Appendix P

SYSTEMA — THERMICA

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Abstract

SYSTEMA, currently in version 4.7.1, is a framework for space physics applications including THERMICA, a package dedicated to thermal simulations. The next version will be the 4.8.0 and will include a new schematic module which will allow the definition of power systems and will ease the thermo-electrical simulation process. Besides, SYSTEMA has the ability to manage the solar system including different moons, like Ganymede, Europa and others for which orbits are approximated by Keplerian laws around a particular date of interest. A trajectory defined around a moon like Ganymede will lead to simulate fluxes both from the moon itself but also from other planets, like Jupiter in this example. Finally, a new applicative module within Systema, called Mapping, offers the possibility to transfer data from one model to another one: fluxes from a Plume analysis to a thermal model, temperatures to an outgassing model or to mechanical mesh. For the temperature mapping, a new method based on a "backward RCN" has been set-up. This method is capable of interpolating temperatures within a re-built quadratic profile onto the thermal mesh and offers then a very accurate mapping consistent with the hypothesis of the thermal simulation.
Systema - Thermica
29th European Space Thermical Analysis Workshop
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03-04 November 2015

Content

Current status

Addition of Jupiter’s moons
• Ganymede use case

Mapping application
Current status

Long Term Support current version: v4.5.3 (08/2013)

Latest Release: v4.7.1 (06/2015)

- CAD simplification
- Post-Processing
- Windows 64bits
- 3D performance
- Python API extended
v4.7.1

Search tool

Multi-edition on Meshing

Integrated User Manual

- Import/Export of ASCII Ephemeris files
- Follow the CIC exchange protocol: restriction of ESA standard CCSDS
- Trajectory Time-Position-Velocity
  - Import of Trajectory:
  - OEM files (Orbit Ephemeris Message) → x, y, z positions
v4.7.1

- Kinematics law “Transformation defined in a file”:
  - Import of Kinematics:
    - AEM files for satellite attitude (Attitude Ephemeris Message) → quaternions
    - MEM files for moving bodies attitude (Mission Ephemeris Message) → rotation angle
  - Export of HDF5 results:
    - MEM files (Mission Ephemeris Message) → thermal results

Next Release: v4.8.0 (S1 2016)
Jupiter’s moons

• Ganymede use case

Implementation of moons in Systema

• Texture of the moon
• Ephemeris information
  ➔ Orbits approximated by Keplerian laws from a fixed date

Make mission and analyses around moons with Systema

JUICE mission

• Launch in 2022 and start of the mission in 2030
• Callisto and Europa flybys
• Orbit around Ganymede
Jupiter's moons

Ganymede
• Available since version 4.7

Europa / Callisto
• Available in 4.8.0
Jupiter's moons

Ganymede Albedo Fluxes (Ganymede behind Jupiter)

Ganymede Eclipse

Jupiter's moons

Ganymede IR Fluxes (Ganymede in front of Jupiter)

Jupiter Eclipse
Jupiter's moons

Jupiter is eclipsed by Ganymede

Satellite motion vs Jupiter

Solar Panels

Cube faces

Jupiter Albedo Fluxes (Ganymede in front of Jupiter)

Jupiter is eclipsed by Ganymede

Satellite motion vs Jupiter

Solar Panels

Cube faces
Conclusions
• Relative positions of planet / moon / sun
• Sun eclipses from both Ganymede and Jupiter
• Jupiter eclipse from Ganymede
• Ganymede and Jupiter fluxes simulated

Realistic simulations around any moons are possible

In the future
• update existing moon's properties
• add new moons
Context: Multi-physics analysis

• Need to transfer data
  – Temperatures from Thermal analysis to Mechanical mesh
  – Fluxes from Plume analysis to Thermal model
  – Temperatures from Thermal analysis to Outgassing model

Geometrical associations

• By projection from detailed to coarse model
  – Detailed elements are projected to the nearest geometry of the coarse model (by ray-tracing)
  – The projection is normal to the coarse geometry
  – Correspondences between mesh are generated
  – Including parametric coordinates of projected points
Mapping

Mapping of fluxes

• According to cross-section of projection

\[ Q_C \rightarrow \phi_C = \frac{Q_C}{A_C} \Rightarrow \phi_d = \phi_C \cos \theta \rightarrow Q_d = A_d \phi_d \]

Mapping of temperatures

• By a backward RCN method

– The RCN method (Reduced Conductive Network) is an innovative algorithm that deals with the conduction in accordance with radiative and external fluxes ray-tracing methods. It is based on a finite volume integration of conductive fluxes computed through a model reduction of a detailed sub-mesh model.

– The model reduction used by the RCN algorithm may also export “backward matrices” allowing to recover a detailed temperature profile from temperatures computed on the thermal model.

– Using the RCN method for the conduction allows then to rebuild an accurate and detailed temperature profile and so to perform a temperature mapping of a very good quality
Mapping

Mapping of temperatures
• Process
  – Import a Nastran file into Systema and save it as Systema native format
  – Create a process with the two models and the mapping module

The backward RCN method
Consistency of the RCN Conduction and RCN backward Mapping

- **Coarse model**

  Boundary @ 0°C

<table>
<thead>
<tr>
<th>Mesh 1</th>
<th>Mesh 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q = 1W/m²</td>
<td>Q = 1W/m²</td>
</tr>
</tbody>
</table>

  - Computed average temperatures with the RCN conduction:
    - T1 = 34.66 °C
    - T2 = 74.66 °C

- **Detailed model**
Consistency of the RCN Conduction and RCN backward Mapping

- Detailed model: Results

Identical results between:
- Detailed simulation (RCN)
- Coarse simulation mapped to detailed model

Consistency of the RCN Conduction and RCN backward Mapping

- Coarse model: Results

The simplified RCN (classical lambda.S/l formulae) leads to a convergence of the temperatures with the mesh discretization
Conclusion

- The new Mapping module allows to transfer data (temperatures, fluxes...) between different models
  - Projected areas may be used to be conservative on the powers
  - Backward RCN brings a complete solution and do not involve any extrapolation of temperatures
    (the temperature profile obtained is such as the really considered at temperature integration level)