Innovations in Thermica

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Content

- Import of CAD geometry
- Temperature Solver
- Accurate modelling of Thermal Conduction

Import of CAD geometry
Emergence of needs

- **For many years**
  - Need to decrease human efforts to build a geometry
  - Need to have an integrated process involving CAD engineers and thermal engineers
- **Recent progress in software technology make possible an import of CAD geometry in a tool like Thermica**
- **However, the import of a CAD geometry is not an easy game**
  - The complexity degree of a CAD model is completely new for an analysis tool like Thermica
- **This means that a new process has to be defined**
  - The software must be compliant with the new needs

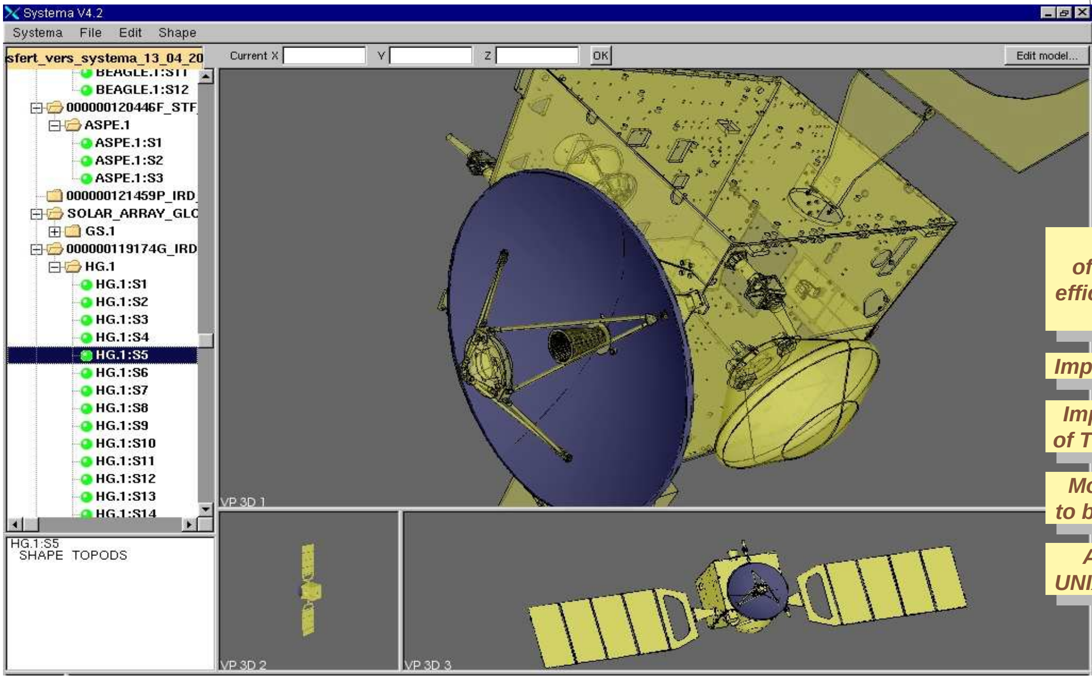
A new process for the import of CAD geometries
In search for a specific methodology

- **2002-2003 : Meetings with thermal analysts, design officers and project managers in EADS Astrium, in order to define the process to follow for the import of CAD models**
- **Process A : recurrent platforms**
  - Assemblies of existing models (previously translated from CAD to analysis)
  - Non-recurrent equipments : apply Process B
- **Process B : new geometries**
  - Software tool showing the CAD model in background
  - Automatic translation of standard surfaces
  - Use of specific points (picked on the CAD model) to build surfaces
  - Complex shapes : meshing into standard surfaces
- **Simplification decided by the thermal engineer**

A new tool to import and translate CAD geometry
Compliant with the process

EADS ASTRIUM

❑ Main window *(import of Mars Express CAD model)*



Manipulation of CAD geometries efficient with classical computers

Import of STEP files

Import / export of Thermica files

Modeler capabilities to build thermal model

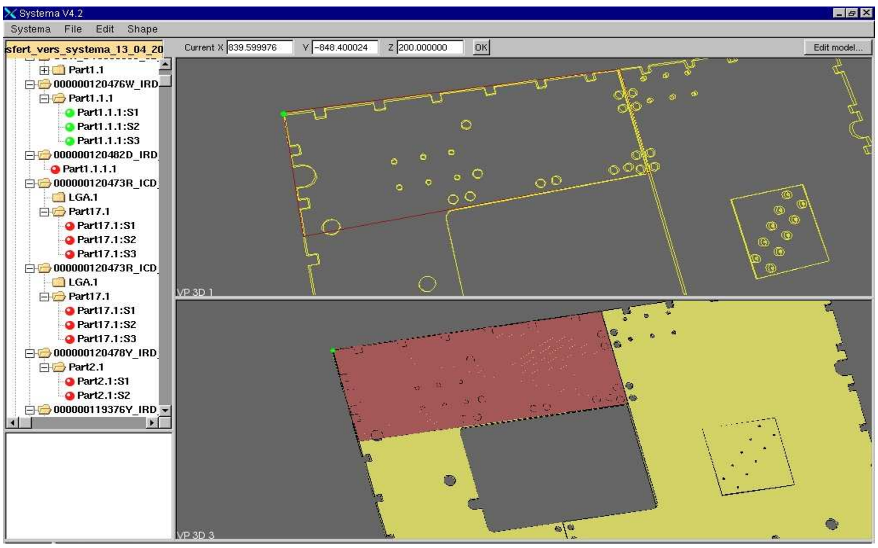
Available on all UNIX & PC platforms

How to manage complexity of CAD geometry (1/2)
Pick of points on the CAD model to build Thermica shapes

EADS ASTRIUM

❑ Semi-automatic simplification

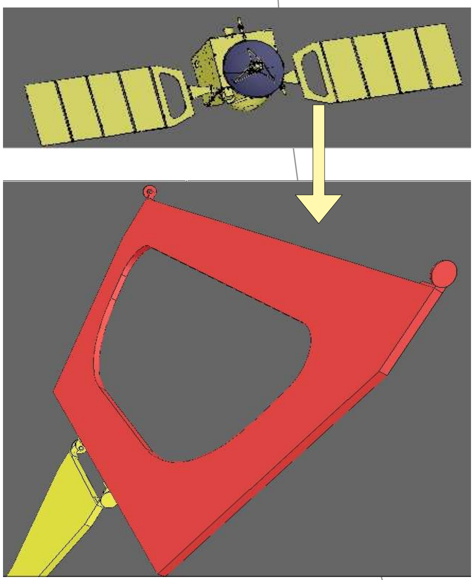
- CAD geometry is used as a layer which gives specific points
- Pick on specific points to define Thermica shapes



Interactive creation of a Thermica rectangle from the CAD layer

How to manage complexity of CAD geometry (2/2)
Translation of standard surfaces

- **Automatic translation of standard surfaces on request (under development)**
  - Thermica simple shapes will be automatically created from the equivalent CAD shapes
  - Complex shapes (i.e. Nurbs) will be meshed into triangles
- **However, this simplification must be made carefully**
  - This solar array structural element is made of about ***more than 80 elementary shapes*** (quadrangles and cylinders)
- **Without simplification, a new family of huge thermal models will appear**
  - Difficult management for thermal software
  - Difficult analysis of results for users



Import of CAD geometries
CONCLUSION

- **Import of CAD geometry is now possible in Thermica**
- **The methodology built within EADS Astrium has supported our approach, it will now benefit to all users**
- **The CAD import module is well suited to this methodology**
- **It will be improved according to the user feed-back**
- **Available in Thermica v3.2.20 (October 2004)**

Temperature Solver
Emergence of needs

- **In a long-term perspective, Thermica needs to be a more and more <u>complete software package</u> for space thermal analysis**
  - Agressive competition of mature software from outside Europe
- **User survey (internal & external users) : need to be compatible with the European standard language Esatan**
  - To allow the computation of previous models
  - To keep the existing process
  - To consolidate the user experience
  - To **<u>preserve harmonization</u>** in Europe

Temperature Solver
Main characteristics

- **Compatibility with the Esatan language**
  - Internal data structure has also been made compatible
  - Other languages could also be introduced if necessary
- **Pre-processing**
  - Very fast, robust, user-friendly (clear error messages)
- **Temperature computation**
  - Standard algorithms have been implemented (Newton Raphson, Crank Nicholson) – *takes benefit of our experience in solvers within other space environment applications (Systema)*
  - Innovative new algorithms have been developed and integrated

Temperature Solver
Validation / Maturity

- **A intensive validation phase has occured in EADS Astrium : near 50 real test cases**
  - Coming from several space projects, different users, different cultures, different project phases, different size (small → very big)
  - MEX, Pleiades, Ariane5, Arabsat, VEX, Melfi, Intelsat10, Inmarsat4, HotBird8, Metop, Amazonas, Anik, W3A, ISS, Gaia, LHP…
- **Results :**
  - Compatibility with Esatan language : near 100%
  - Compatibility with user subroutines & libraries
  - Temperature results have been extensively validated

    (with standard methods : Newton Raphson & Crank Nicholson)

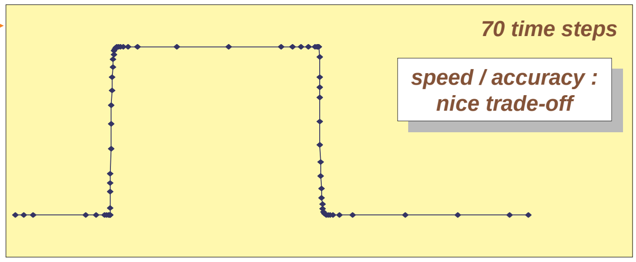
Innovation 1 : Automatic time-stepping
Main principle

- **The user specifies the accuracy he wants to have on the temperatures**
- **During the computation, the error is estimated**
  - The error is not just only evaluated by ΔT but is given by a more complex mathematical development of the Crank Nicholson scheme (more accurate)
- **Then, the time step is automatically changed in order to obtain the desired accuracy**
- **This process is completely automatic…**
  - No need to program manual changes for eclipse entry/exit, instruments activation, …
- **…and managed by the only interesting criteria : <u>accuracy</u>**

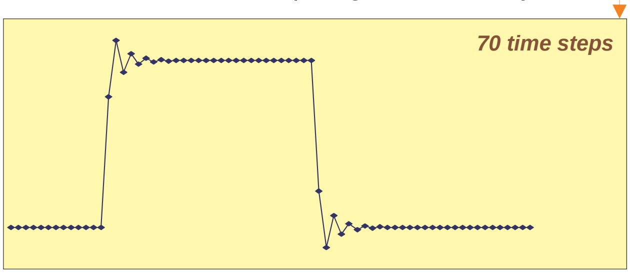
Innovation 1 : Automatic time-stepping
Application

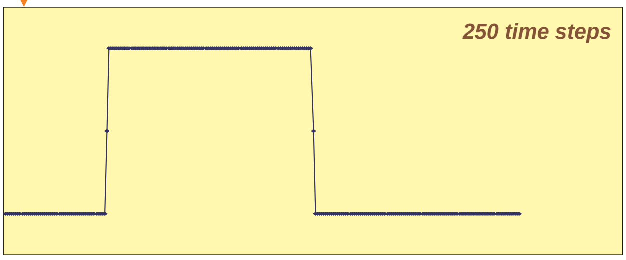
- **Model = 1 diffusive node (C=10) + 1 boundary node which temperature switches between 0°C and 20°C, GL=10**

- **Automatic time stepping**
  - 70 time steps
  - Good accuracy



- **Constant time step**
  - 70 time steps : bad accuracy
  - 250 time steps : good accuracy





Innovation 2 : Parallel time-stepping
Main principle

- **In a large number of applications, all thermal nodes don't have the same time scales in their temperature variations**
  - satellite vs equipments
  - satellite vs external appendices
  - equipments vs fluid loops

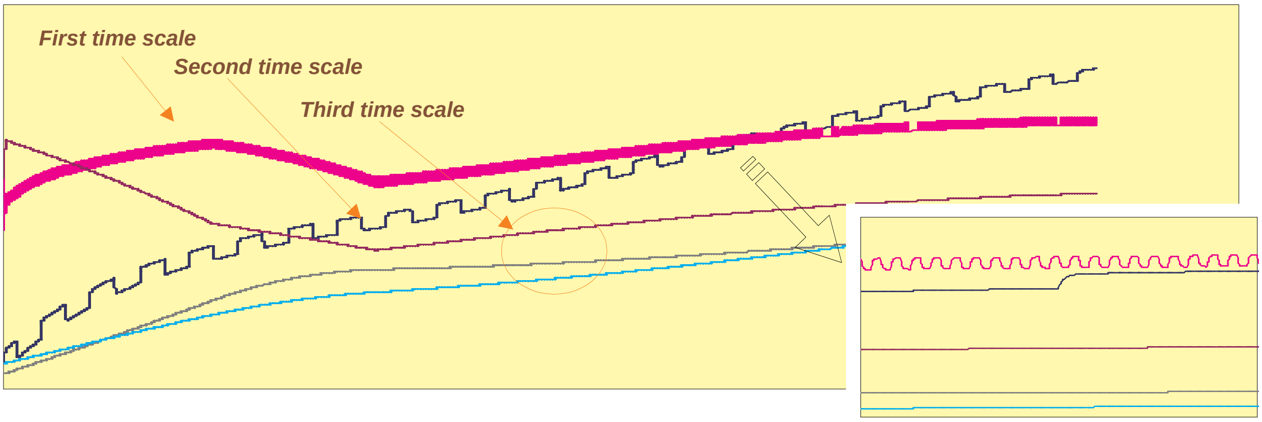
- **During the computation, the nodes are automatically classified into several families**
  - One family per time scale
  - <u>Each family has its own time step</u>

- **<u>Mix of simultaneous different time steps</u>**

- **Optimization of CPU time without loss of accuracy**

Innovation 2 : Parallel time-stepping
Application

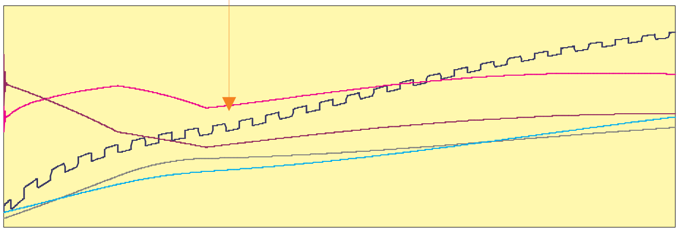
- **Model made of 200 nodes**
  - 1 node has temperature variations with a 1s period
  - 1 node has temperature variations with a 20s period
  - 198 nodes have variations with a large time scale (whole satellite)



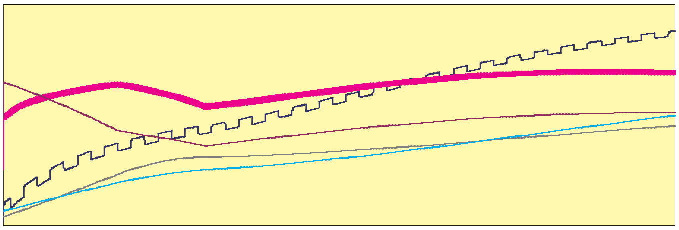
- **The parallel time-stepping gives <u>accurate results</u> with an <u>optimized CPU time</u> (mix between dt=50s, dt=2s and dt=0.1s)**

Innovation 2 : Comparison with standard methods
Classical methods are not suited to models with several time scales

- **A fix time step algorithm with dt=1s gives wrong results for the high frequency variations**



- **A fix time step algorithm with dt=0.1s has a correct accuracy (but dt=0.1s is <u>applied to all the nodes</u> !)**



- **For this kind of models, the classical methods can be 10 times slower than the parallel time-stepping algorithm**

Temperature Solver
CONCLUSION

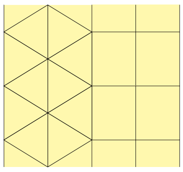
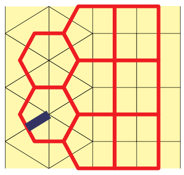
- **Thermica Solver is in line with the European standards**
- **The development has been driven by the user needs**
- **It has been successfully validated in many space projects**
- **It offers a reliable mastering of accuracy**
- **This solver comes with new approaches for the current & future needs with innovative algorithms**
- **Available in Thermica v3.2.20 (October 2004)**

Accurate modelling of thermal conduction
Emergence of needs

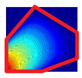
- **Classical approaches use geometrical considerations and apply classical λS/L-like formulas**
  - We have no idea of the validity in general cases
  - No idea of the accuracy
  - No idea of the limits
- **When accuracy is needed, a real numerical simulation is necessary : strict derivation of Fourier's law on the meshing**
- **Methods investigated : inspired from <u>Finite Volumes</u> and <u>Finite Elements</u>**
  - Need to apply these methods to standard Thermica geometries
  - Compatibility with the lumper parameter approach (nodal method) is requested : <u>conductive study = computation of couplings</u> (temperatures are solved later)

Accurate modelling of thermal conduction
Two main theoretical approaches

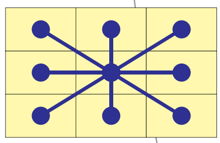
- **Option 1 : inspired from a Finite Volume approach**
  - Construction of a dual meshing, temperature smooth interpolations in dual meshes and computation of fluxes crossing initial shapes

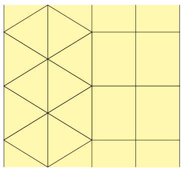
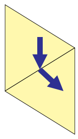
$$T(x,y)=\sum_k \alpha_k(x,y)T_k$$



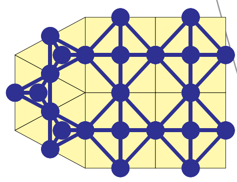
$$\Phi = -\int e\lambda\ \vec{\nabla} T\cdot\vec{n}\ d\sigma$$
$$= \cdots = \sum a_{pq}\left(T_q - T_p\right)$$



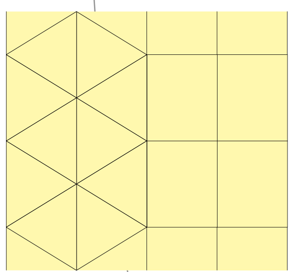
- **Option 2 : inspired from a Finite Element approach**
  - Linear temperature profile inside meshes, leading to couplings between centers and edges

$$T(x,y)=a+b\,x+c\,y$$
$$\Phi = -\int e\lambda\ \vec{\nabla} T\cdot\vec{n}\ d\sigma$$

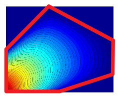


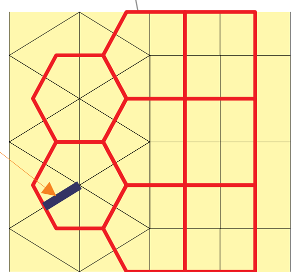
Option 1 : Simulation by Finite Volume method
Description of the algorithm



- **The Finite Volume method creates a <u>dual meshing</u> based on the <u>center</u> of each shape *(global approach)***
- **In each dual mesh, the temperature is interpolated from the temperatures of initial user meshes :**

$$T(x,y)=\sum_k \alpha_k(x,y)T_k$$

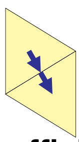




- **In each dual mesh, the flux crossing two shapes is :**

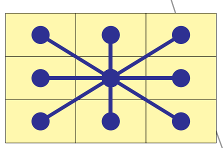
$$\Phi_\sigma = -\int_\sigma e\lambda\ \vec{\nabla} T\cdot\vec{n}\ d\sigma = \cdots = \sum a_{pq}\left(T_q - T_p\right)$$

- **This flux is a continuous function**



- **Then, a global assembly of the linear coefficients a_{pq} leads to a set of couplings between thermal nodes**

$$GF(i,j)=\sum_{p,q} a_{pq}$$



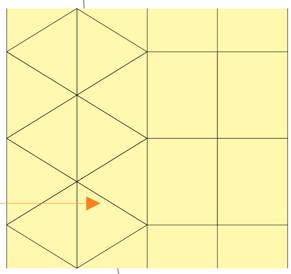
- **<u>Many couplings between neighbours</u>**

Option 2 : Simulation by Finite Element method
Description of the algorithm

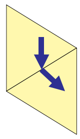
- The Finite Element method apply Fourier's law in each individual triangle *(local approach)*

- A linear temperature profile is assumed in each triangle

$$T(x,y) = a + b\,x + c\,y \qquad \nabla T = (b,c)$$

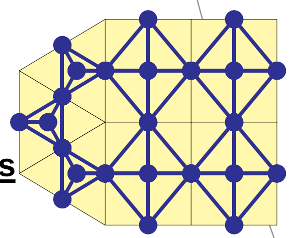


- The flux crossing two nodes is not continuous



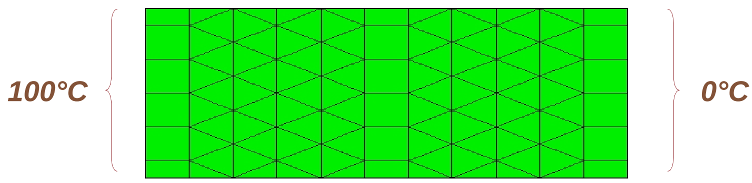
- A lot of additional thermal nodes are automatically created (edge centers)

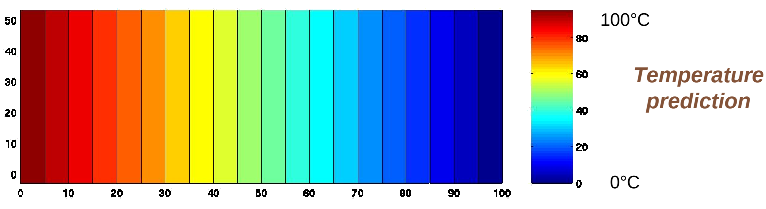
- <u>Many couplings inside shapes, independant from neighbours</u>

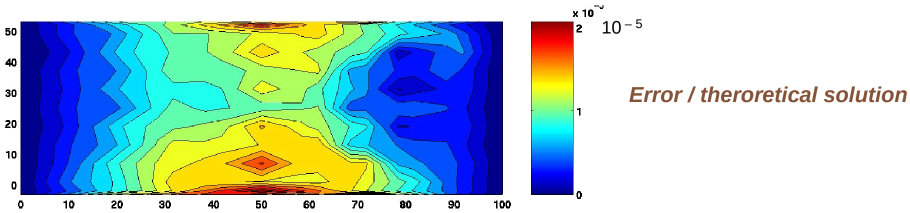


Validation of the two methods (1/2)
Academic tests

- Application to the classical rectangle with boudary temperatures on left & right (0°C and 100°C)
- Error / theoretical solution < <u>10^{-5} °C ! *(10^{-7} %)*</u>

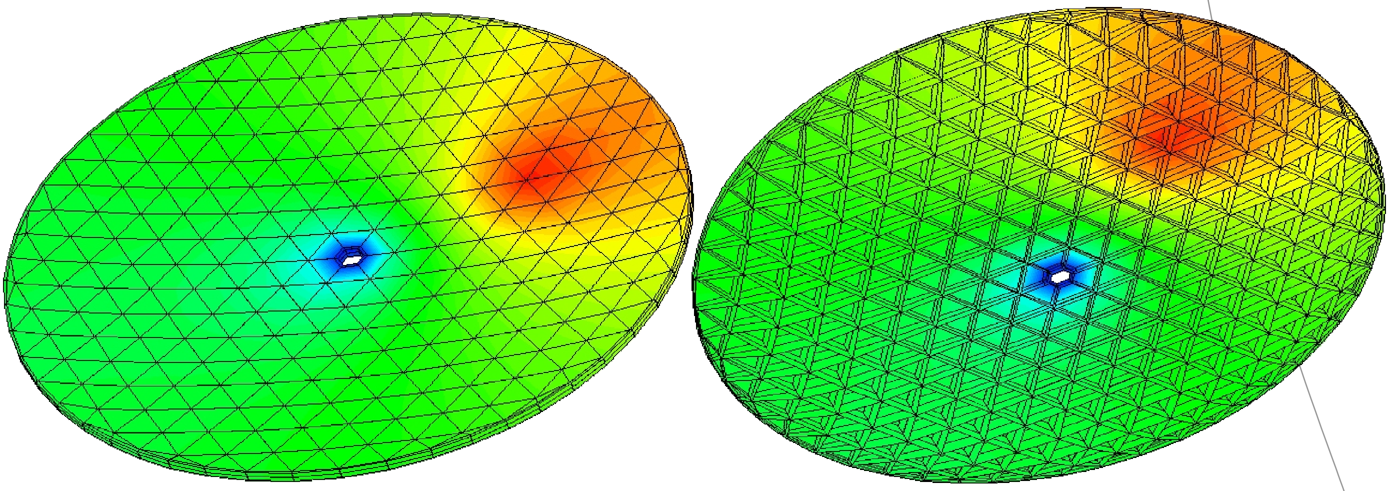






Validation of the two methods (2/2)
Application to an industrial project

- **Application to the mirror of an observation spacecraft**
  - Boundary temperature at the center
  - Solar flux on 2 meshes
- **These new algorithms are perfectly correlated with the operational method used on current projects**



Accurate modelling of thermal conduction
CONCLUSION

- **These new methods give very promising results**
  - High accuracy
  - Compatibility with classical Thermica geometries
- **Next step in the integration to Thermica : a trade-off will be made to select F.V. approach or F.E. approach**
  - Maybe both of them will be available
- **Schedule : at <u>beginning of 2005</u> the new conduction module will be fully integrated in the standard Thermica package**

CONCLUSION

- **Thermica : a more and more complete European software package for Space Thermal Analysis**
  - Framework : 3D modeler, interactive menus, post-processing
  - Mission : orbit & kinematics, standard & complex missions
  - Thermal radiation : accurate Monte Carlo Ray Tracing, complex planetary fluxes (Earth, Mars, Venus, Mercury, …)

    Current version v3.2.19 (applies to the three items above)
  - Thermal conduction (accurate FV and FE method) → *Beginning 2005*
  - Temperature solver → *v3.2.20 : October 2004*
  - Connexion with CAD → *v3.2.20 : October 2004*
  - New framework with high interactivity & new ergonomy → *v4.1 : June 2005*
- **We try to enlarge the offer with new modules and innovative solutions in accordance to the user needs**
- **These improvements are delivered with no price increase**