Appendix R

A new tool for 3D thermal modeling

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A new tool for 3D thermal modeling

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2006 Thermal & ECLS software ESA workshop

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- Context / Objectives
  - 2002 : requirement overview
    - Lack of reactivity and accuracy in thermal analysis for 3D **conductive modeling**
    - Science / Observation Programs : ~ half time of a complete thermal analysis is dedicated to conductive modeling
    - Optical structures are particularly concerned
- Outcome
  - A tool to have the possibility to use a 2D or 3D detailed conductive model (FEM type) at (sub)-system level (lumped parameter type) assuming :
    - Flexible and automated process (➔ reactivity and model readability)
    - Physically consistent method (➔ accuracy)
    - Low impact on the system level model (➔ model reduction)
    - Optimized link for thermo-elastic analysis (➔ by use of initial FEM detailed model)
- No satisfactory solution available on market at the beginning of the study

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History

- **2002-2005** : URD, development, optimisation, testing THERM3D
- **2005-2006** : Validation, Documentation, Transfer to AAS users and maintenance
- Used for several instrument thermal analysis (Pleiades, Earth-Care, ...)

Synoptics

- A complete S/W chain from CAD to thermo-elastic analysis

Presentation & requirements of the tool

- Users aspects and methods

S/W Validation phase

- Many academic and realistic tests
  - comparison with pure FEM analysis for simple and complex models
  - comparison with FDM based computations
  - Comparison with traditional modeling method (radiative & conductive) for optical instrument
  - sensitivity to mesh density and quality
    - Light GMM acceptable for typical condition of use ➔ validation of utilization of CIGAL2 mesher
    - Improve gain for the thermal modeling process (radiative & conductive model possible in one shot)

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Conclusion

- THERM3D was assessed better than traditional conductive modeling method (by hand) in terms of user-friendliness, reliability and accuracy so that it is now in use for industrial programs
- Typical time to compute TLP conductors from CAD file for a complex mirror structure has been reduced from week(s) to days(s) compared with traditional process
  - Interest of the tool increase with the complexity of the geometry of the model
- Gain also in managing the conductive model (change in the model or in the thermal engineer)

In progress and short term perspective (2006-2007)

- Integrating THERM3D tool in the conductive module of CORATHERM s/w suite
- Development of a module for temperature re-computation on the original FEM model (thermo-elastic link with NASTRAN)

Proposition of external diffusion of the conductive suite

- AAS is open to discussion concerning the possibility to diffuse its new conductive modeling s/w chain (CIGAL2 – Conductive module)

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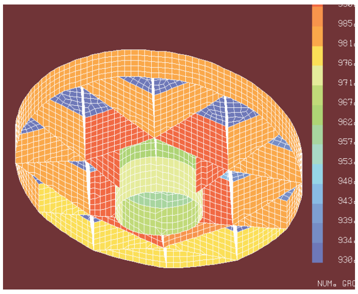
Presentation & requirements of the tool (1/2)



- Interactif mode or by reading a command file
  - Possibility to run also traditional DFM or FEM thermal analyses
  - Integrated graphical Pre & post processing
- GMM import
  - FEM type GMM (see accepted elements)
  - CIGAL2 , PATRAN , GMSH (free 3D mesher)
  - Meshing tools linked to CAD via STEP or IGES
- Material properties
  - Identification of material by its number in the GMM
  - Definition of properties (λ, ρ, thickness, C_p) in THERM3D command file
- ***TLP Nodal breakdown definition***
  - Groups of elements corresponding to the radiative nodal breakdown ("structure nodes") and to the localisation of unit or I/F ("unit nodes")
  - Defined interactively with the meshing tool on the surface of the object
  - Imported in THERM3D via a simple text file
- Thermal capacitance automated computation
  - Strict FEM method for surfacic GMM models
  - Approximation for volumic GMM models (Improvement in progress)

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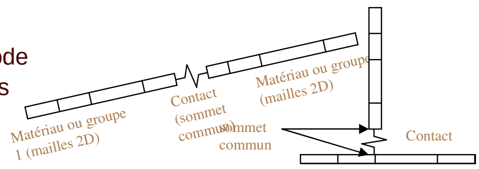
Presentation & requirements of the tool (2/2)

- Definition of "unit nodes" feature (sub-system level model)
  - Nodes connected to the 3D object only by conduction
  - Represents units, heaters, or any conductive interface with the (sub)-system level model
  - Defined by their surface conductance (W/K/m²)
- Elementary conductive couplings
  - FEM computation : a thermal node is a vertex or a unit node
  - Within 3D shell or volumetric structure and with unit nodes
  - Automated computation of 2D contacts for shell models



- ***"Equivale" type reduction of the FEM model***
  - Detailed FEM model ➔ instrument level TLP model (averaged structure nodes and unit nodes only)
  - Transform thousands FEM nodes into tens TLP nodes
  - Take count of radiative aspects on structure node (assuming a uniform radiative flux per node)
  - Output : Equivalent couplings between TLP nodes leading to
    - Averaged temperature for structure nodes
    - Classical TLP temperature for unit nodes
  - Possibility to gather 2D and 3D conductive models via interface nodes
  - Possibility to group or eliminate TLP nodes or to perform temperature zoom ("partial nodes")
- Export equivalent couplings towards thermal solver (CORATHERM, ESATAN)

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Typical Command file for a FEM conductive model reduction

```
ANALYSE EF
LIGEO DEMO.GEO
LIGROUP DEMO.NOD
DOCAR
NUM 1 H 0.003 LLX 160 LLY 160 LLZ 160  RO 2530 C 821
NUM 2  LLX 160 LLY 160 LLZ 160  RO 2530 C 821
FIN
DOEQUIPT 1 500 6 800
CALCULER MAT FIN
EQUIVALE3D DEMO.TXT
MCNOEUD
SAVFAD DEMO.TXT
```

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THERM3D requirements

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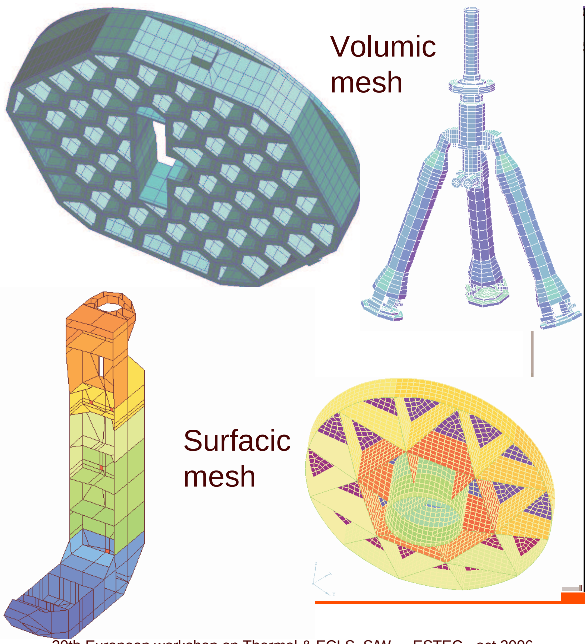
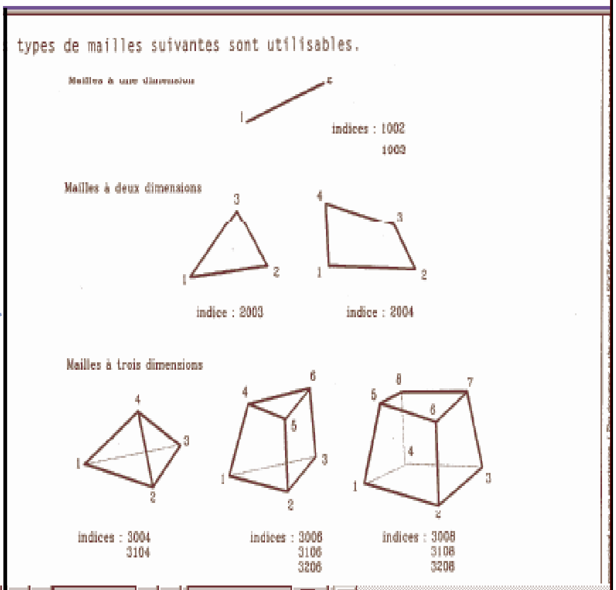
Allowed Mesh forms for THERM3D





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Geometrie File .GEO

```
1     3.3333333e+001   2.5000000e+001   0.0000000e+000
2     0.0000000e+000   2.5000000e+001   0.0000000e+000
3     0.0000000e+000   0.0000000e+000   0.0000000e+000
4     3.3333330e+001   0.0000000e+000   0.0000000e+000
                            (…)
2547  3.3333000e+001   2.5000000e+001   1.0000000e+002
 0 0 0 0 0 0 0 0 0 0
        1 2004    1      1      2      3      4
        2 2004    1      5      6      7      8
        3 2004    1      8      7      9     10
        4 2004    1     10      9     11     12
        5 2004    1     12     11     13     14
        6 2004    1     14     13     15     16
        7 2004    1      6      4     17      7
                            (…)
```

Element-to-TLP node correspondance file .NOD

```
GROUPE 1 MAILLES 70 FIN
GROUPE 2 MAILLES
3        4        5        6       7
8        9        10       11      12
FIN
(…)
GROUPE 456 MAILLES
1169  1171  1174  1175   1176
FIN
```

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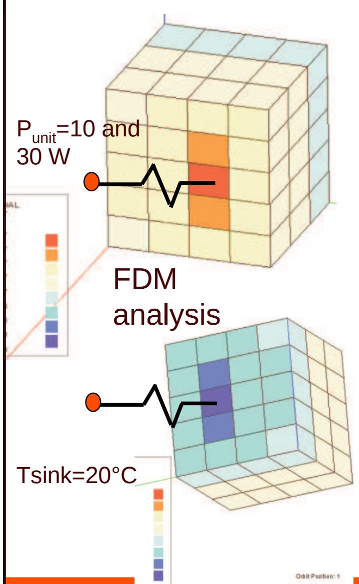
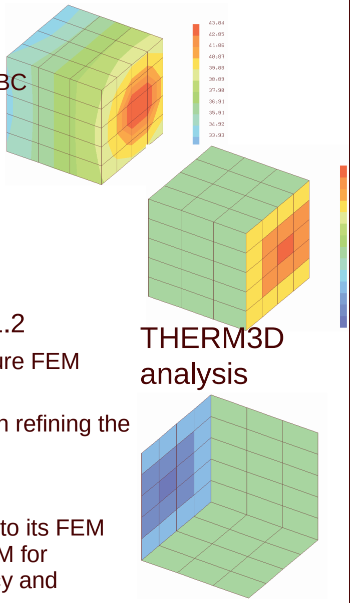
Comparative test with FDM based model



- GMM
  - Same shell cube, mesh, properties and BC
- Methods
  - **FDM** based vs **THERM3D** (FEM→TLP)
  - Only conductive couplings considered
- Results (T_{moy} and T_{unit})
  - Significant discripancy :
    - typically for unit : $T_{FDM}/T_{THERM3D} \sim 1.2$
  - THERM3D results are confirmed by a pure FEM computation
  - FDM results join THERM3D results when refining the mesh
- **Conclusion**
  - THERM3D is a very interesting tool due to its FEM based methods (more powerful than FDM for conduction modeling in terms of accuracy and applicable to non cartesian geometry)



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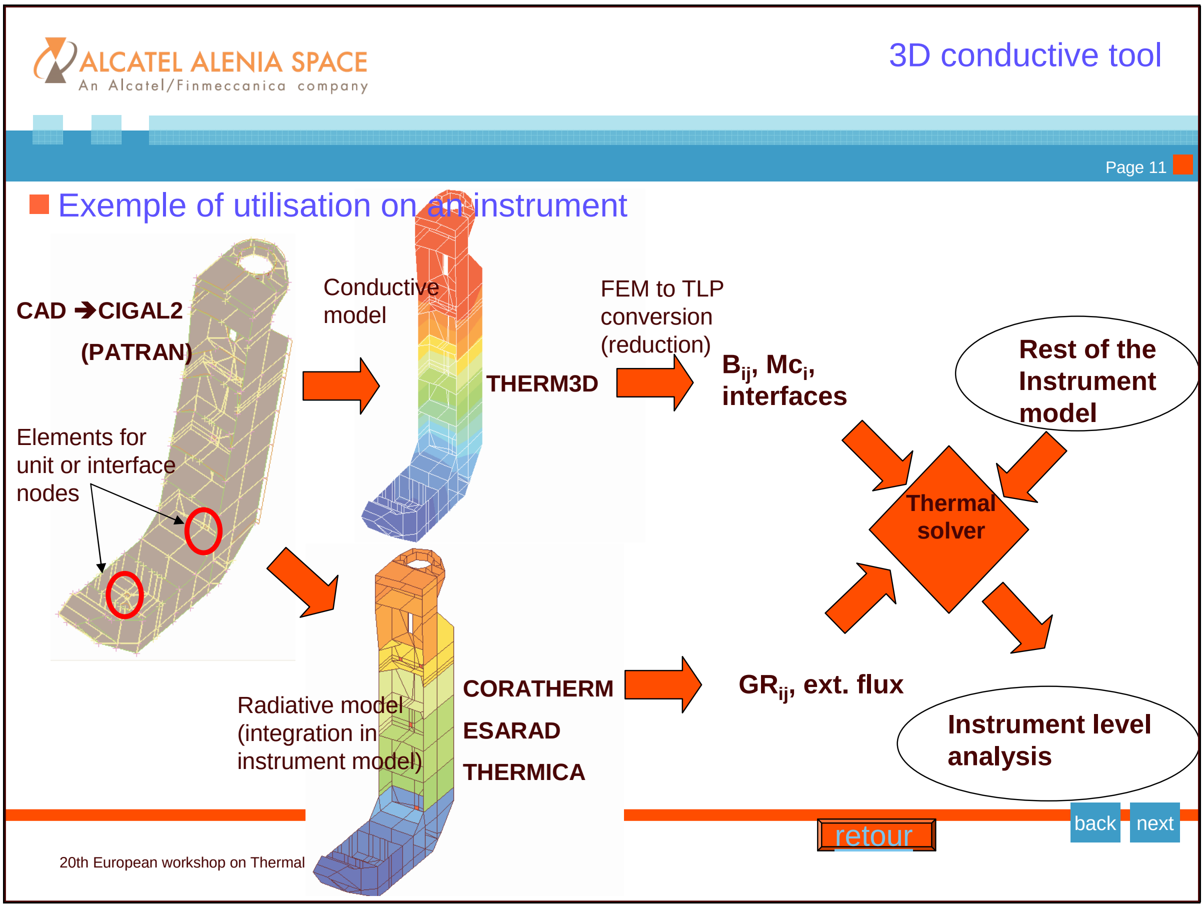
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Exemple of utilisation on an instrument
CAD → CIGAL2
(PATRAN)
Elements for unit or interface nodes
Conductive model
THERM3D
FEM to TLP conversion (reduction)
B_{ij}, Mc_i, interfaces
Rest of the Instrument model
Thermal solver
Radiative model (integration in instrument model)
CORATHERM
ESARAD
THERMICA
GR_{ij}, ext. flux
Instrument level analysis
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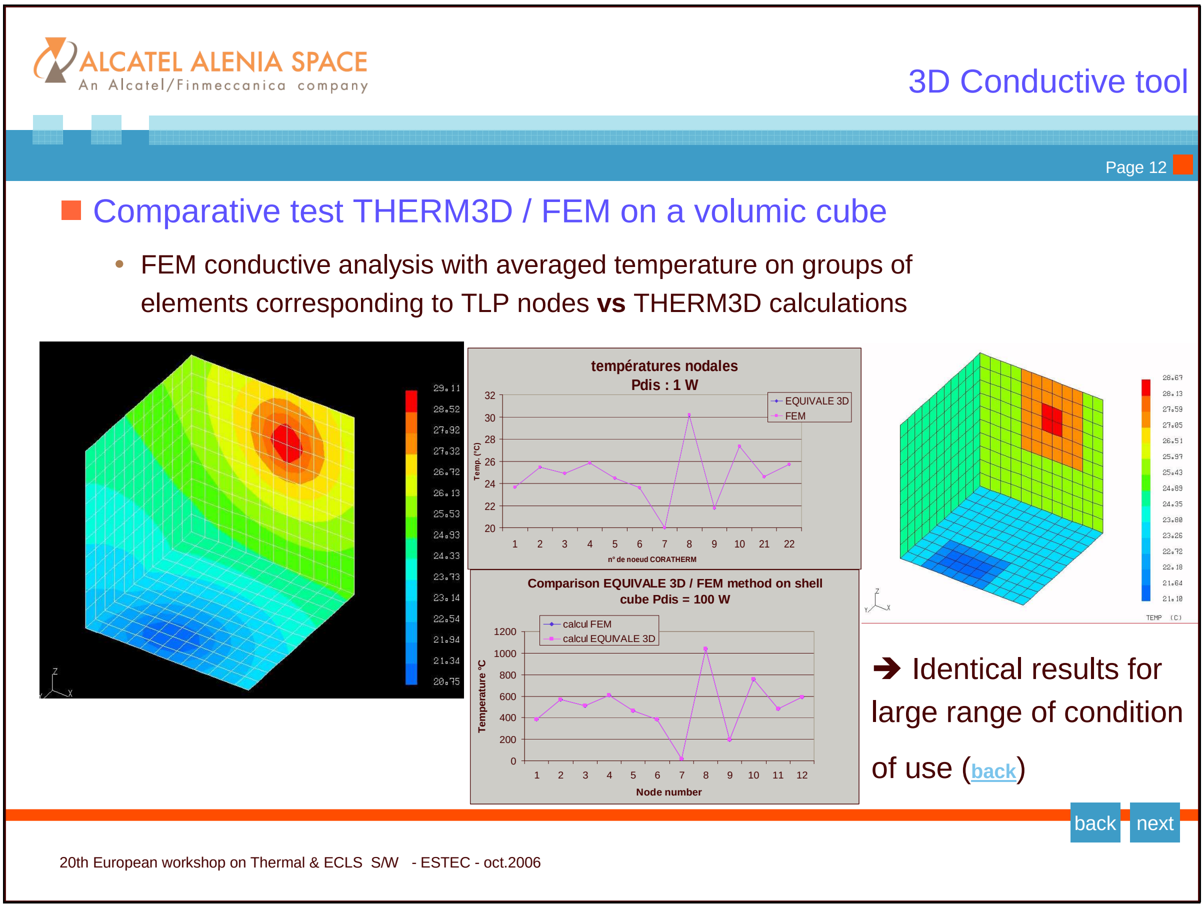
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Comparative test THERM3D / FEM on a volumic cube
FEM conductive analysis with averaged temperature on groups of elements corresponding to TLP nodes vs THERM3D calculations
températures nodales
Pdis : 1 W
EQUIVALE 3D
FEM
Comparison EQUIVALE 3D / FEM method on shell cube Pdis = 100 W
calcul FEM
calcul EQUIVALE 3D
Temperature °C
Node number
→ Identical results for large range of condition of use (back)
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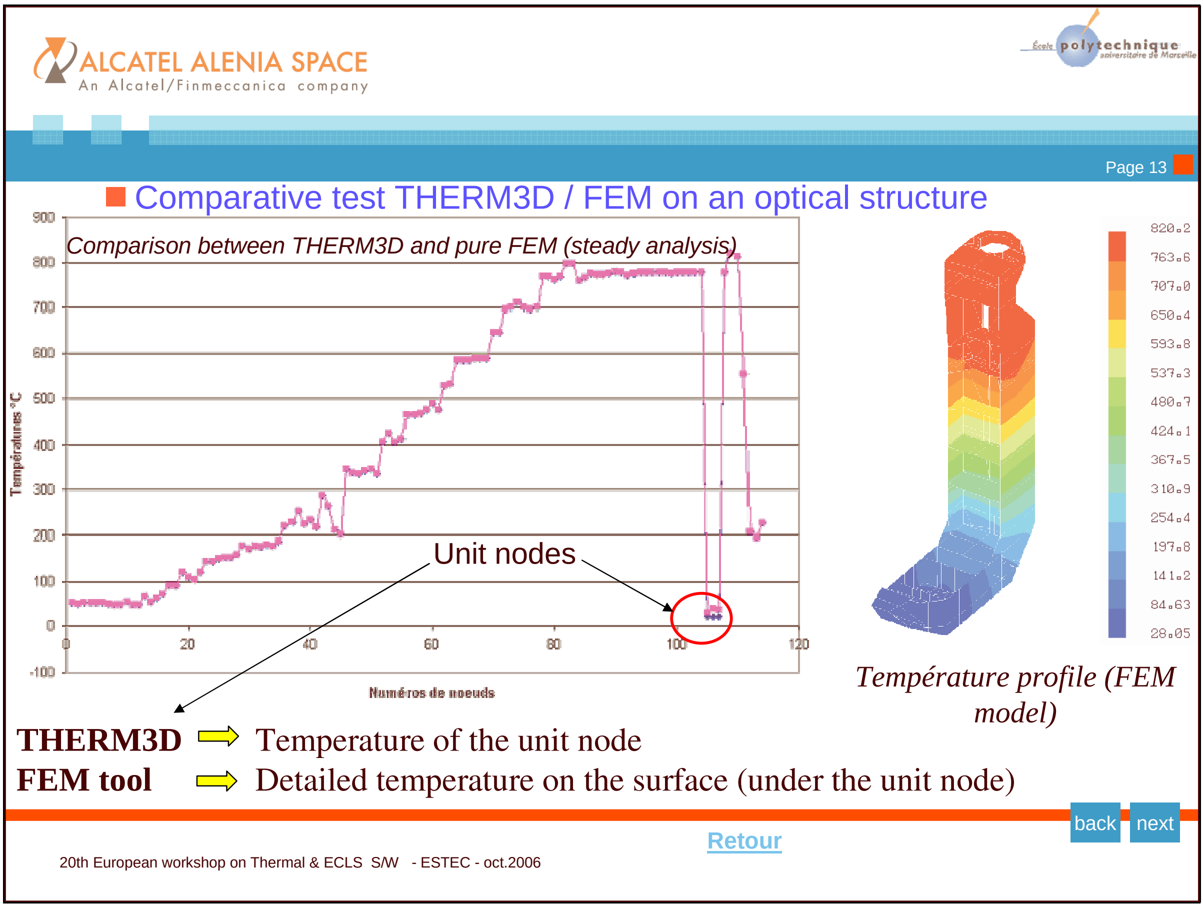
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Comparative test THERM3D / FEM on an optical structure
Comparison between THERM3D and pure FEM (steady analysis)
Températures °C
Numéros de noeuds
Unit nodes
820.2
763.6
707.0
650.4
593.8
537.3
480.7
424.1
367.5
310.9
254.4
197.8
141.2
84.63
28.05
Température profile (FEM model)
THERM3D ⇨ Temperature of the unit node
FEM tool ⇨ Detailed temperature on the surface (under the unit node)
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