Appendix Q

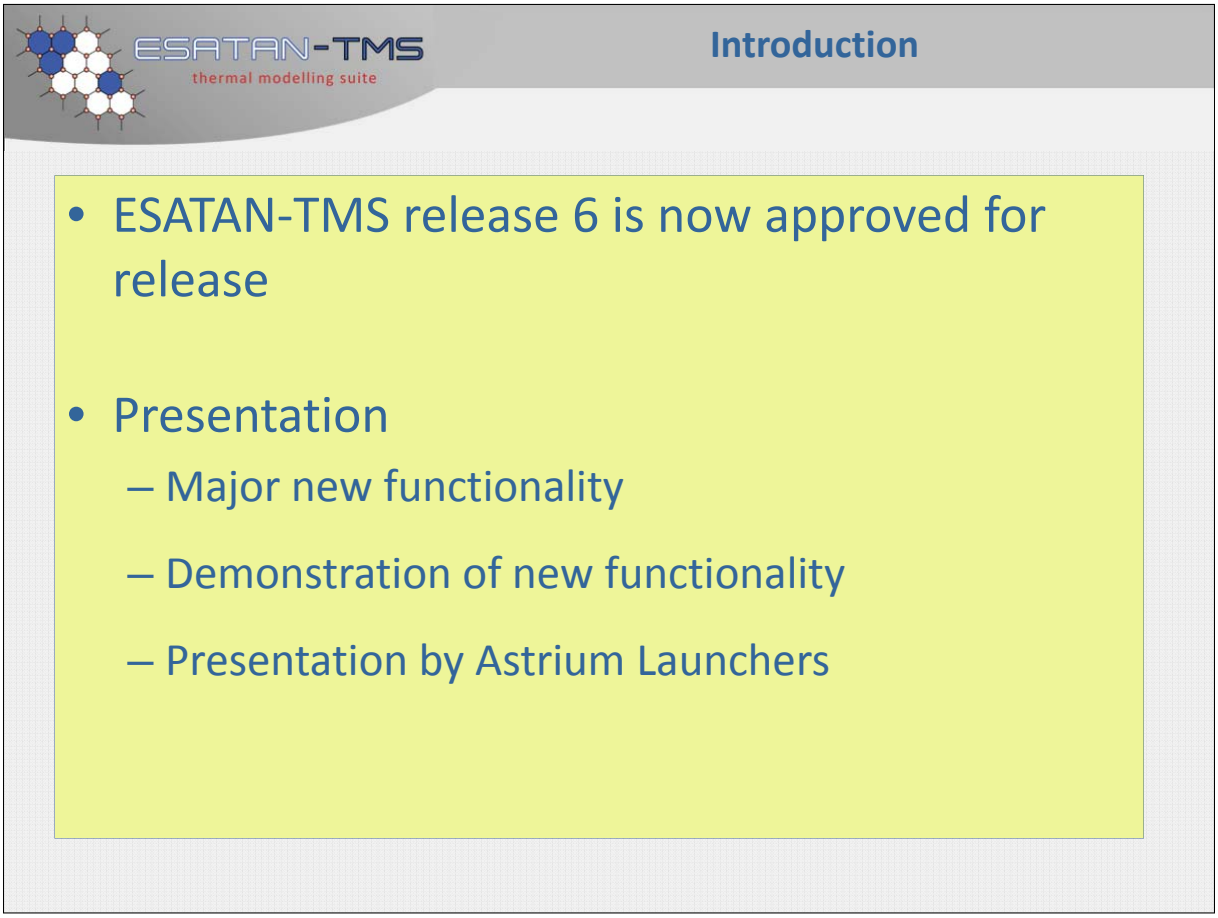
ESATAN Thermal Modelling Suite
Product Developments and Demonstration

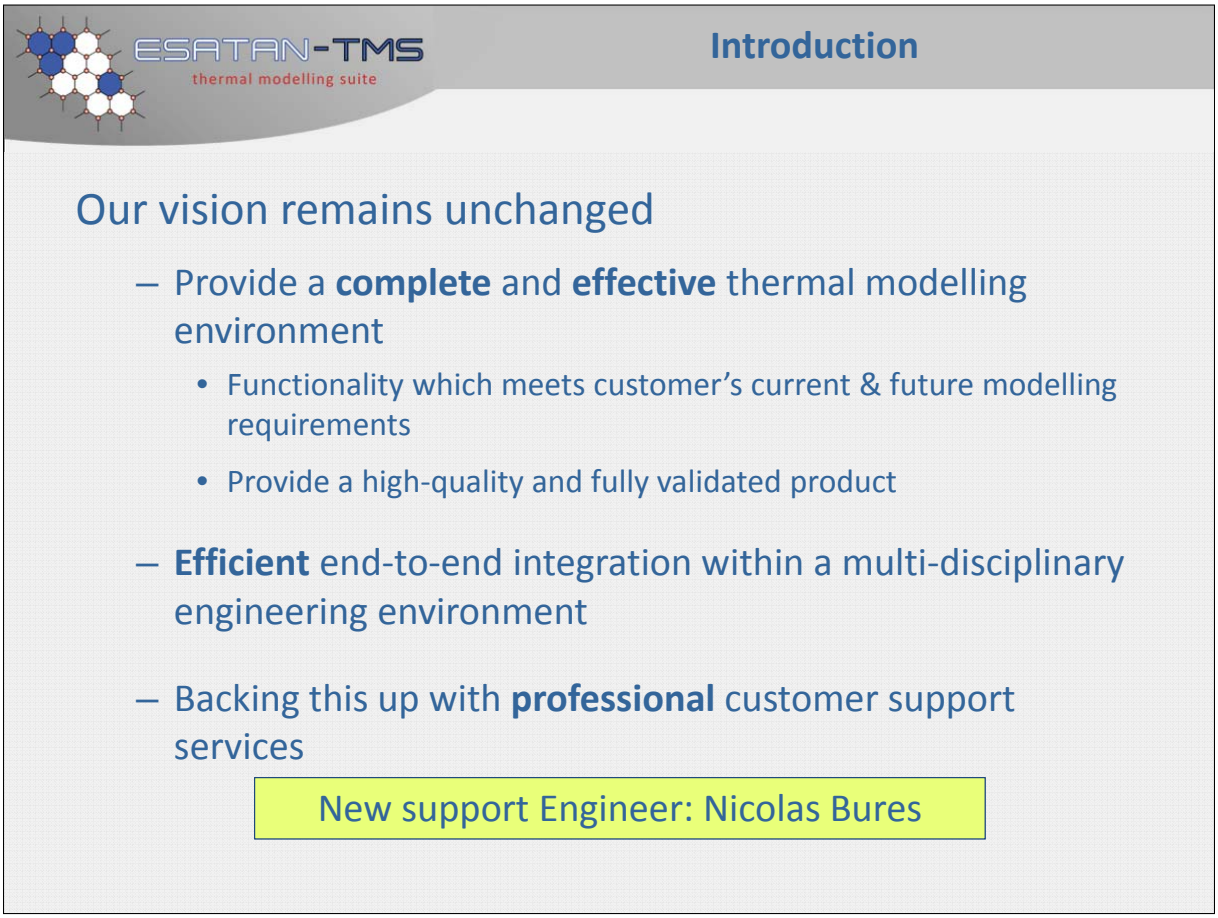
Chris Kirtley Henri Brouquet
(ITP Engines UK Ltd, United Kingdom)

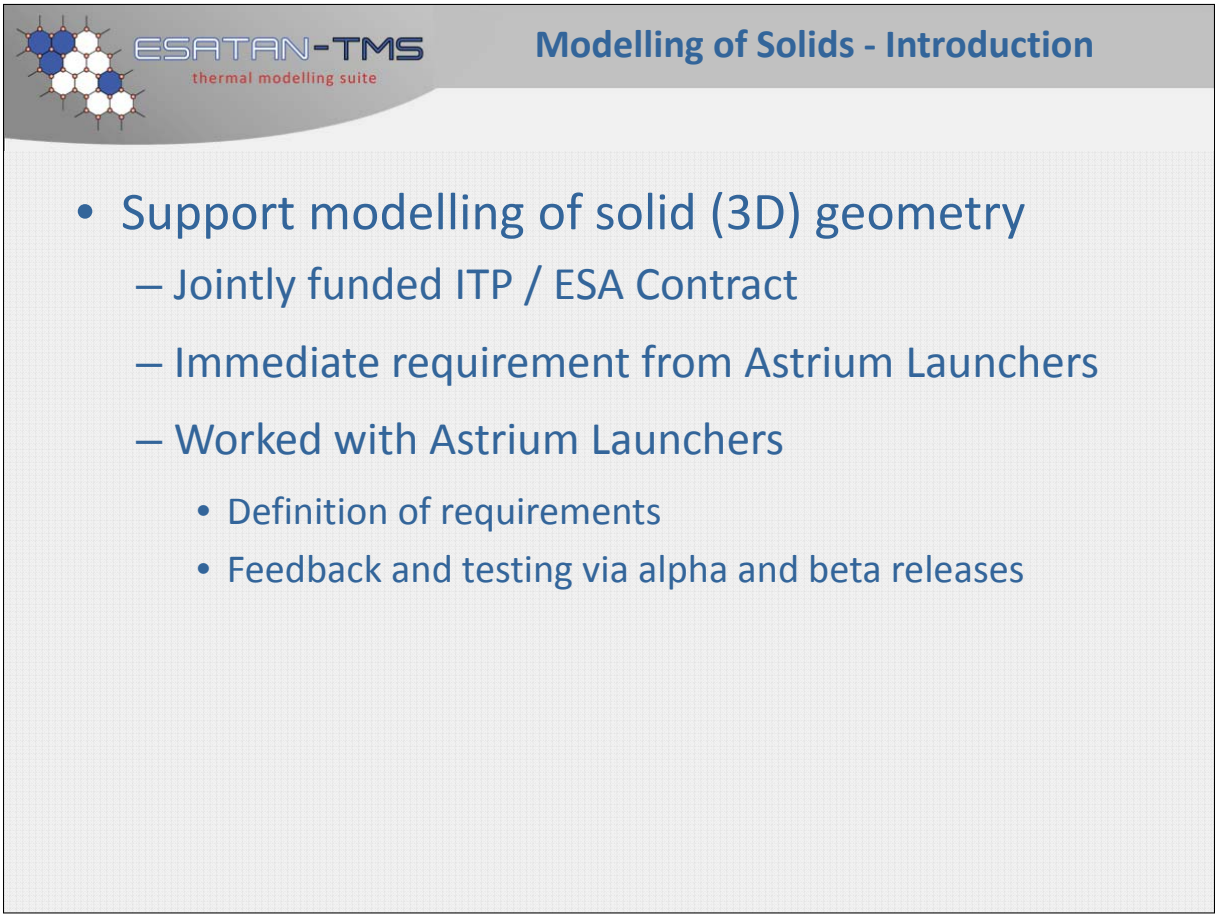
Abstract

ESATAN-TMS provides a complete and powerful integrated thermal modelling environment. ESATAN-TMS r6 sees a major evolution of the product, with advances to its geometry modelling and 3D visualisation capabilities. This presentation outlines the developments going into the new release of the product.
A demonstration of ESATAN-TMS r6 will be given, building a model to demonstrate the new functionality.


ESATAN-TMS
thermal modelling suite
ESATAN-TMS
Product Overview
Chris Kirtley
Henri Brouquet

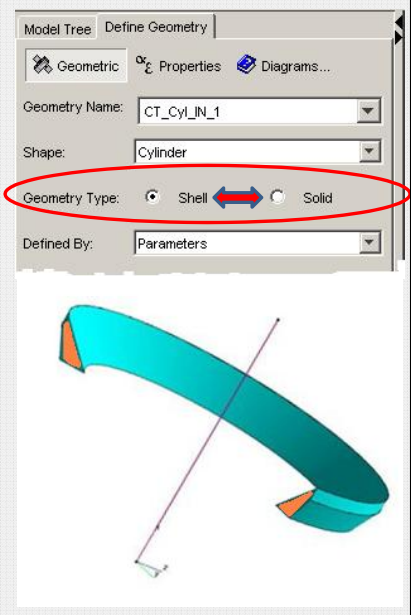

ESATAN-TMS
thermal modelling suite
Introduction
• ESATAN-TMS release 6 is now approved for release
• Presentation
– Major new functionality
– Demonstration of new functionality
– Presentation by Astrium Launchers


ESATAN-TMS
thermal modelling suite
Introduction
Our vision remains unchanged
– Provide a complete and effective thermal modelling environment
• Functionality which meets customer's current & future modelling requirements
• Provide a high-quality and fully validated product
– Efficient end-to-end integration within a multi-disciplinary engineering environment
– Backing this up with professional customer support services
New support Engineer: Nicolas Bures


ESATAN-TMS
thermal modelling suite
Modelling of Solids - Introduction
• Support modelling of solid (3D) geometry
– Jointly funded ITP / ESA Contract
– Immediate requirement from Astrium Launchers
– Worked with Astrium Launchers
• Definition of requirements
• Feedback and testing via alpha and beta releases

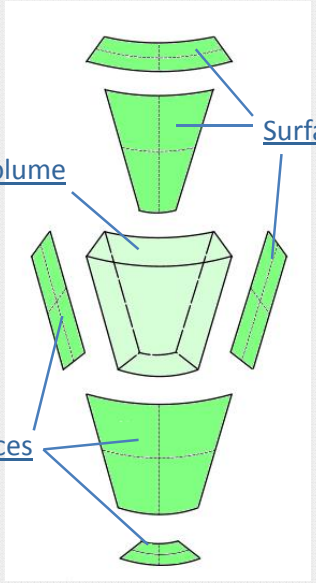
Modelling of Solids - Solid Primitives

- Initial work performed on the product's architecture
- Ability to define a shell or solid primitives
- Logical extension to existing framework
- Solid cone, cylinder, paraboloid, quadrilateral, rectangle, sphere and triangle
- Definition by points or parameters
- Definition of a solid cone or cylinder by rotation of a quadrilateral
- Solid can be truncated or segmented

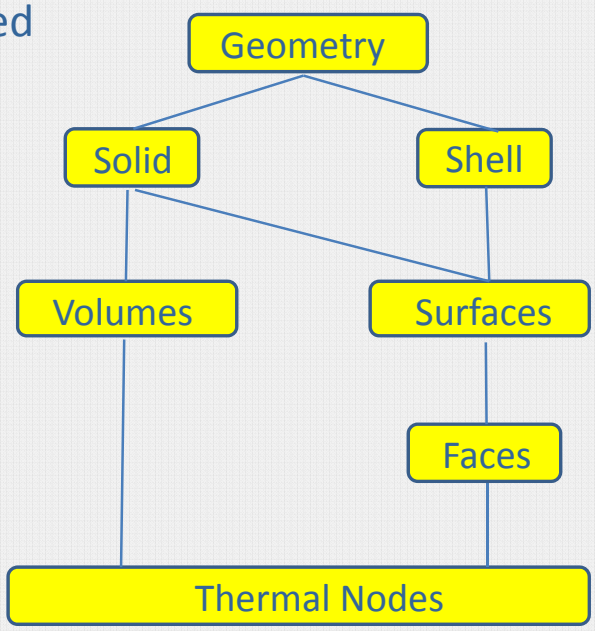


Modelling of Solids - Solid Primitives

- Terminology generalised

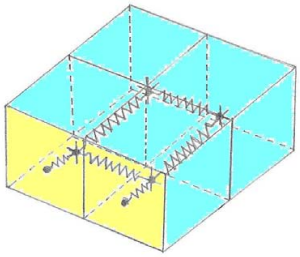


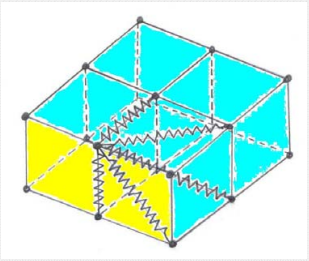
Solid Cone, Truncated & Segmented



Modelling of Solids - Conductance

- **Lumped parameter** and **finite element** analysis supported through the Analysis Type
- Thermal network depends on the analysis type
- Lumped parameter
  - Single thermal node for each volume
  - Volume nodes connected within a solid
  - Arithmetic nodes on external faces
  - Solids connected via Conductive Interfaces

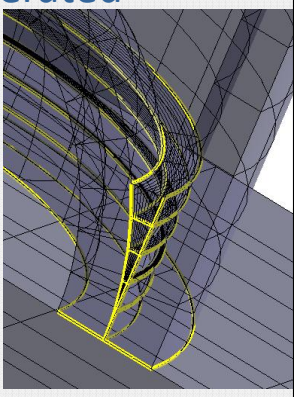




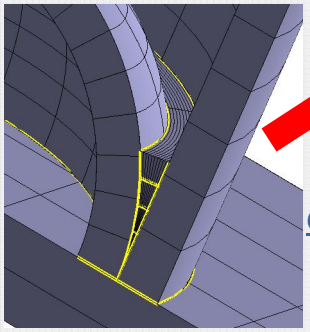
- Finite Element
  - Linear finite elements
  - Thermal nodes at each element vertices
  - Nodes connected to neighbouring nodes

Modelling of Solids - Conductance

- Conductive interfaces are automatically generated
- Detects surfaces in contact
  - Geometry based
  - For LP or LP/FE no reliance on mesh congruency
  - POINT_COINCIDENT tolerance used
  - Fused by default
- Identifies interface exists
- Edit via Process Conductive Interface dialog
- Conductances calculated on output to analysis file



Transparency

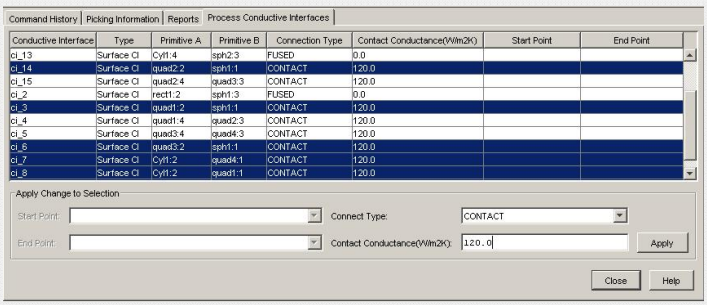


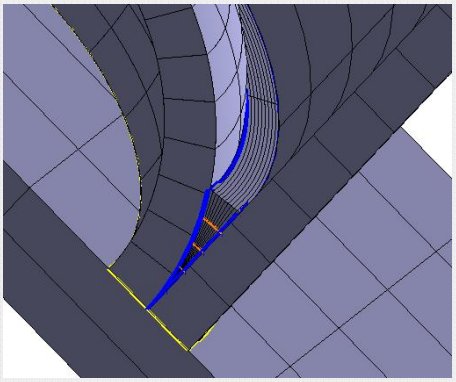
Contact outlined

ESATAN-TMS thermal modelling suite

Modelling of Solids - Conductance

- Process Conductive Interfaces
  - Contact type introduced (point, edge & surface)
  - Select interface in the dialog or in the visualisation
  - Set the contact type (contact , fused or not connected)
  - Multiple selection of interfaces
  - Default type is fused



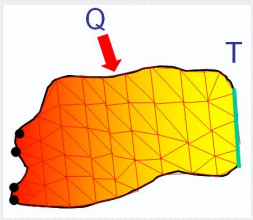


ESATAN-TMS thermal modelling suite

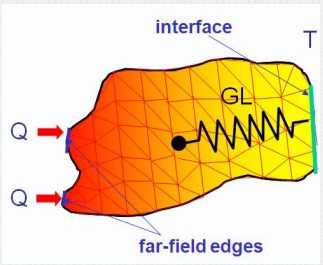
Modelling of Solids - Conductance

- Lumped parameter conductance calculation
  - Calculated on output to analysis file
  - Far-field method extended to 3D geometry
    - Implicit method, derives **understandable** conductances (≡ k.A/x)
    - Generated conductances **represent heat flows**
    - **Generic** method employed within primitives & across interfaces

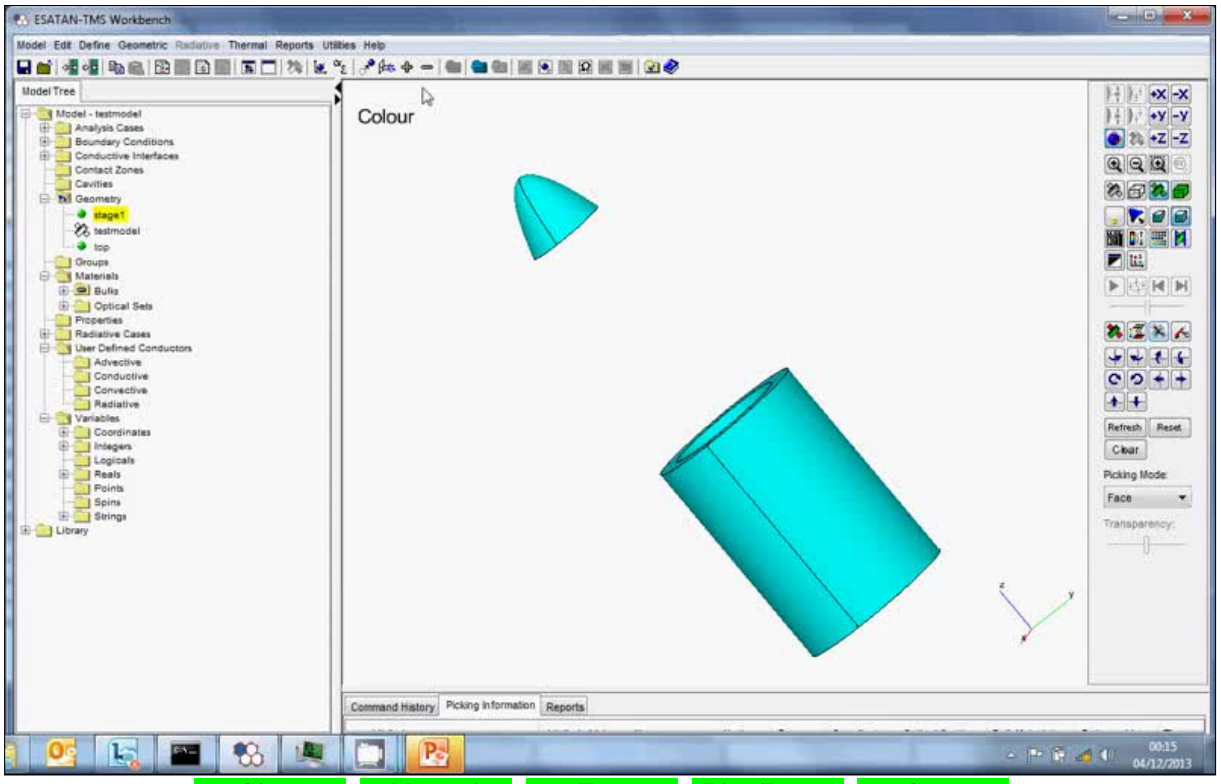
Calculate far-field nodes



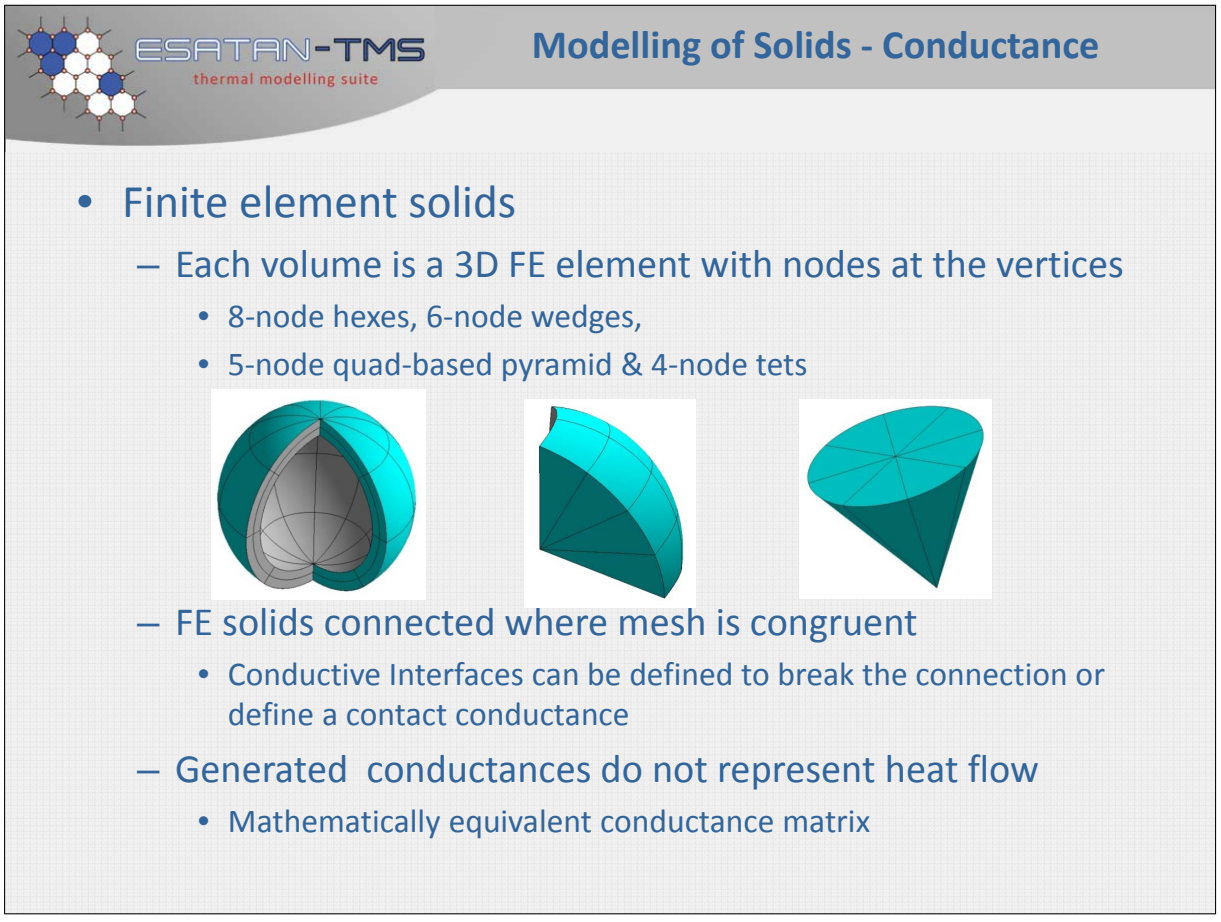
Derive Conductance



- Ref. *Automatic Linear Conductor Generation Solution for Lumped Parameter Models*, ITP & ESA, ICES 2005-01-3059, 2005



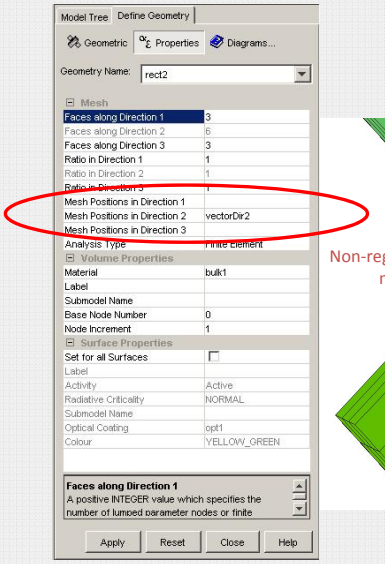
Slow Normal Fast Play/Pause Stop

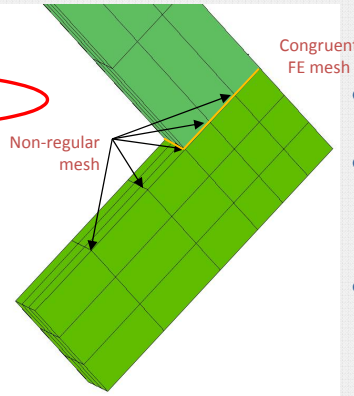


ESATAN-TMS thermal modelling suite

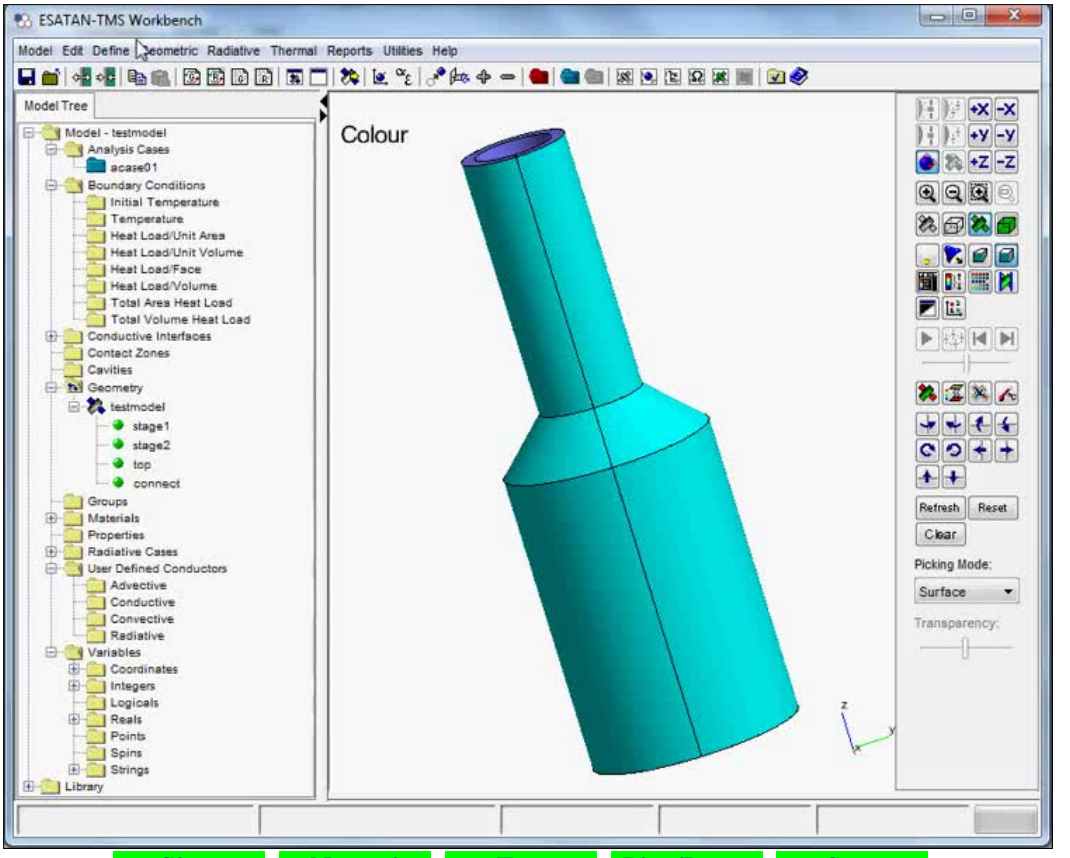
Modelling of Solids - Non-regular Mesh

- New meshing option introduced
- Control of mesh by definition of the mesh positions





- Positions for each direction defined using a vector
- Positions 0.0 => 1.0
- Supported for both shells & solids
- Foundation for future extension



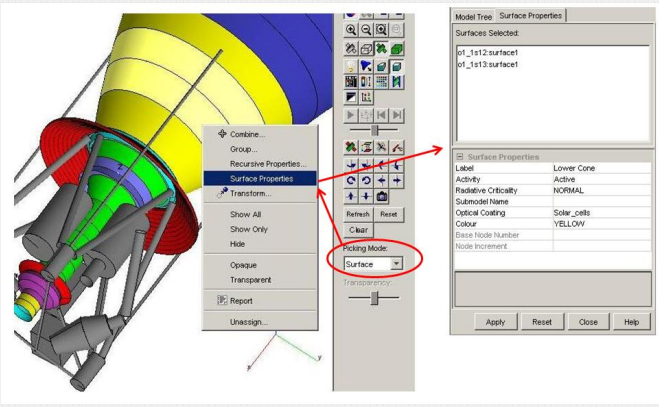
Slow Normal Fast Play/Pause Stop

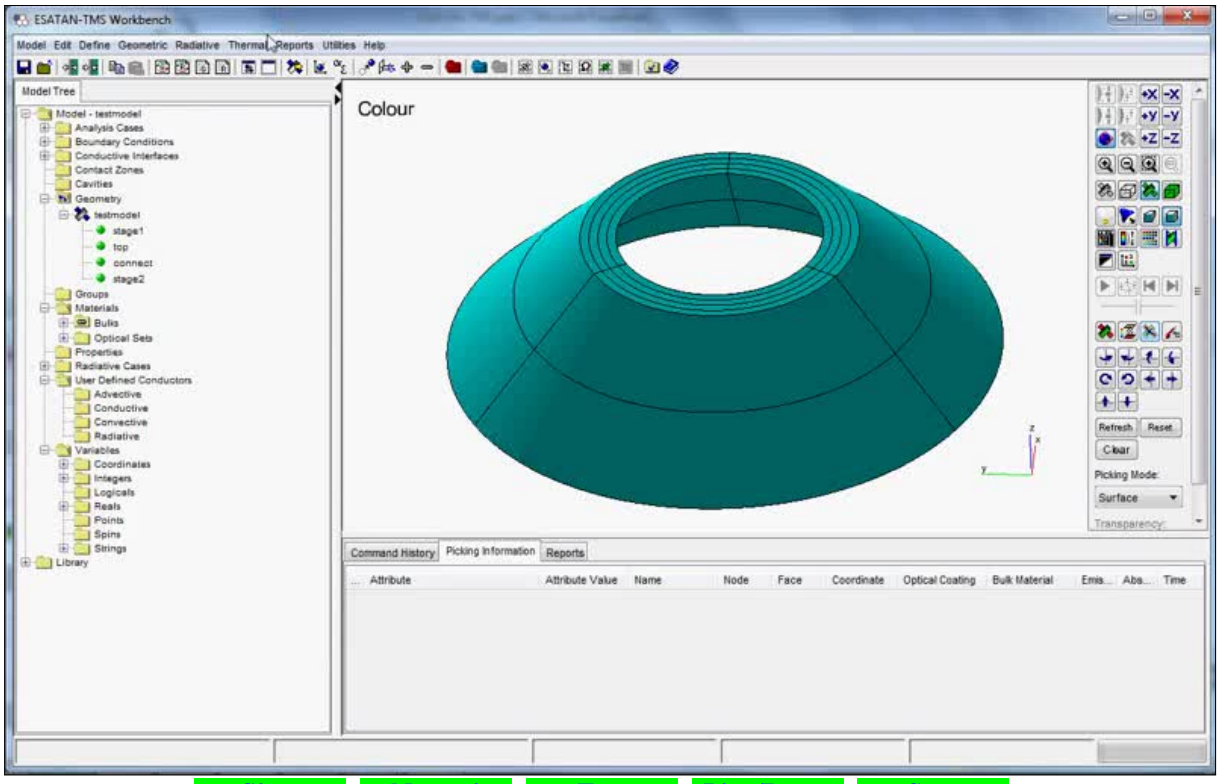
Modelling of Solids - Surface Properties

- Definition of surface properties
  - On definition of shells, individual surface properties can be defined
    - Surface 1 & Surface 2 (was Side1 & Side 2)
    - Optical, criticality, colour, label & submodel name
  - On definition of solids, the same surface properties are applied to all surfaces
  - Ability to set properties to specific surfaces is supported through the Surface Properties dialog

Modelling of Solids - Surface Properties

- Select surface(s)
  - New Surface picking mode available
    - Points, Faces, **Volumes**, **Surfaces**, Geometry, Points & Distance
  - Faces on the selected surface highlighted
  - Multiple selection of surfaces is supported
- Launch Surface Properties dialog
- Define surface properties
- Use pre-process overlays to validate the model

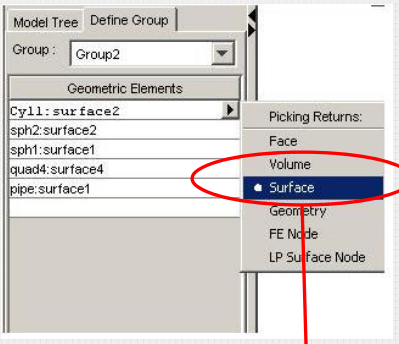


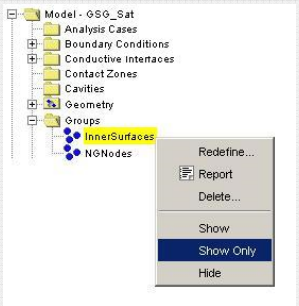


Slow | Normal | Fast | Play/Pause | Stop

Modelling of Solids - Groups

- Support for Groups
  - Introduced in ESATAN-TMS r2
  - Extended for **solids & terminology**
  - Used in the definition of Boundary Conditions, Contact Zones & User-defined Conductors
  - Support definition of lists of **surfaces** and **volumes**
  - Surface & volume picking modes
  - Can also be used to control the display via Show/Show Only/Hide

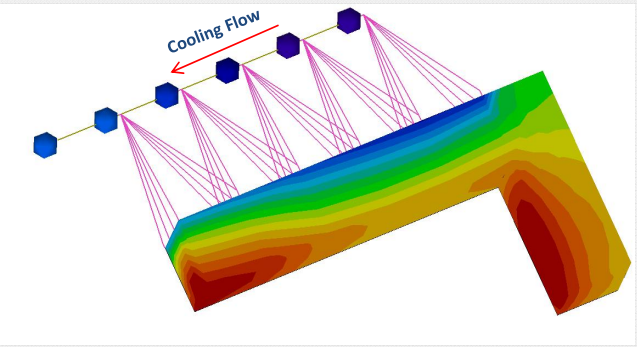




ESATAN-TMS thermal modelling suite

Modelling of Solids - User-defined Conductors

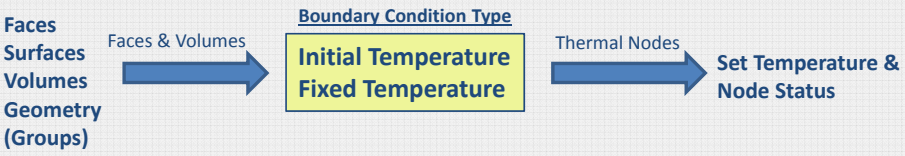
- Support for User-defined Conductors
  - Introduced in ESATAN-TMS r1
  - Extended for **solids & terminology**
    - Links between solid & shell geometry
  - Generate thermal conductors (Conduction, Convection, Advection & Radiation)
  - Workbench to provide a complete thermal modelling environment



ESATAN-TMS thermal modelling suite

Modelling of Solids - Boundary Conditions

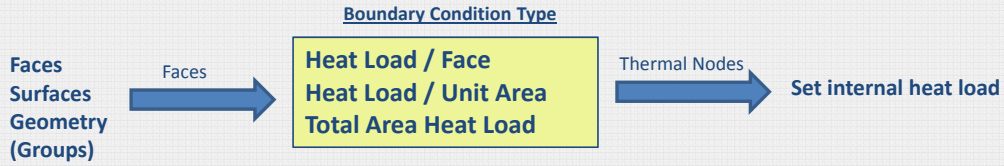
- Additional boundary condition support
  - Boundary conditions introduced within ESATAN-TMS r1
  - Extended for **new terminology**
  - Apply boundary conditions to surfaces & volumes
  - Extended for **boundary conditions on solid geometry**
    - Heat Load / Volume
    - Heat Load / Unit Volume
    - Total Volume Heat Load
  - Supported boundary conditions are:



ESATAN-TMS thermal modelling suite

Modelling of Solids - Boundary Conditions

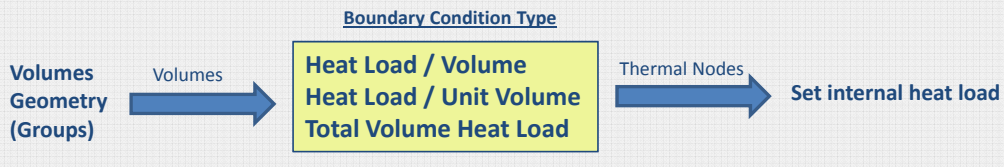
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Modelling of Solids - Boundary Conditions

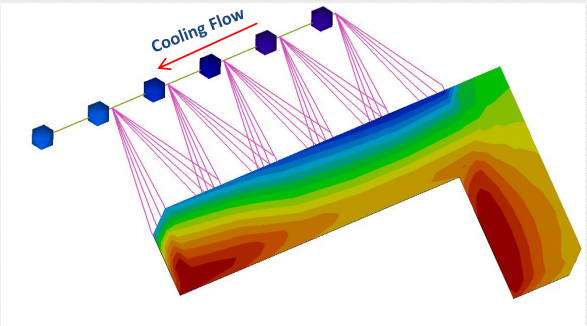
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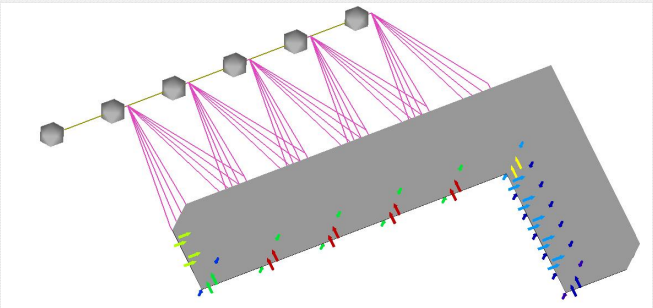


ESATAN-TMS thermal modelling suite

Modelling of Solids - Summary

- Solid geometry
- Non-geometric Nodes & User-defined Conductors representing cooling flow
- User-Defined Conductors modelling convection
- Finite element analysis type
- Non-regular mesh applied





- Heat load applied to surfaces & volumes
- Post-processing temperatures & surface node heat loads
- Complete model built, run & post-processed within Workbench

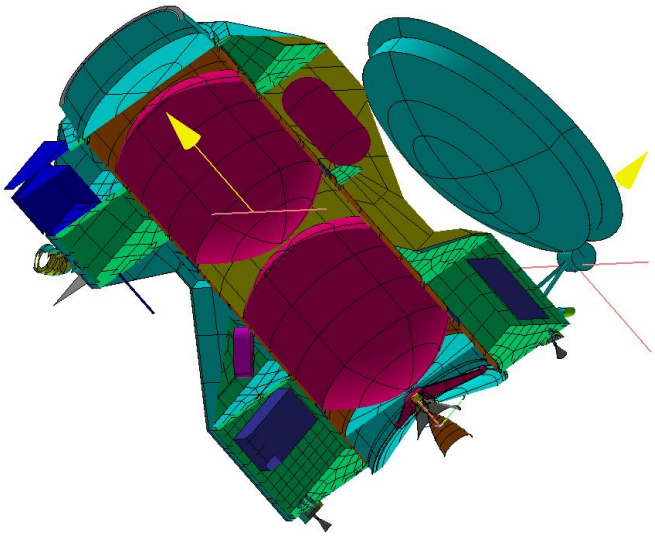
ESATAN-TMS thermal modelling suite

Modelling of Solids - Conclusion

- Modelling of Solids, Conclusion
  - Major architectural development of the product
  - Clean & logical extension to the product
  - 3D version of the primitives
  - Supported throughout the modelling process
    - Groups, User-defined Conductors, Contact Zones, Boundary Conditions, Pre- & Post-process Radiative & Thermal, …
  - Conclusion of ESA contract
  - Meets the immediate needs of Astrium Launchers

ESATAN-TMS
thermal modelling suite

Courtesy of OHB System AG

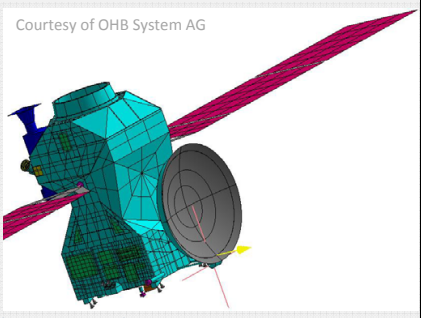


Radiative Cavities

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thermal modelling suite

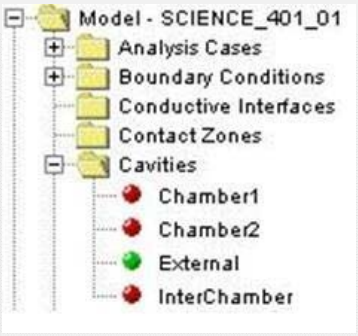
Radiative Cavities - Introduction

Courtesy of OHB System AG

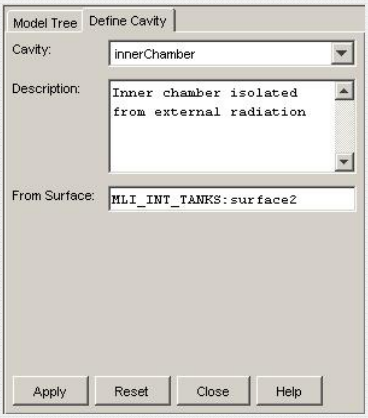


- Modelling of Radiative Cavities
  - Request from industry
  - Partition a model into cavities
  - Each cavity is radiatively isolated
    - Internal geometry can be modelled as enclosures
    - External geometry REFs depend on orbital position
  - Repeat radiative analysis only if cavity's geometry or optical properties change
  - Leads to more efficient thermal modelling

Radiative Cavities - Definition

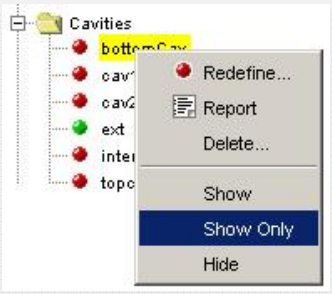


- Definition of a cavity
  - New Cavity symbol on the model tree
  - Create named cavities
  - Specify a surface to define a cavity

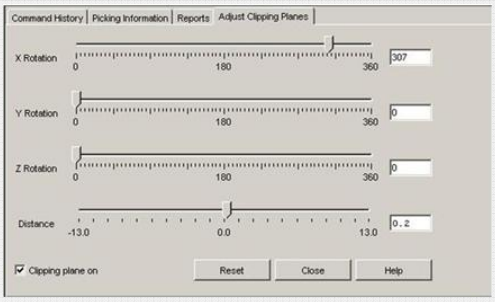


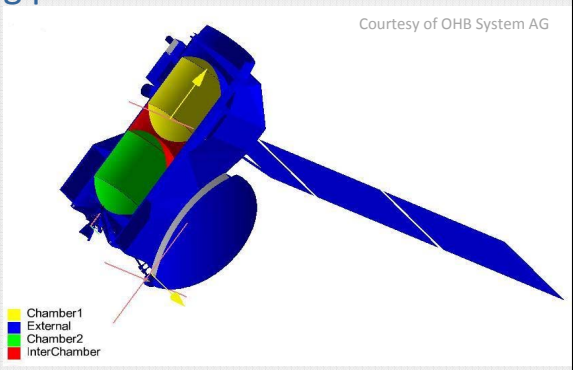
  - View factor calculation performed on complete model
  - VF results stored for future cavity def'n
  - Cavity definition "out of date" only if cavity geometry or optical properties change
  - Improved "sensitivity" of VF/REF/HF results

Radiative Cavities - Post-processing



- Report cavity definition
- Show/Hide cavity geometry
- New cavity overlay
- New "clipping planes" functionality
  - Fixed clipping plane w.r.t. model
  - Translate or rotate clipping plane
  - Clipping plane On / Off

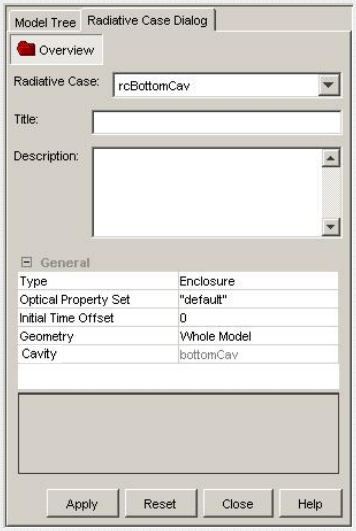




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Radiative Cavities - Radiative Analysis

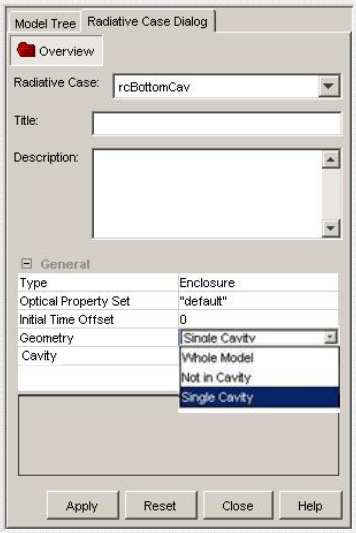
- Radiative analysis performed on each cavity
  - Introduced Geometry attribute on Radiative Case definition



ESATAN-TMS thermal modelling suite

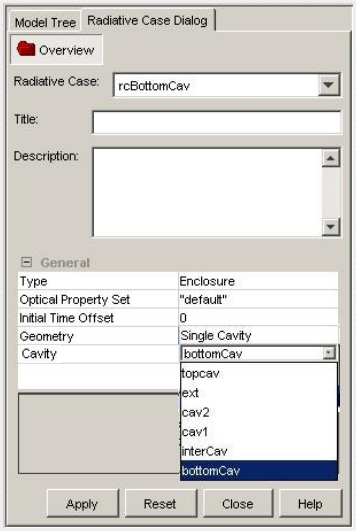
Radiative Cavities - Radiative Analysis

- Radiative analysis performed on each cavity
  - Introduced Geometry attribute on Radiative Case definition
  - Select geometry, Whole Model, Cavity or Not in Cavity
  - Default Whole Model



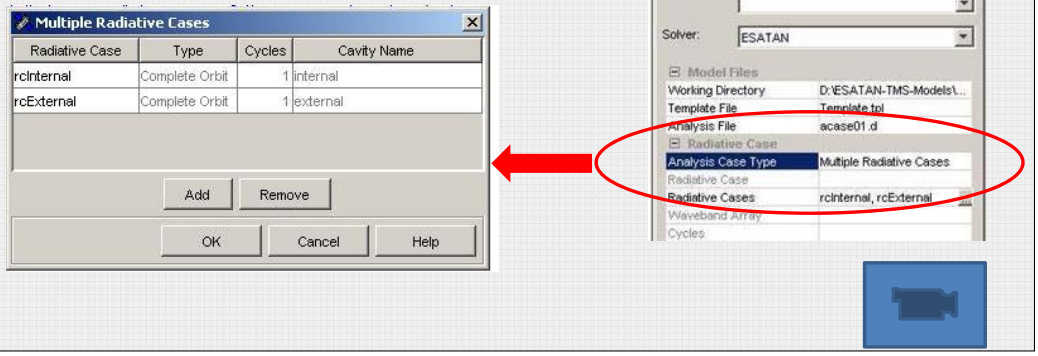
Radiative Cavities - Radiative Analysis

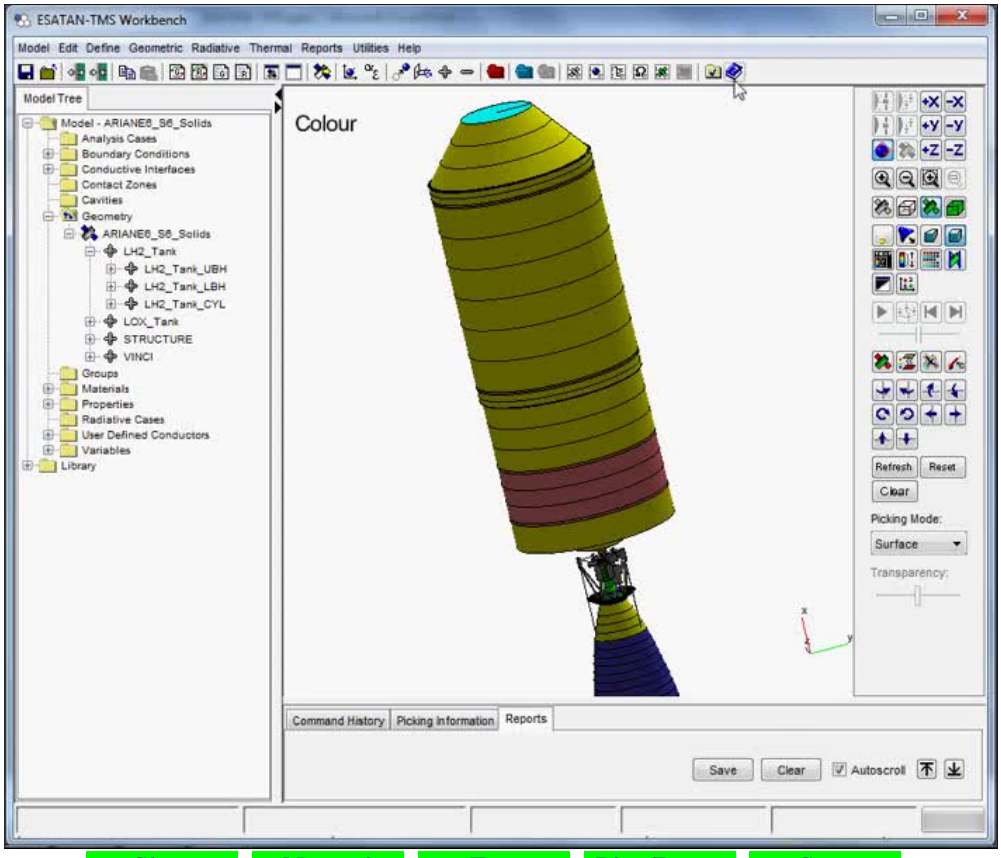
- Radiative analysis performed on each cavity
  - Introduced Geometry attribute on Radiative Case definition
  - Select geometry, Whole Model, Cavity or Not in Cavity
  - Default Whole Model
  - Select Cavity
  - VF/REF/HF results depend only on cavity geometry/properties



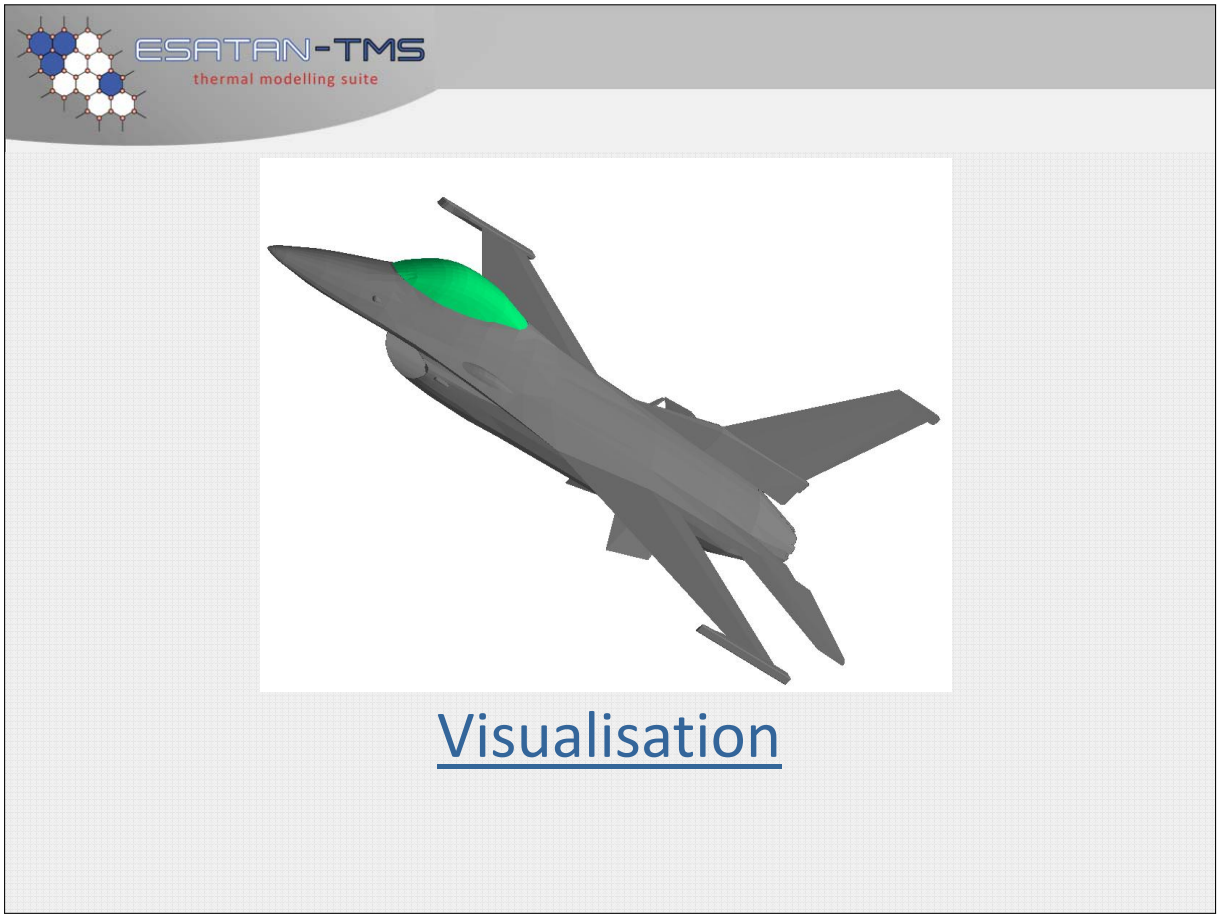
Radiative Cavities - Thermal Analysis

- Analysis Case used to run the analysis as a single case
  - New Analysis Case Type “Multiple Radiative Cases”
  - Select Radiative Cases
  - Generate single analysis file
  - Post-process thermal results as normal





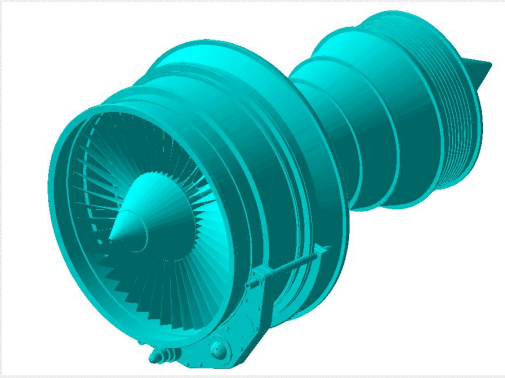
Slow Normal Fast Play/Pause Stop



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3D Visualisation

- Visualisation is the heart of Workbench
- More & more functionality driven from the visualisation
  - Interactive model construction
  - Pre- & post-processing of data
- Complete re-write of 3D visualisation component
- Third-party high-performance graphics library
- Major architectural change
- Graphics performance significantly enhanced



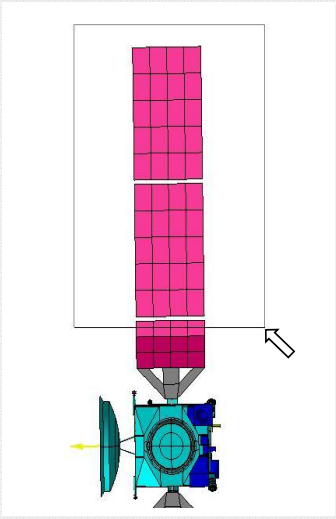




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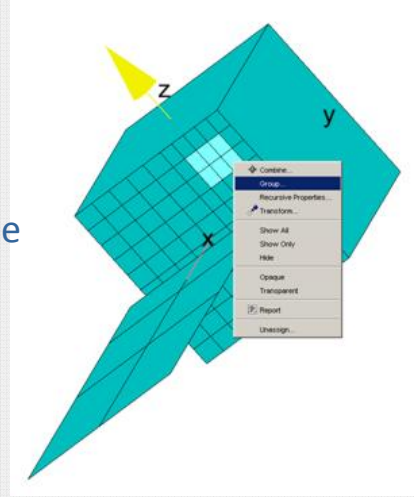
3D Visualisation – Multiple Selection

- Improved highlighting mechanism
  - True highlighting of selected entities
  - Select points, faces, volumes, surfaces & geometry
- Support for multiple selection
  - Ctrl-select or box-select supported
  - Concept of current selection
  - Selection depends on picking mode



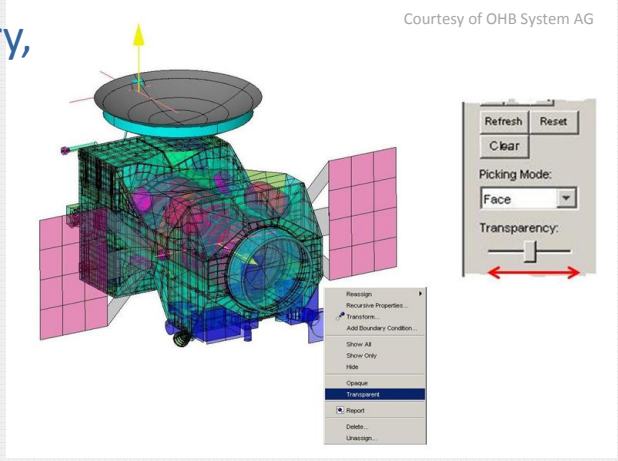
3D Visualisation - Interactivity

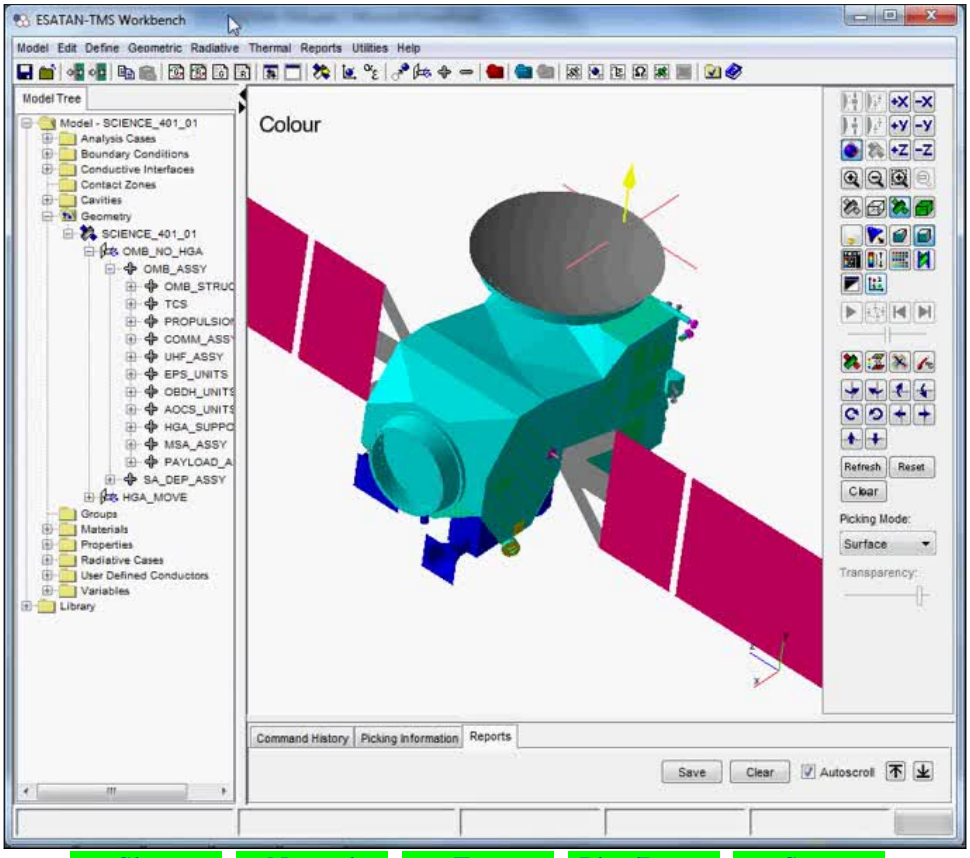
- Improved highlighting mechanism
  - True highlighting of selected entities
  - Select points, faces, volumes, surfaces & geometry
- Support for multiple selection
  - Ctrl-select or box-select supported
  - Concept of current selection
  - Selection depends on picking mode
  - Dialogs updated to work with multiple selection
    - Groups dialog
    - Combine Geometry dialog
    - Process Conductive Interfaces dialog



3D Visualisation - Transparency

- Support for transparency provided
- Select geometry from model tree or visualisation
- Global transparency level
- Expose internal geometry, conductive interfaces, cavities, ….





Slow | Normal | Fast | Play/Pause | Stop

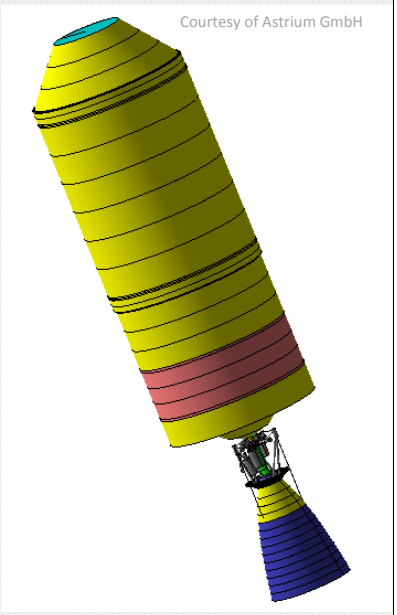
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thermal modelling suite

ESATAN-TMS r6 - Overall Conclusion

- ESATAN-TMS release 6 is now approved for release
- >10 man-years of development
- Major architectural changes to the product

ESATAN-TMS r6 - Overall Conclusion

- Support for 2D and 3D geometry
  - Major architectural change
  - Clean & logical extension
  - Terminology & solids support extended through the product
  - Performed under joint ESA / ITP contract
  - Meets the primary requirements of Astrium Launchers
    - Involvement in the definition of the requirements
    - Provision of alpha & beta releases



ESATAN-TMS r6 - Overall Conclusion

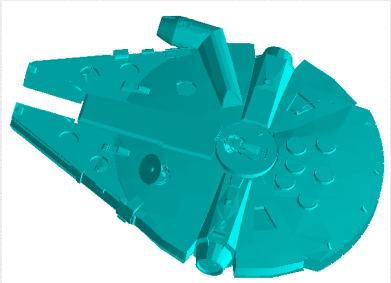
- New visualisation component
  - Major architectural change
  - High-performance graphics
  - Provide platform for future developments
  - Added transparency, revised clipping plane & multiple selection

The large investment demonstrates both ESA's and ITP's continued commitment to ESATAN-TMS

ESATAN-TMS thermal modelling suite

Future Development

- Where are we going?
  - "Provide a **complete** and **effective** thermal modelling environment"
    - Further developments are already underway
    - Create more of the thermal model through Workbench
    - Efficient handling of the thermal data
    - Better pre- & post-processing of data, the right information at the right time of the process

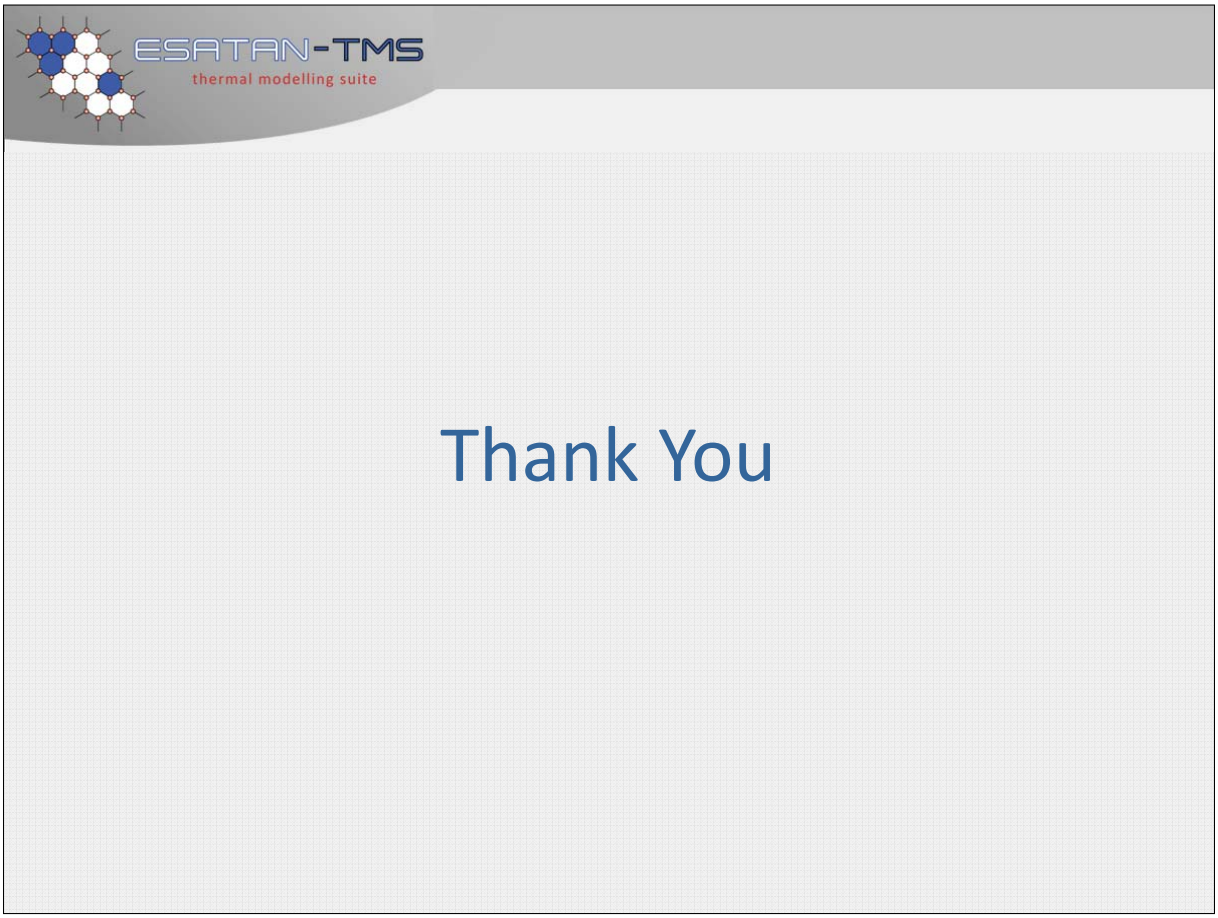


ESATAN-TMS thermal modelling suite

Overall Conclusion

- Input through the customer survey
  - Currently processing results from recent survey
  - Thank you for your response to the survey
  - Information will be fed directly into our development plan
  - Prize winner is Bryan Shaughnessy, Head of the Thermal Engineering Department at RAL Space




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Thank You