Appendix S

First Application of Esatan-TMS r6 Solids for a Launcher Upper Stage Thermal Model

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Abstract

The development of this new feature of Esatan was driven by the need for thermal software that allows a volumetric modeling for heavy launcher structures and the applied thermal protection with thicknesses of up to several cm. This presentation assesses the first experiences with this tool applied on an existing upper stage model created within the Ariane 6 development program. Due to the early project status with a limited number of nodes this model is considered a good test. The advantages in particular of the automatic conductor generation (ACG) in comparison with the previous shell approach will be discussed.

First Application of Esatan-TMS r6 Solids for a Launcher Upper Stage Thermal Model

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Esatan-TMS – Why Solid Modelling?

- The development of Esatan r6 was based on the needs of Astrium Les Mureaux and Bremen for a common thermal software for launcher development
- Special emphasis was laid on the introduction of solid type nodes in addition to the usual shell nodes
- It was of particular interest to get a software that was able to generate the majority of the linear conductors within a model (ACG)
- Experiences with ACG in r5 where a thickness and bulk properties were assigned to shells were not satisfying
- This is explained on the following slides

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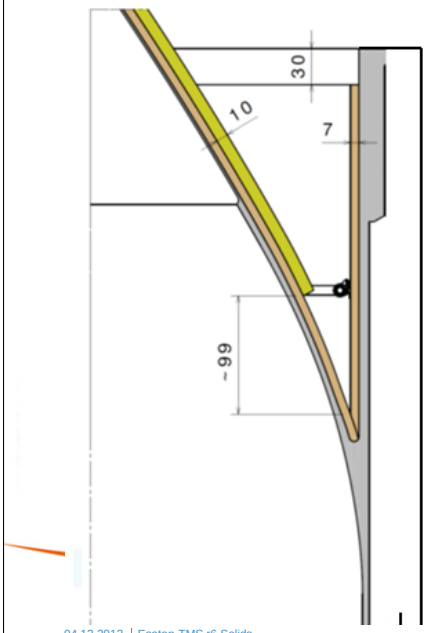
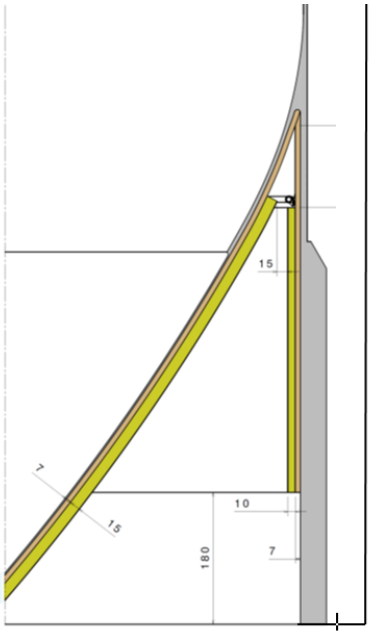
Esatan-TMS – Why Solid Modelling?

- The sample below shows a typical configuration that requires Solid Modelling



- Propellant tank upper skirt and bulkhead (left) and lower skirt and bulkhead (right)
- Structure with varying thickness
- Multiple layers of thermal insulation
- Thickness depending surface areas



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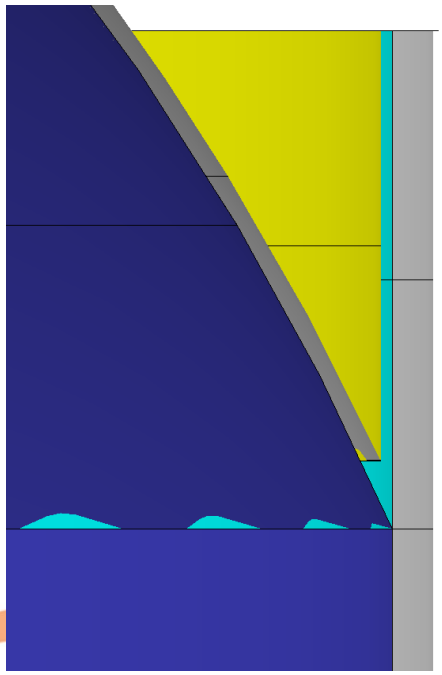
Esatan-TMS - Modelling with Shells in r5 - 1

- Insulation surfaces are represented by shells
- Structure is represented by shells (geometrical thickness neglected)
- Advantage of this approach:
  - Surface areas are defined correctly
- Disadvantage:
  - Only partial ACG application is possible due to conflicts with inner/outer area and node numbers
  - Work around was to use multiple GMMs for structure GLs, for insulation GLs and for radiation to be then combined in one TMM



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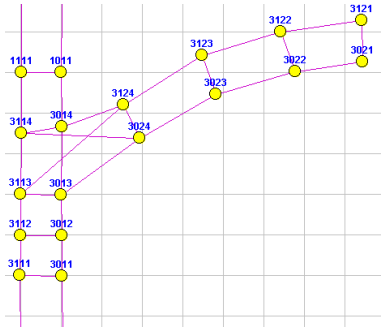
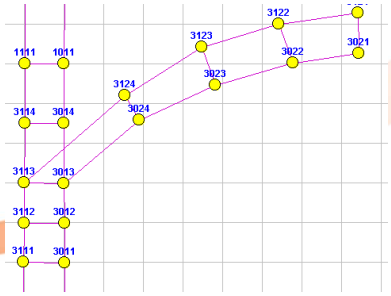
Esatan-TMS - Modelling with Shells in r5 - 2

- In this approach the structure and the applied insulation layers are represented by one shell only.
- Advantage of this method:
  - All conductive links except in case of multiple insulation layers are automatically generated by ACG
- Disadvantage:
  - For the latter case only one conductor can be computed by ACG
  - Further disadvantage: Surface areas are not correctly computed
  - Wrong conductors are generated at junctions (next slide)

Esatan-TMS - Modelling with Shells in r5 – 2 (cont'd)

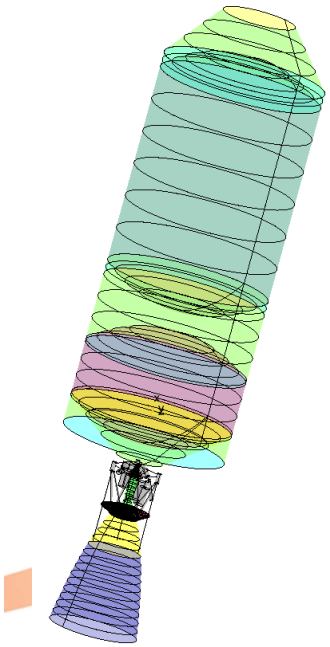
- At the junction tank/skirt wrong conductors are generated as shown in the upper figure:
  - Bulkhead insulation node 3124 is connected to outer insulation node 3113
  - Bulkhead structure node 3024 is connected to outer insulation node 3114
- Redefining conductive interfaces as shown in the lower figure does not solve the problem
- Manual work around required, i.e. delete the relevant GLs from the results file





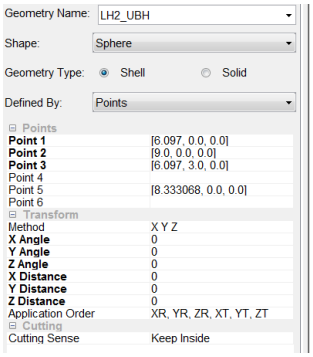
Esatan-TMS - Solid Modelling in r6

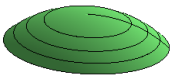
- Testing was already done in Astrium with previous Alpha and Beta versions leading to some discussions with ITP
- The Esatan version that is subject of the current presentation is r6rc5 which is already quite close to the final release and was available since 3 weeks from today
- An existing simple model of an Upper Stage that consists of two propellant tanks, the structure and the engine was selected for the first application
- Due to the limited time frame only the upper (LH2-) tank was transformed into solids
- The figure is shown in the new transparent mode that allows a view inside without cutting

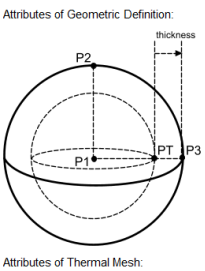


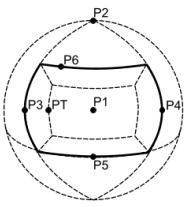
Esatan-TMS – Issue with Spheres in r6

- This issue concerns the definition of points 5 and 6 that cut a full sphere to a calotta
- In r5 only one coordinate is sufficient as shown in the sample
- Using this definition for solids leads to ignoring this point, i.e. the full sphere appears
- r6 requires a second coordinate to define the point laying on the sphere‘s surface although this could easily be computed by the software
- Problem: when one of the coordinates is wrong it is not clear where Esatan puts the cutting plane (no warning given)



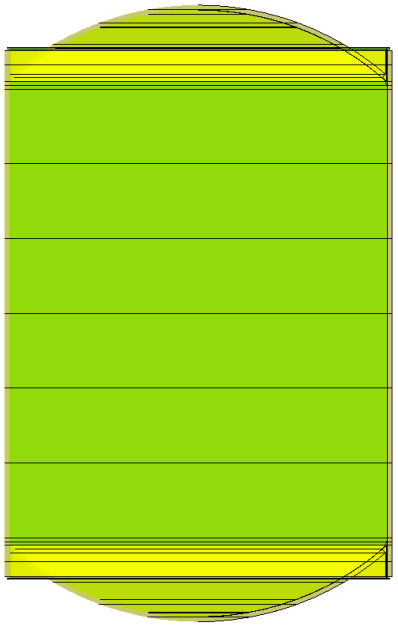






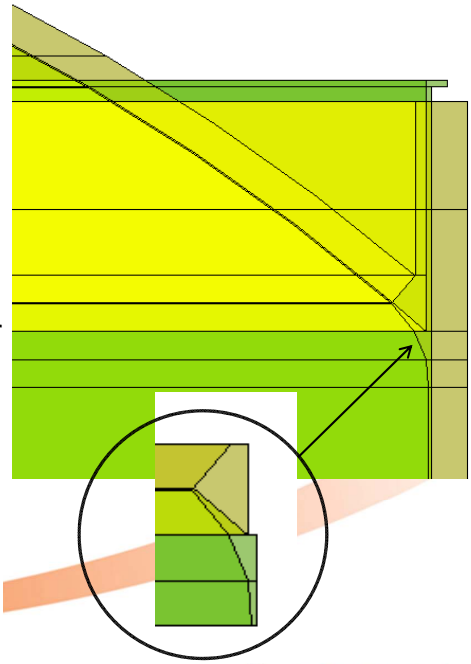
Esatan-TMS - Solid Modelling in r6 (continued)

- The figure on the right shows the LH2 tank alone in transparent view
- It is characterised by the following:
  - Nodal discretisation in circumferential direction is one node only
  - Tank consists of the main cylinder and the identical upper and lower bulkheads with skirts including thermal insulation
  - Structure thicknesses are between 2mm (bulkheads) and 8mm (skirts), which is small compared to the diameter of 4m and makes it difficult to be recognised as solids
  - Insulation thickness on bulkheads and outer side of cylinder including skirts is 50mm, on skirts inner side 16mm.



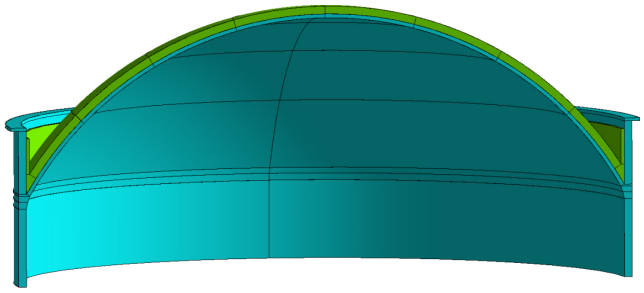
Esatan-TMS - Solid Modelling in r6 (continued)

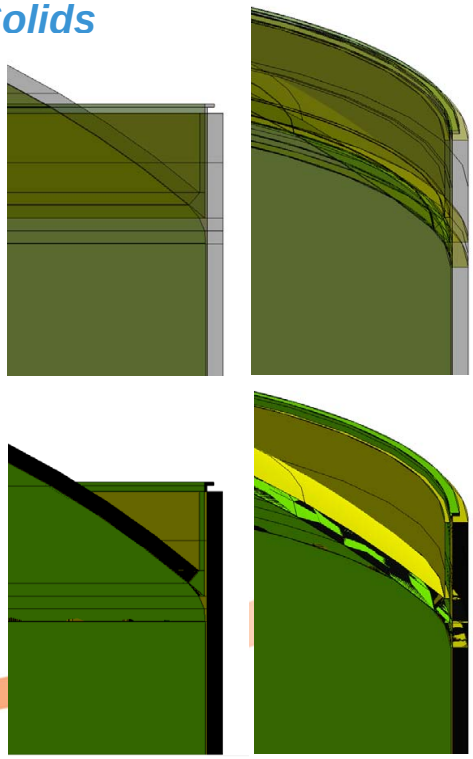
- This figure shows a detailed view of the skirt area where the varying structural thicknesses can be seen
- The central y-ring to which cylinder, bulkhead and skirt are welded is approximated by a new type of primitive
- This new primitive is a cone generated by rotation of a quadrilateral about a user defined rotation axis
- Four of them are shown as sample in the detail figure: the y-ring and the gap between bulkhead and skirt insulation
- Dependant on the chosen quadrilateral this primitive can also be used to define a cylinder or a disc



Esatan-TMS - Visualisation of Solids

- Different options for visualisation available:
  - Samples on the right are with clipping plane on, in transparent mode (upper) and opaque mode (lower)
  - Half model (180° or any other angle) as in sample below that was used for 1st Alpha testing of r6





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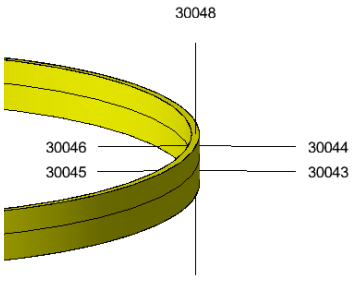
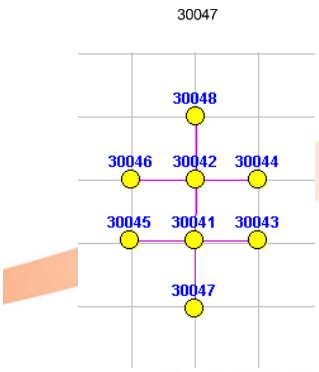
Esatan-TMS – Solids Node Numbering

- In general each solid consists of 7 nodes: the central node representing the bulk properties, and one arithmetic node for each surface
- The sample on the right is a cylinder with two nodes in height direction, i.e. two bulk nodes and the corresponding surface nodes
- However, as it is a complete cylinder the surface nodes at 0° and 360° disappear and in fact makes it a two dimensional problem
- Node numbering starts with the bulk node using the initial number and increment as defined by the user
- Bulk node numbers are not displayed in Workbench but can be seen in ThermNV (in this case nodes 30041 and 30042)





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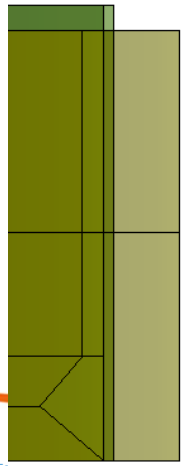
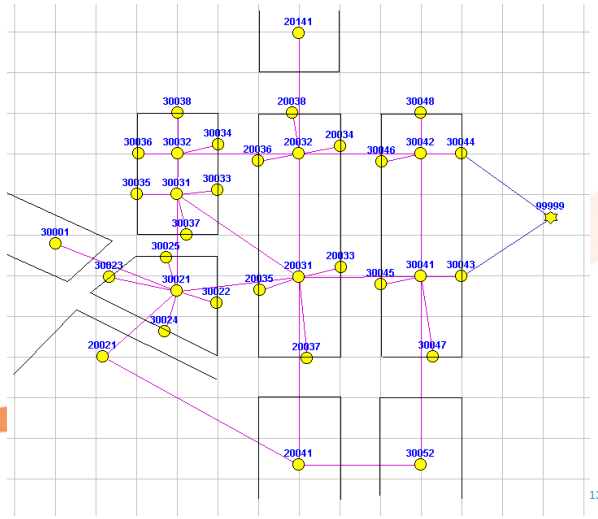
Esatan-TMS – Solids Linking in ACG

- The sample below shows the solid from the previous slide, which is the Upper Skirt outer insulation, in addition the skirt itself and the inner insulation in the gap plus some adjacent nodes
- It shows how solids are connected with each other by ACG





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Esatan-TMS – Solids Linking in ACG (cont'd)

- Before ACG is started, the AutoGenerate Conductive Interfaces Option has to be executed in Workbench. Different from Release5 the default setting is "fused", so you can continue immediately
- As shown in above sample two solids that are in contact are linked by a direct conductor between the relevant bulk nodes
- The surface nodes that represent the contact area between the two remain nevertheless in the model and are linked with the bulk node
- These nodes and conductors are not used in the temperature calculation, but are needed for temperature overlay when these surfaces are displayed during post processing. They will then show the bulk temperature

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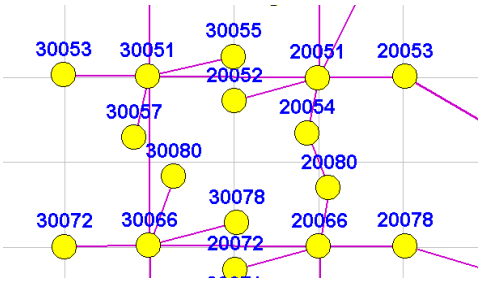
Esatan-TMS – Solids Linking in ACG (cont'd)

- From an analysis point of view the preferrable solution would be to have the surface nodes linked (or even better merged) instead of generating the direct link. This is for the following reasons:
  - To avoid useless information in the TMM. The number of nodes for the LH2 tank was doubled w.r.t. the modelling with shells only. Also the number of conductors is increased
  - In case of two different materials with temperature dependant conductivities the additional node is needed for more accurate temperature interpolation
  - Typical sample of such conductor:
  - GL(20051,30051) = 1.0 / (
    (1.0 / (113. * CNDFN1(T20051, T30051, k_A6_AL2219, 1))) +
    (1.0 / (20.7 * CNDFN1(T20051, T30051, k_A6_FOAM, 1))));

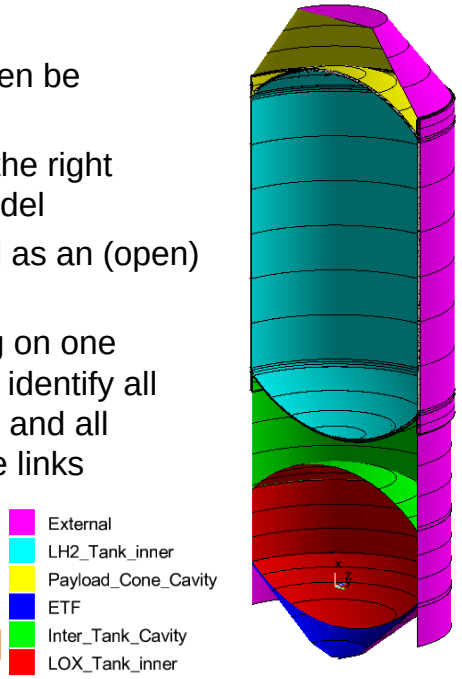
Esatan-TMS – Solids Linking in ACG (cont'd)

- When defining a conductive interface as "Contact" the additional contact conductor is placed between the two surface nodes (which is correct) as shown below between node 20054 and 20080
- In this case interpolation is done with the correct temperatures



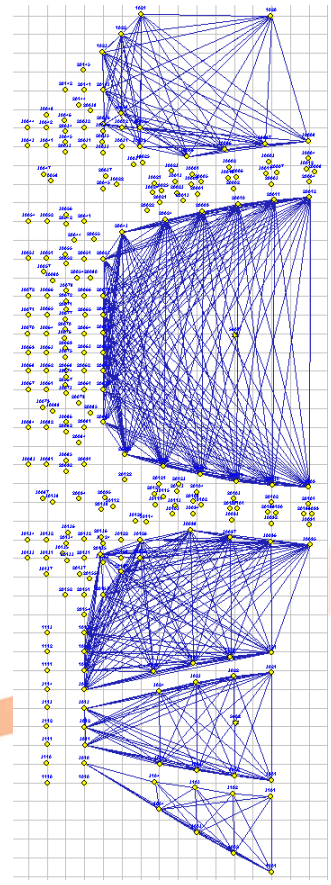
Esatan-TMS – Cavities

- r6 allows to define cavities that can then be computed independently
- The overlay applied on the model on the right shows the cavities defined for that model
- Also the external surfaces are defined as an (open) cavity
- Cavities are defined by simply clicking on one surface in that cavity. Esatan will then identify all surfaces to which it has radiative links and all surfaces to which these have radiative links



Esatan-TMS – Cavities (continued)

- Loading the model with the radiative results of the 5 internal cavities in ThermNV shows that the cavity definition was correct because there is no radiation to outside
- Linear conductors have been switched off for a clearer view on GRs
- External GRs are also not shown here
- External radiation including natural radiation can now be re-computed as often as needed (for different orbits, solar aspect angles e.t.c) without re-computing the internal radiation.



Esatan-TMS – Conclusion

- First application of solid modelling on a real model shows that ACG can now generate the complete GL matrix except of links between shells and solids. These can be derived manually from the existing conductors
- Further discussions on how to treat the non connected surface nodes and their conductors deemed useful
- The cavity feature that allows separate calculation of separate cavities works for internal and external cavities
- A numerical validation of the ACG results was not yet performed
- Due to the limited time frame since delivery of the current version of r6, not all of the requested features have been tested. At least for solids and cavities and as far as current testing has shown r6 meets the requirements

Esatan-TMS – Outlook

- Further features required for next release r7:
  - Allow cutting in ACG (shells and solids)
  - Extend perimeter of primitives: Torus (needed e.g. for line modelling), Ellipsoid (needed e.g. for special shape tank bulkheads)
  - Allow different properties for the surfaces of one solid
  - Provide compatibility of material libraries between different releases