managed by the user
Difficulties to identify the Edges:
The numbering of edges is not controlled by the user
Knowing which edges belong to which shapes is not trivial
Difficulties to get conductive fluxes between surface nodes
The conductive flux shall be computed by a sum of coupling contributions
This requires to identify the edges of the nodes
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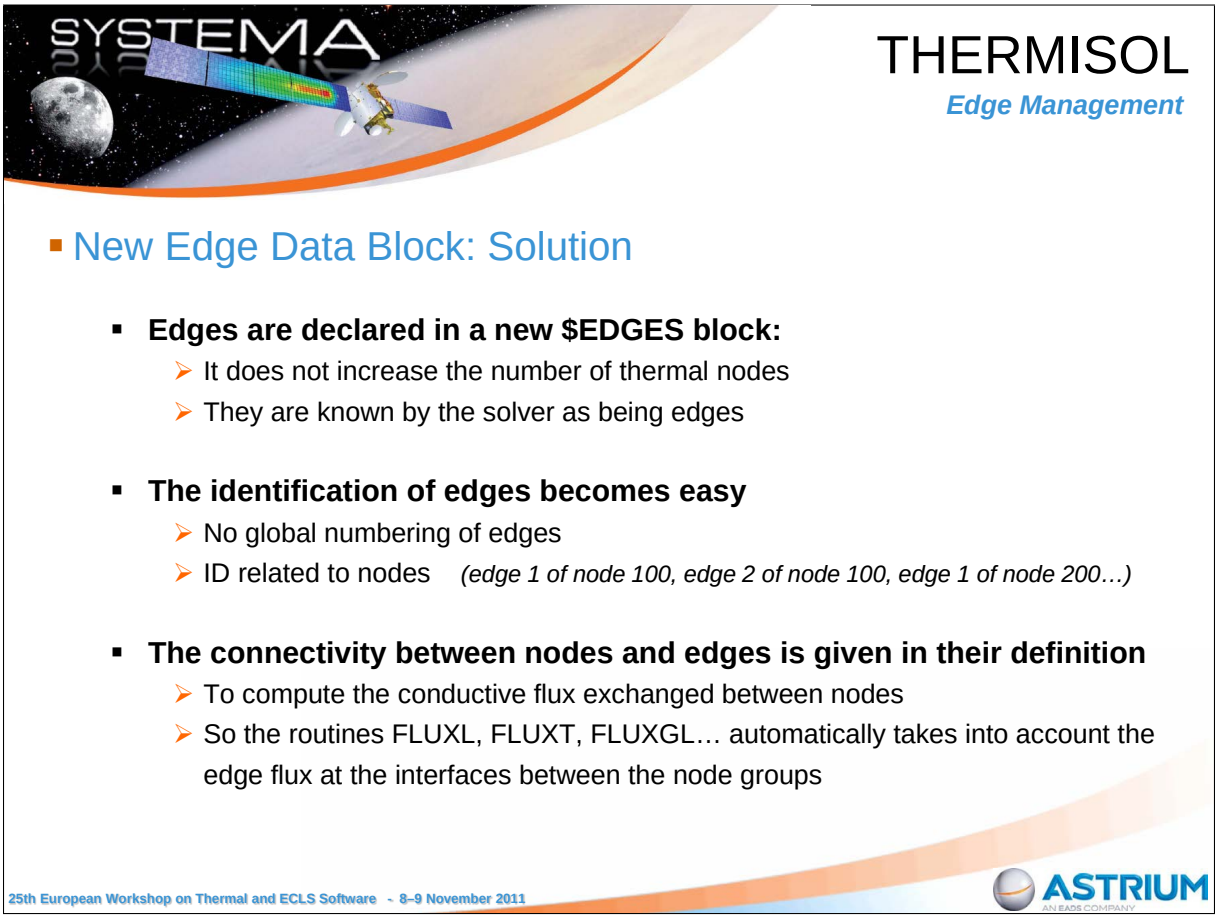
SYSTEMA
THERMISOL
Edge Management
New Edge Data Block: Solution
Edges are declared in a new $EDGES block:
It does not increase the number of thermal nodes
They are known by the solver as being edges
The identification of edges becomes easy
No global numbering of edges
ID related to nodes (edge 1 of node 100, edge 2 of node 100, edge 1 of node 200…)
The connectivity between nodes and edges is given in their definition
To compute the conductive flux exchanged between nodes
So the routines FLUXL, FLUXT, FLUXGL… automatically takes into account the edge flux at the interfaces between the node groups
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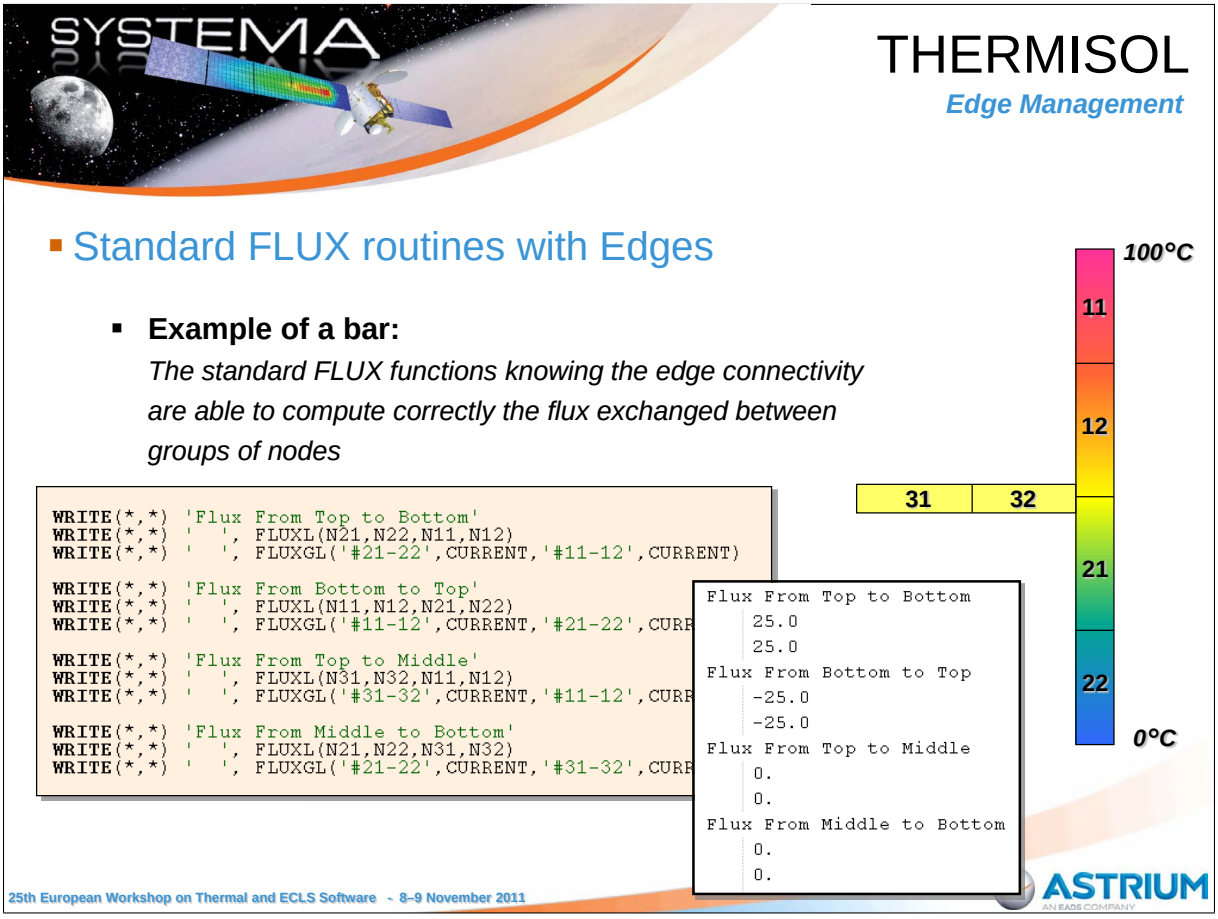
SYSTEMA
THERMISOL
Edge Management
Standard FLUX routines with Edges
Example of a bar:
The standard FLUX functions knowing the edge connectivity are able to compute correctly the flux exchanged between groups of nodes
WRITE(*,*) 'Flux From Top to Bottom'
WRITE(*,*) ' ', FLUXL(N21,N22,N11,N12)
WRITE(*,*) ' ', FLUXGL('#21-22',CURRENT,'#11-12',CURRENT)
WRITE(*,*) 'Flux From Bottom to Top'
WRITE(*,*) ' ', FLUXL(N11,N12,N21,N22)
WRITE(*,*) ' ', FLUXGL('#11-12',CURRENT,'#21-22',CURR
WRITE(*,*) 'Flux From Top to Middle'
WRITE(*,*) ' ', FLUXL(N31,N32,N11,N12)
WRITE(*,*) ' ', FLUXGL('#31-32',CURRENT,'#11-12',CURR
WRITE(*,*) 'Flux From Middle to Bottom'
WRITE(*,*) ' ', FLUXL(N21,N22,N31,N32)
WRITE(*,*) ' ', FLUXGL('#21-22',CURRENT,'#31-32',CURR
Flux From Top to Bottom
25.0
25.0
Flux From Bottom to Top
-25.0
-25.0
Flux From Top to Middle
0.
0.
Flux From Middle to Bottom
0.
0.
100°C
11
12
31
32
21
22
0°C
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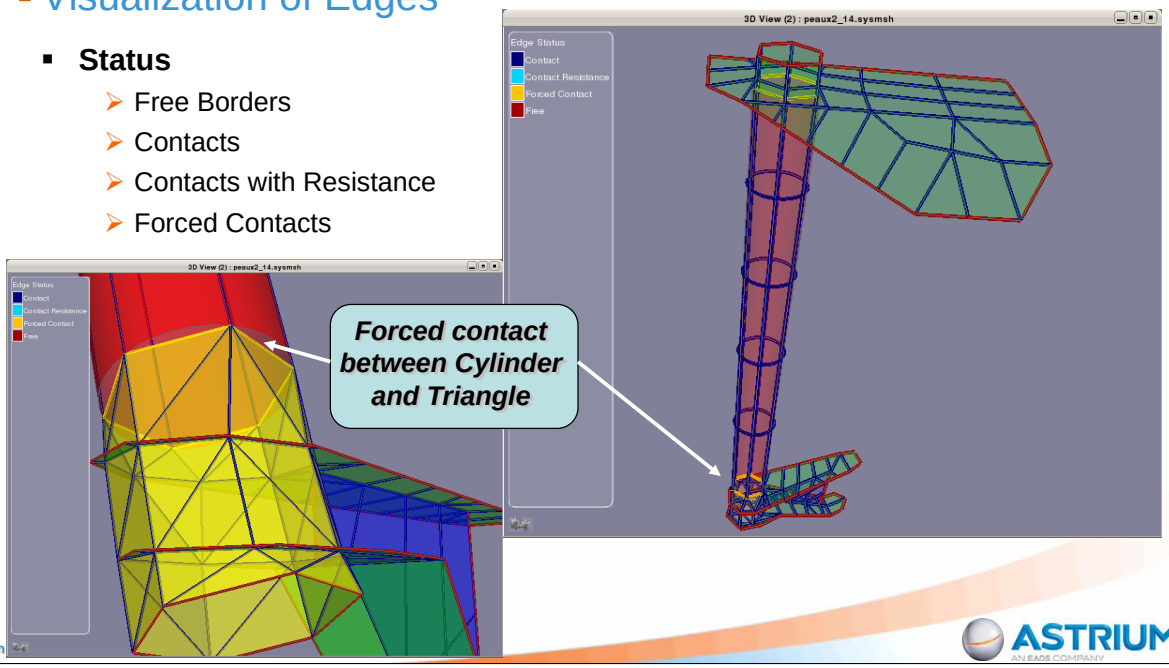
Edge Management

Visualization of Edges

- **Status**
  - Free Borders
  - Contacts
  - Contacts with Resistance
  - Forced Contacts



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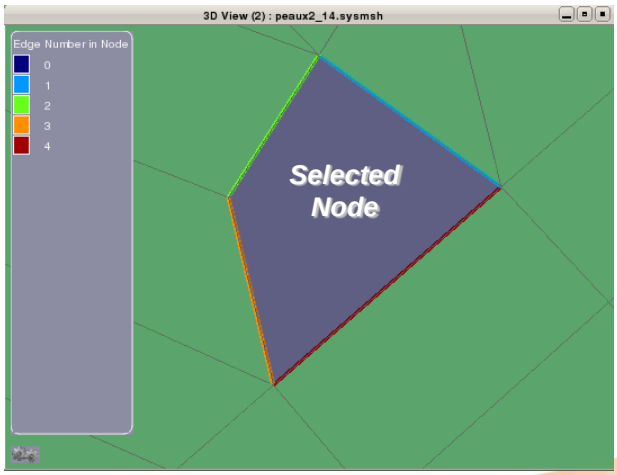
Edge Management

Visualization of Edges

- **Numbering**



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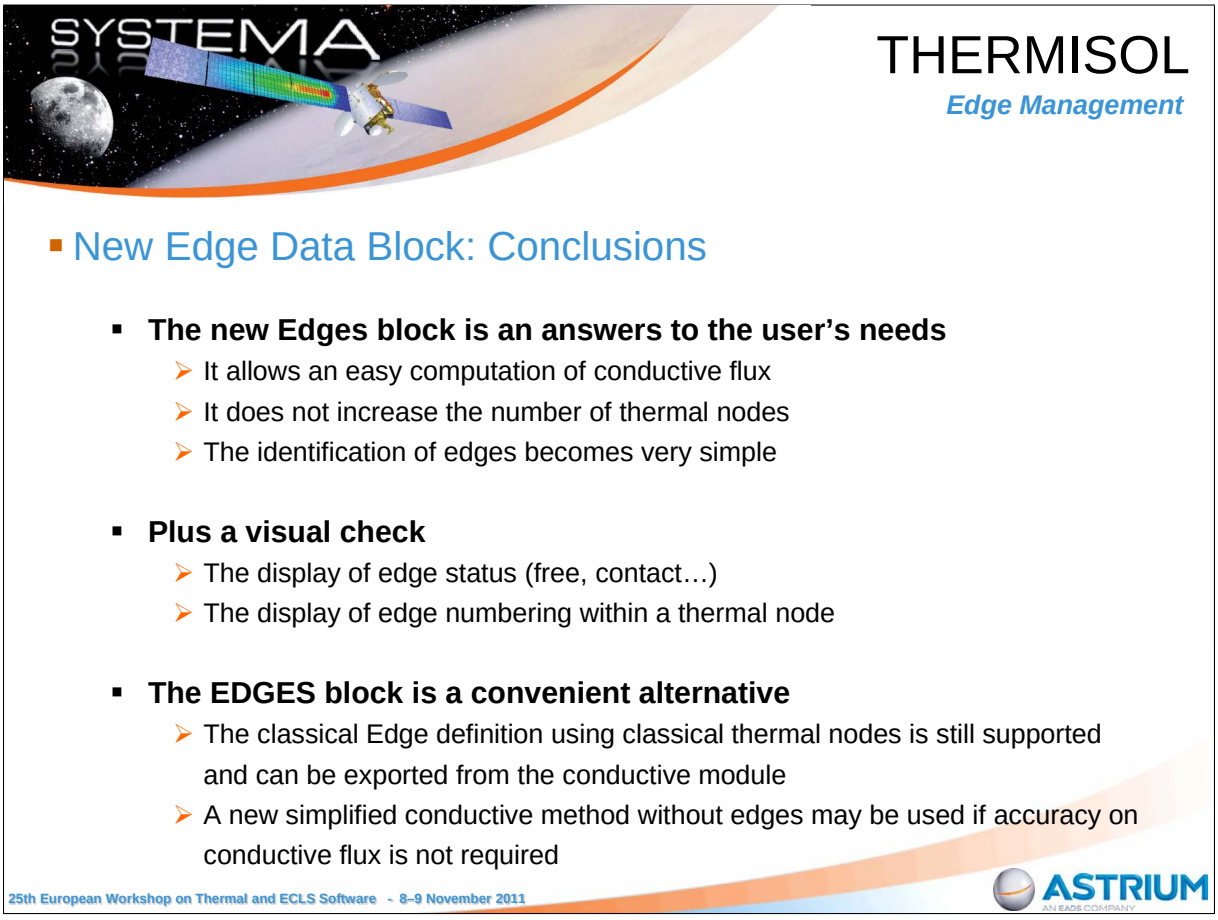
SYSTEMA
THERMISOL
Edge Management
New Edge Data Block: Conclusions
The new Edges block is an answers to the user's needs
It allows an easy computation of conductive flux
It does not increase the number of thermal nodes
The identification of edges becomes very simple
Plus a visual check
The display of edge status (free, contact…)
The display of edge numbering within a thermal node
The EDGES block is a convenient alternative
The classical Edge definition using classical thermal nodes is still supported and can be exported from the conductive module
A new simplified conductive method without edges may be used if accuracy on conductive flux is not required
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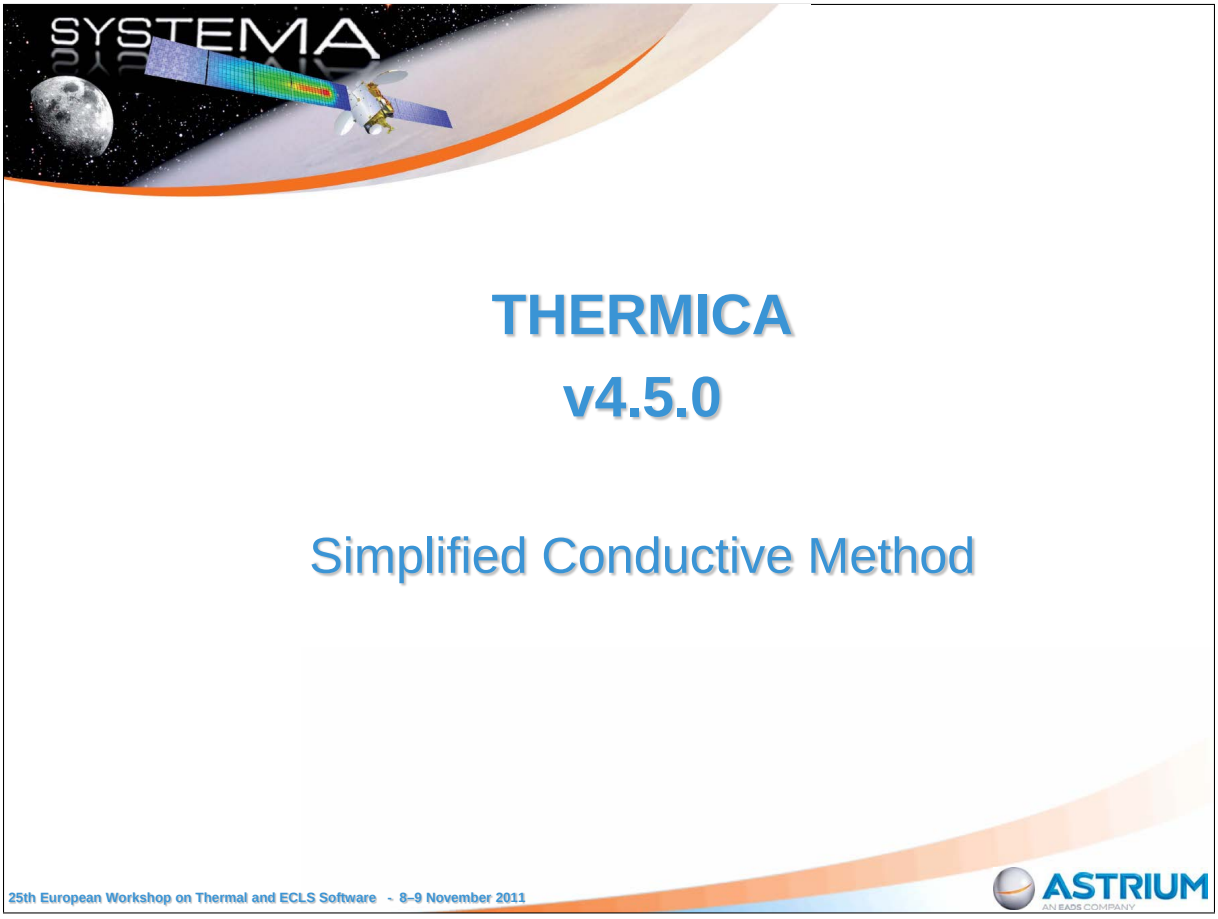
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v4.5.0
Simplified Conductive Method
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Simplified Conductive Module

Need for a simplified method

- The classical shape-to-shape approach was an easy-to-understand method leading to a simple expression of couplings directly related to the conductive heat transfer
- This topology of GL couplings is an approximation of the conductive effects but which may be sufficient if the temperature solution is quite closed to a linear profile
- The oldest geometrical approach had difficulties to handle complex shapes, condensation or non-conformances. The new shape-to-shape conductive coupling method shall handle them correctly in order to avoid the accumulation of approximations.

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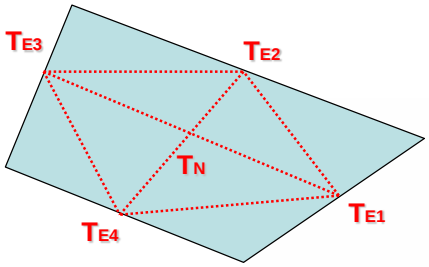
Simplified Conductive Module

Simplified RCN method (1/2)

- Based on the 2nd order RCN method, a simplified expression of the couplings is derived as follow:

Computation of RCN couplings



Expression of Conductive Flux to each Edge

$$\varphi_{Ei} = GL_{N,Ei}(T_N - T_{Ei}) + \sum_{Ej} GL_{Ei,Ej}(T_{Ej} - T_{Ei})$$

Simplification of Temperature Gradients

Assuming a linear temperature profile

$$T_{Ej} - T_{Ei} = \frac{\overrightarrow{E_iN}.\overrightarrow{E_iE_j}}{\left\|E_iN\right\|^2}(T_N - T_{Ei})$$

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Simplified Conductive Module

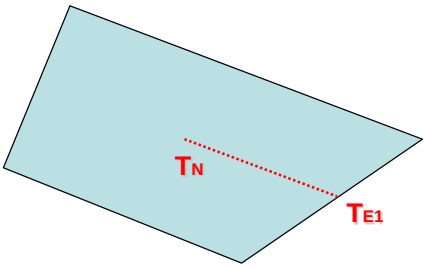
Simplified RCN method (2/2)

Expression of Conductive Flux to each Edge

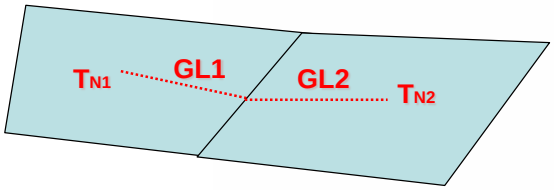
Assuming a linear temperature profile

$$\varphi_{Ei} = \left(GL_{N,Ei} + \sum_{Ej} \frac{\overrightarrow{E_iN}.\overrightarrow{E_iE_j}}{\left\|E_iN\right\|^2} GL_{Ei,Ej} \right)(T_N - T_{Ei})$$

$$= GL^*_{N,Ei}(T_N - T_{Ei})$$



Association of Half Couplings



$$GL_{N1,N2} = \frac{1}{\frac{1}{GL1} + \frac{1}{GL2}}$$

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Simplified Conductive Module

Simplified RCN method: Conclusions

- Equivalent to known formulas in simple cases
  (rectangle, equilateral triangle)
- Hypothesis introduced: Linear Temperature Profile
- Consequences: The Simplified RCN method has the same limitations than all other shape-to-shape formulation but handles complex geometries, condensed nodes and non-conformant mesh
- The conductive flux is approximated and the temperature solution will be less accurate than with the complete RCN method
  But the choice is given to use a simplified expression of couplings

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Other Improvements

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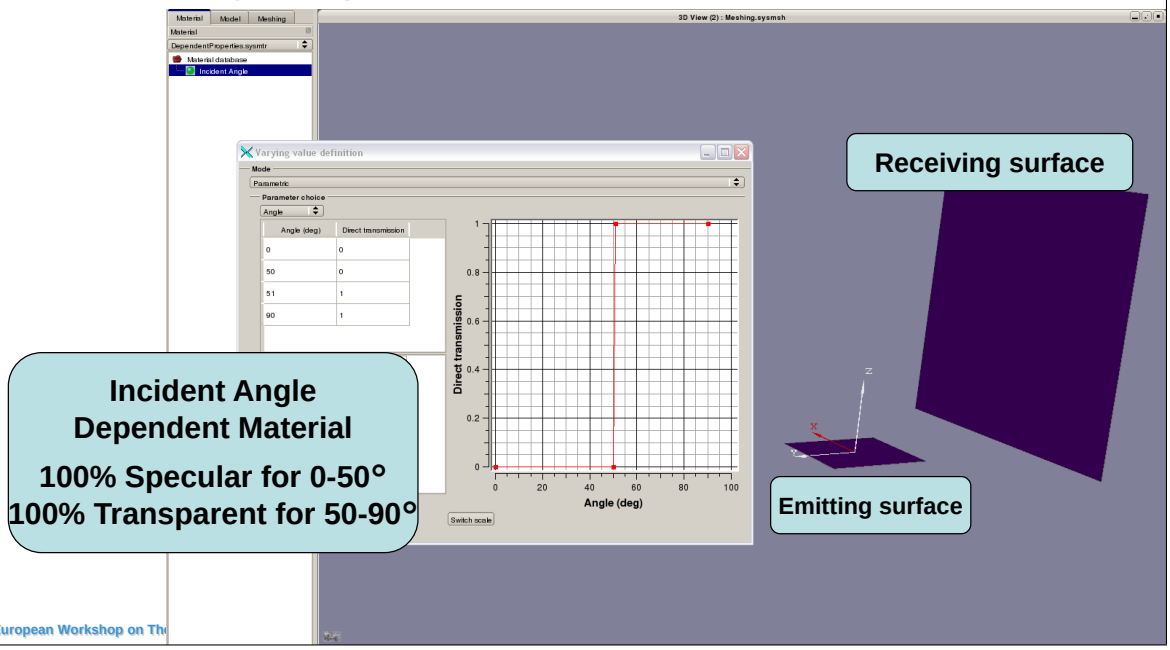
Improvements

- Incident Angle Dependencies

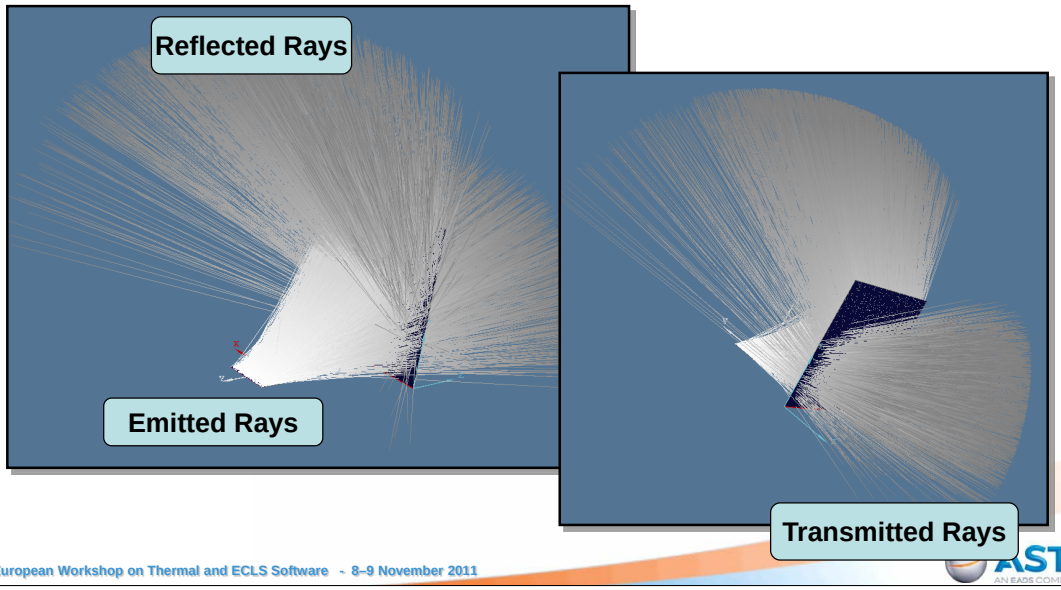


SYSTEMA

THERMICA

Improvements

- Incident Angle Dependencies



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Improvements

- Co-Planar Shapes Management
  - Sometimes, it has been seen that geometrical models had overlaid shapes
    - The Ray-Tracing behavior is not predictable (which shape shall be impacted ???)
  - The version 4.4 already tracks superposed shapes and return warnings
  - Manual model corrections are often a time consuming task
  - Now the 4.5 is able to correct some commonly found errors
  - Errors that cannot be corrected are listed for further manual corrections

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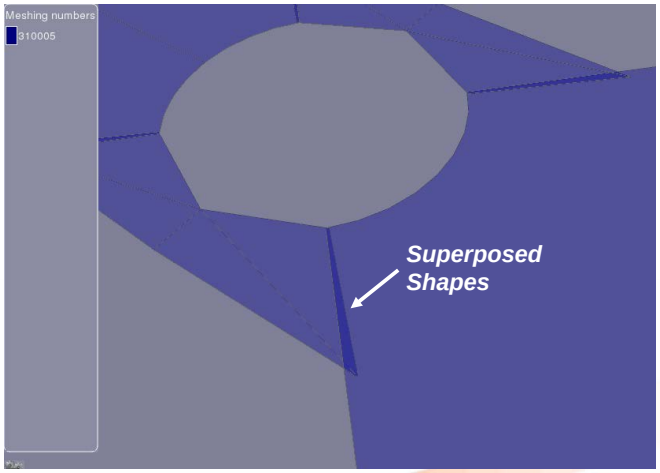
Improvements

Co-Planar Shapes Corrections

- **Inaccurate condensed node**

Corrections:

- Ray density preserved
- Re-computed node area



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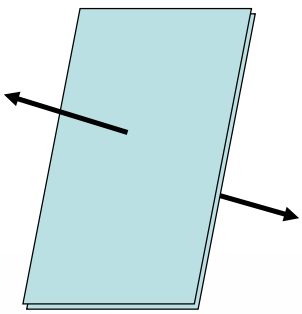
Improvements

Co-Planar Shapes Corrections

- **Distinct shape orientation**

Correction:

- The impact is considered to be on the shape being active on its impacted side



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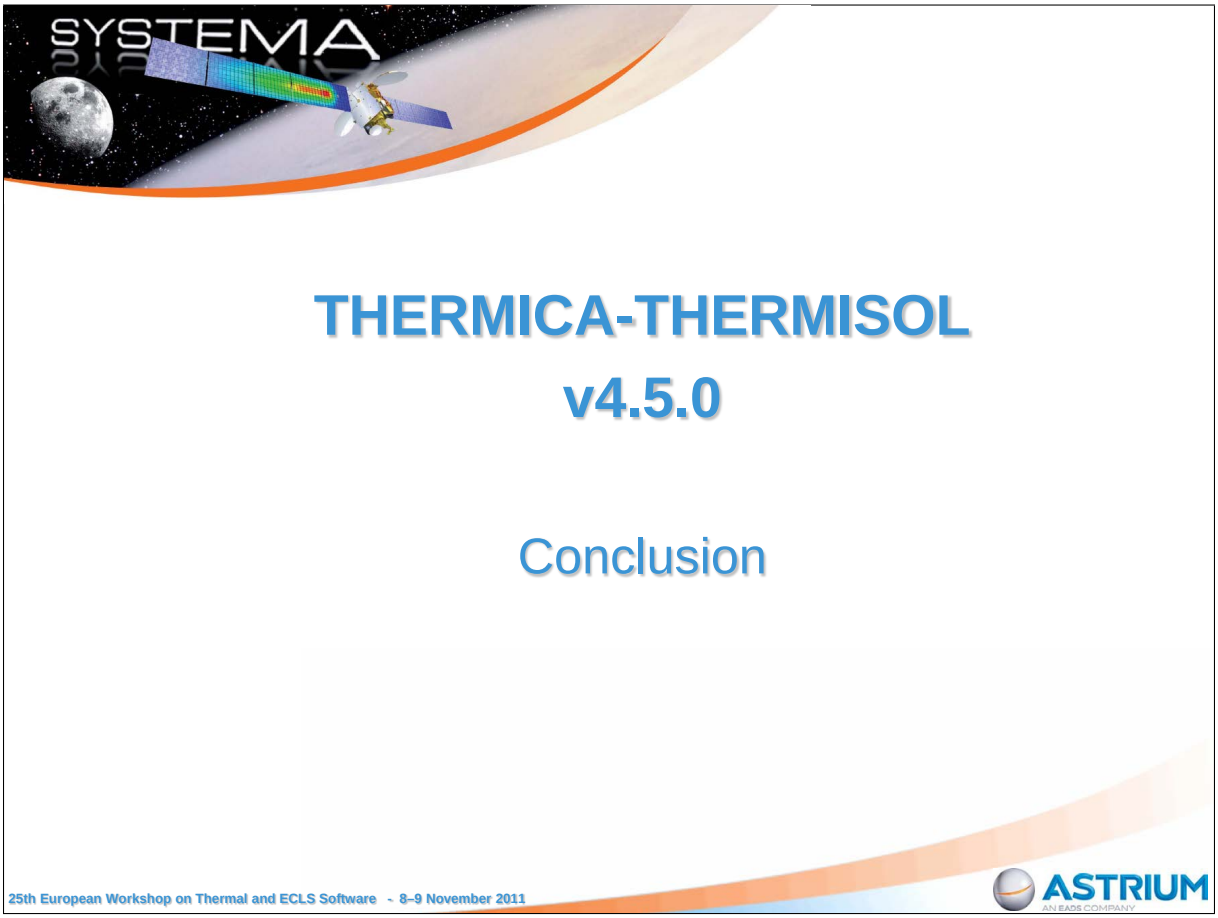
SYSTEMA
THERMICA-THERMISOL
v4.5.0
Conclusion
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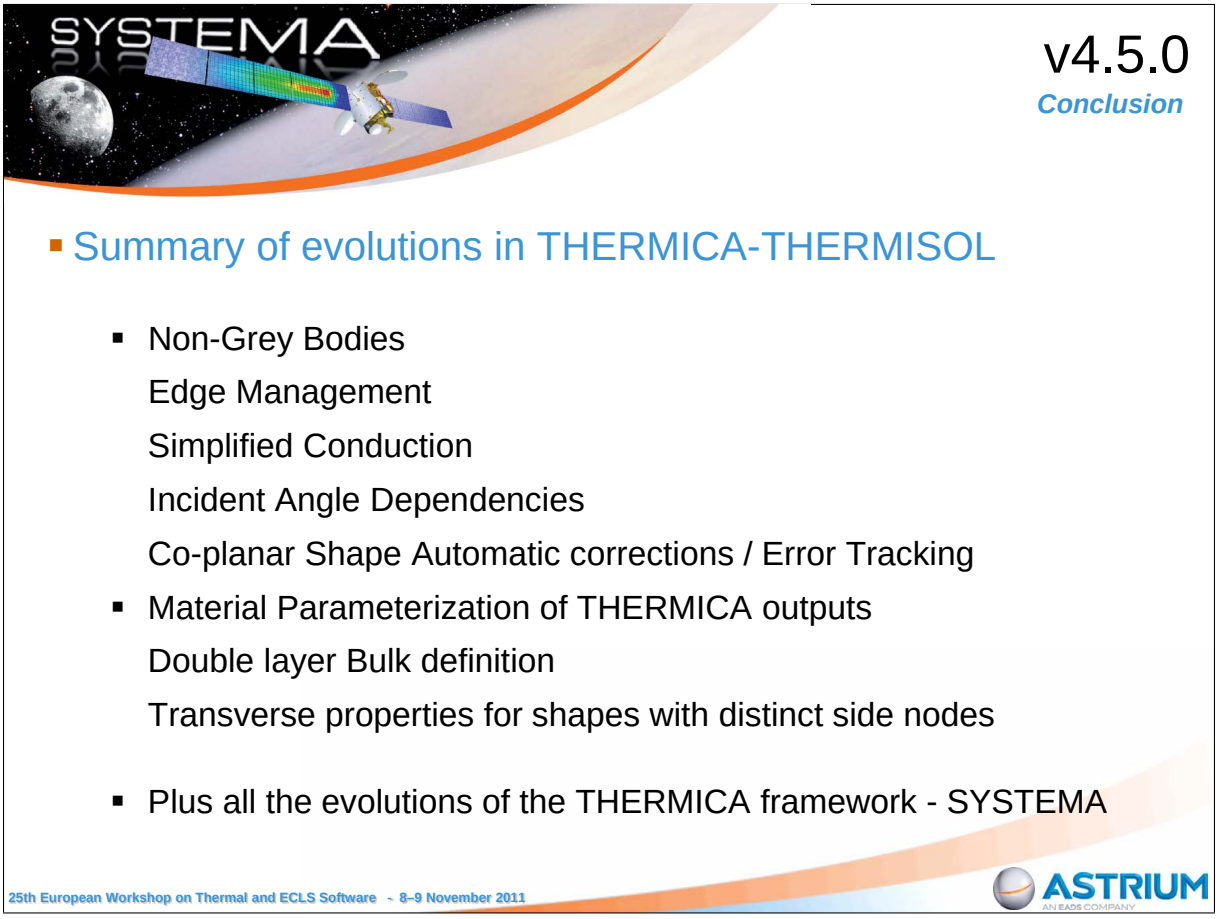
SYSTEMA
v4.5.0
Conclusion
Summary of evolutions in THERMICA-THERMISOL
Non-Grey Bodies
Edge Management
Simplified Conduction
Incident Angle Dependencies
Co-planar Shape Automatic corrections / Error Tracking
Material Parameterization of THERMICA outputs
Double layer Bulk definition
Transverse properties for shapes with distinct side nodes
Plus all the evolutions of the THERMICA framework - SYSTEMA
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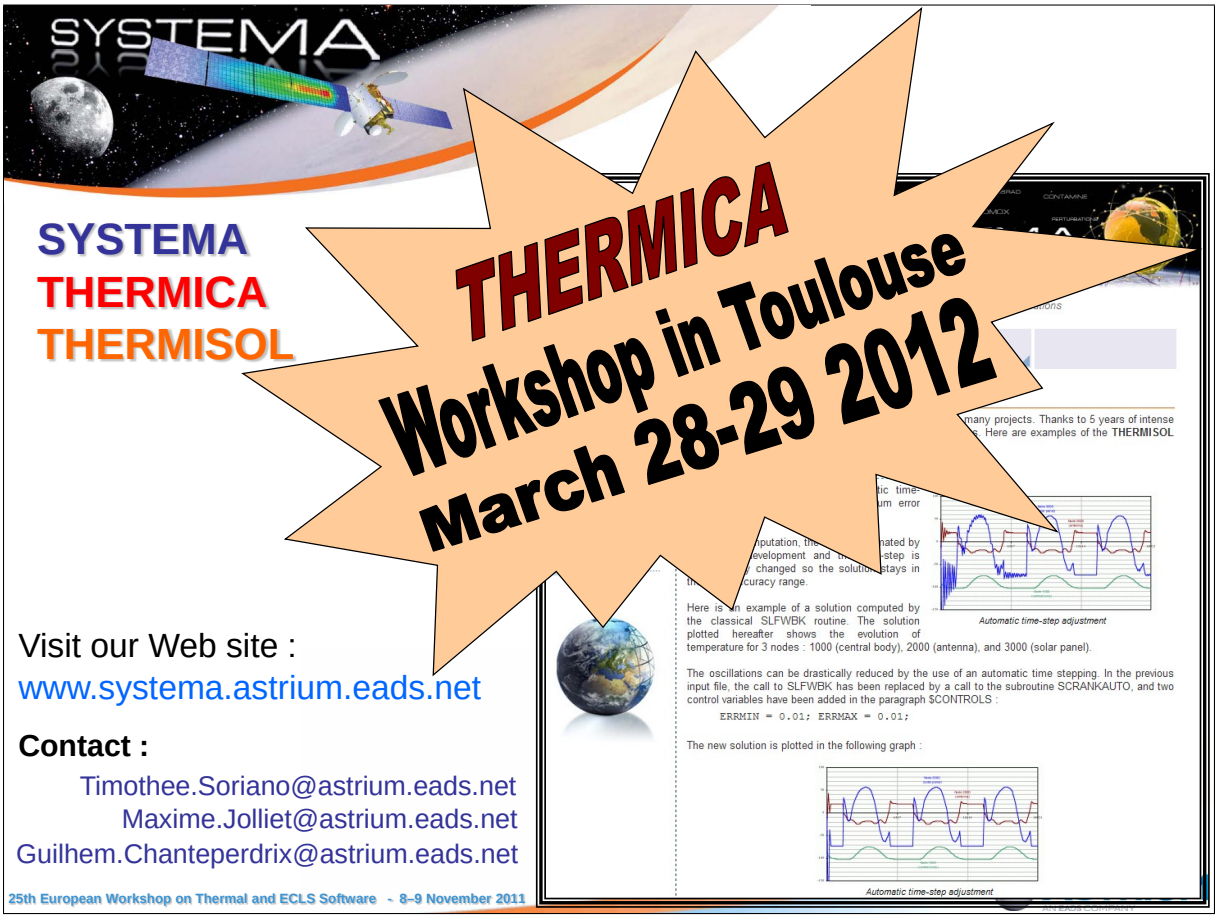
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Automatic time-step adjustment
ERRMIN = 0.01; ERRMAX = 0.01;
Automatic time-step adjustment