Appendix K

TMRT

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Abstract

The presentation will start with the introduction of the need to perform a thermal model reduction and present TMRT as one solution for the task.
Then the general working principles of TMRT and the way of using the toll will be presented. In conclusion, the availability of the tool will be announced.
The presentation will be user oriented and aim at convincing people to try TMRT.

Thermal Model Reduction Tool

TMRT

24th European Workshop on Thermal & ECLS Software

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Overview

- Thermal Model Reduction Needs
- TMRT Origins
- TMRT Reduction Working Principle
- TMRT Other Functionalities
- TMRT User Interface

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Thermal Model Reduction Needs

- To cope with contract:
  - Delivering a sub-system reduced thermal model is often contractual with a specified maximum number of nodes and a specified accuracy.
  - With a little number of nodes, a sub-system reduced thermal model is easier to integrate at system level and easier to understand.
- To improve complex element modelling process:
  - The modelling of complex element can be performed using a great number of thermal nodes and simple coupling definitions.
  - Then, it can be reduced to cope with thermal analysis needs.

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TMRT Origins

- The will to harmonize reduction methods (CNES, ESA, THALES ALENIA SPACE & ASTRIUM)
- Existing tools in THALES ALENIA SPACE and ASTRIUM based on the same methodology:
  - EQUIVAL in THALES ALENIA SPACE
  - THERMIRED in ASTRIUM
- Methodology efficiency proven
- Either tool could not be commercialized as is.

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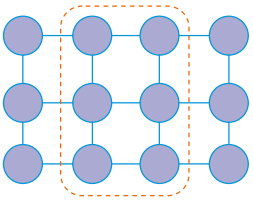
TMRT Reduction Working Principle

- A reduction is defined by making groups of nodes:
  - Each group defines a reduced model node: $T_A = \sum_G a_{AG} T_G$
  - The groups should be made considering the hypothesis of proportionality of the non-conductive powers: $P_G = a_{GA} P_A$



- The reduced model is valid as long as the hypothesis above is well respected.

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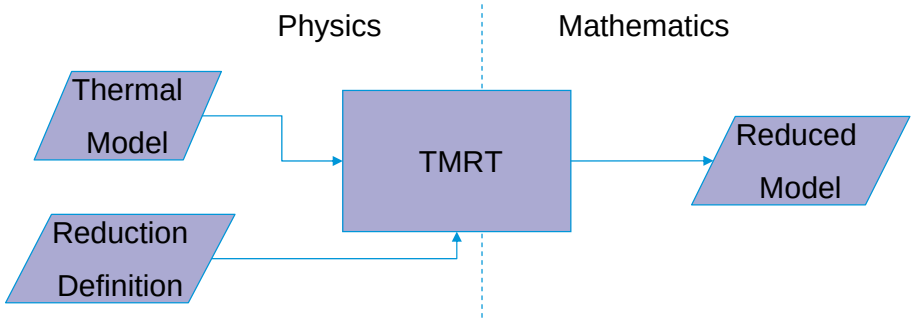
TMRT Reduction Working Principle

- Equivalent Reduction: linear conductors of the reduced model must be considered as a whole, not individually.



- Works with ESATAN/THERMISOL format and CORATHERM format.

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TMRT Reduction Current Applications

- In THALES ALENIA SPACE and ASTRIUM, the model reduction based on this methodology is used to reduce:
  - Telecom payload panels.
  - Antenna assemblies.
  - Electronic units.
  - Instruments.
  - Spacecraft models for launcher analyses.
  - Brackets.

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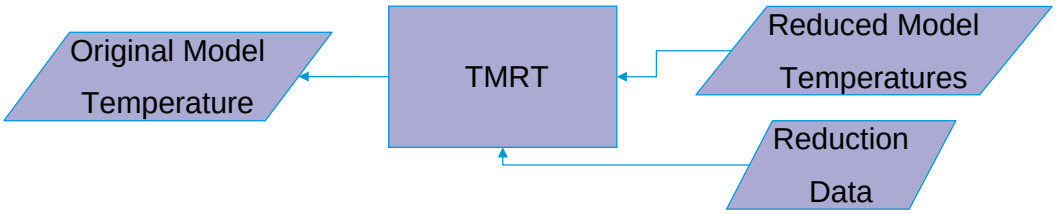
TMRT Other Functionalities

- Temperature Recovery (Secondary Functionality):



- Advanced Functionalities:
  - Node suppression
  - Power distribution
  - Post-processing nodes
  - Reduced model filtering

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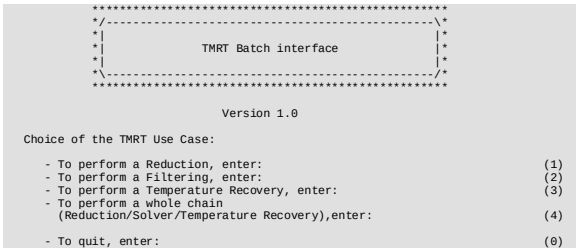
TMRT User Interface

- TMRT User Interface consists in a series of menus:
  - For specifying the TMRT use case.
  - For specifying the input and output files.



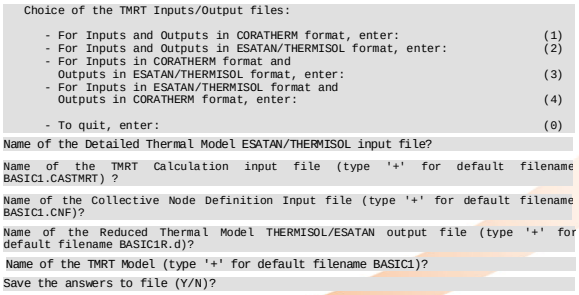
```
*********************************************************
*/-----------------------------------------------------\*
*|                                                     |*
*|              TMRT Batch interface                   |*
*|                                                     |*
*\-----------------------------------------------------/*
*********************************************************

                        Version 1.0

Choice of the TMRT Use Case:

   - To perform a Reduction, enter:                              (1)
   - To perform a Filtering, enter:                              (2)
   - To perform a Temperature Recovery, enter:                   (3)
   - To perform a whole chain
     (Reduction/Solver/Temperature Recovery),enter:              (4)

   - To quit, enter:                                             (0)
```



```
Choice of the TMRT Inputs/Output files:

   - For Inputs and Outputs in CORATHERM format, enter:                  (1)
   - For Inputs and Outputs in ESATAN/THERMISOL format, enter:           (2)
   - For Inputs in CORATHERM format and
     Outputs in ESATAN/THERMISOL format, enter:                          (3)
   - For Inputs in ESATAN/THERMISOL format and
     Outputs in CORATHERM format, enter:                                 (4)

   - To quit, enter:                                                     (0)

Name of the Detailed Thermal Model ESATAN/THERMISOL input file?

Name of the TMRT Calculation input file (type '+' for default filename
BASIC1.CASTMRT) ?

Name of the Collective Node Definition Input file (type '+' for default filename
BASIC1.CNF)?

Name of the Reduced Thermal Model THERMISOL/ESATAN output file (type '+' for
default filename BASIC1R.d)?

Name of the TMRT Model (type '+' for default filename BASIC1)?

Save the answers to file (Y/N)?
```

- TMRT can be launched without going through the menus by providing an answer file.

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TMRT Availability

- TMRT is a now available.
- It is license protected.
- Licenses can be obtained by contacting ASTRIUM THERMICA service (fee covering maintenance & distribution costs)
- Documentation is available:
  - User Manual
  - Theoretical Manual

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Conclusion

- TMRT is a powerful thermal model reduction tool now available to the community.
- It can be used to perform very simple reductions or complex ones.
- Reduction definition is performed manually by the user. Modules on thermal modelling tool could be developed in order make it more user friendly.
- Such modules could also be used to perform the geometrical reduction.

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Annexes

- TMRT Reduction Example
- TMRT Theory

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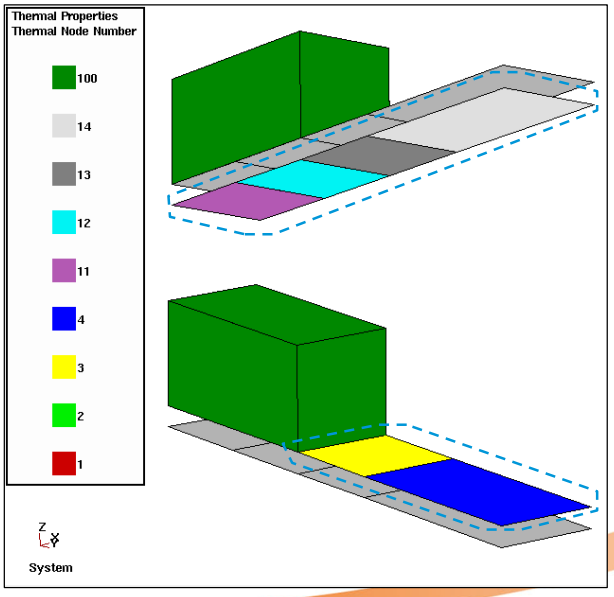
TMRT Reduction Example



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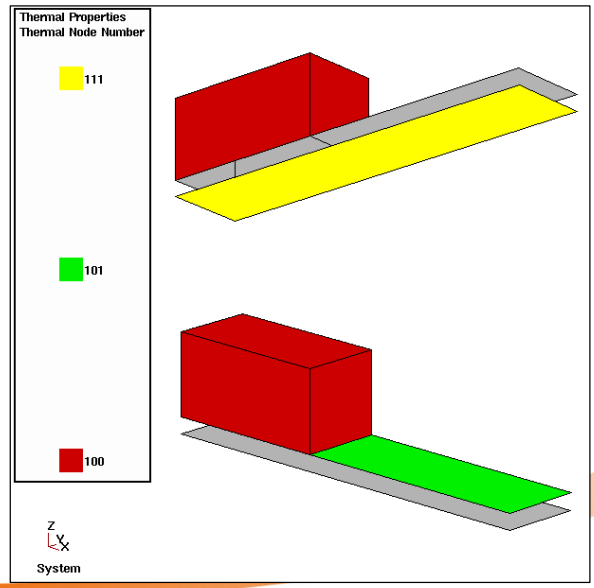
TMRT Reduction Example

```
$SUPPRESSED
1 100
$Q
2 100
3
$NREC
3
4
#
$AVERAGE
CAPACITANCES
$101
3 1
4 1
$102
11 1
12 1
13 1
14 1
#
```



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TMRT Theory

- Thermal System: $CT + M\frac{\partial T}{\partial t} = q + p = q'$
- Projection Method: $T = R\hat{T} \qquad \tilde{R}^t\left[CR\hat{T} + MR\frac{\partial \hat{T}}{\partial t}\right] = \tilde{R}^t[q' + r]$

$$\hat{C}\hat{T} + \hat{M}\frac{\partial \hat{T}}{\partial t} = \hat{q}'$$

$$\hat{C} = \tilde{R}^t C R, \qquad \hat{M} = \tilde{R}^t M R, \qquad \hat{q}' = \tilde{R}^t q'$$

- Guyan-Irons Reduction:

$$\begin{bmatrix} C_{\alpha\alpha} & C_{\alpha\beta} \\ C_{\beta\alpha} & C_{\beta\beta} \end{bmatrix}\begin{Bmatrix} T_\alpha \\ T_\beta \end{Bmatrix} = \begin{Bmatrix} q'_\alpha \\ q'_\beta \end{Bmatrix} \qquad T = \begin{Bmatrix} T_\alpha \\ T_\beta \end{Bmatrix} = R\hat{T} = RT_\alpha$$

$$R = \begin{bmatrix} I_\alpha \\ -C_{\beta\beta}^{-1}C_{\beta\alpha} \end{bmatrix}, \qquad \tilde{R}^t = R^t = \begin{bmatrix} I_\alpha & -C_{\alpha\beta}C_{\beta\beta}^{-1} \end{bmatrix}$$

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TMRT Theory

- Linear Constraints: $g = AT$
- Lagrangian Multipliers:

$$g = 0 = AT \qquad \begin{bmatrix} C & A^t \\ A & 0 \end{bmatrix}\begin{Bmatrix} T \\ \lambda \end{Bmatrix} = \begin{Bmatrix} q' \\ 0 \end{Bmatrix}$$

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TMRT Theory

- TMRT Equation:

$$\begin{bmatrix} C_{KK} & C_{KS} & C_{KG} & 0 & 0 \\ C_{SK} & C_{SS} & C_{SG} & 0 & 0 \\ C_{GK} & C_{GS} & C_{GG} & 0 & A_{AG}^t \\ 0 & 0 & 0 & 0 & A_{AA} \\ 0 & 0 & A_{AG} & A_{AA} & 0 \end{bmatrix} \begin{Bmatrix} T_K \\ T_S \\ T_G \\ T_A \\ \lambda \end{Bmatrix} = \begin{Bmatrix} q'_K \\ q'_S \\ q'_G \\ q'_A \\ 0 \end{Bmatrix}$$

$$T_{A_i} = \sum_{i \in G_i} a_{A_i i} T_i \qquad T_A = A_{AG} T_G$$

$$g = \begin{bmatrix} A_{AG} & A_{AA} \end{bmatrix} \begin{Bmatrix} T_G \\ T_A \end{Bmatrix} = A \begin{Bmatrix} T_G \\ T_A \end{Bmatrix} = 0$$

$$A_{AA} = -I_A$$

$$C_{\alpha\alpha} = \begin{bmatrix} C_{KK} & 0 \\ 0 & 0 \end{bmatrix}, \qquad C_{\beta\beta} = \begin{bmatrix} C_{SS} & C_{SG} & 0 \\ C_{GS} & C_{GG} & A_{AG}^t \\ 0 & A_{AG} & 0 \end{bmatrix},$$

$$C_{\alpha\beta} = C_{\beta\alpha}^t = \begin{bmatrix} C_{KS} & C_{KG} & 0 \\ 0 & 0 & A_{AA} \end{bmatrix}$$

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TMRT Theory

- TMRT Reduced Equations:

$$\hat{C} = C_{\alpha\alpha} - C_{\alpha\beta} C_{\beta\beta}^{-1} C_{\beta\alpha}$$

$$\hat{M} = M_{\alpha\alpha} + C_{\alpha\beta} C_{\beta\beta}^{-1} M_{\beta\beta} C_{\beta\beta}^{-1} C_{\beta\alpha}$$

$$\hat{q}' = q'_\alpha - C_{\alpha\beta} C_{\beta\beta}^{-1} q'_\beta$$

$$T_\beta = -C_{\beta\beta}^{-1} C_{\beta\alpha} T_\beta + C_{\beta\beta}^{-1} q'_\alpha$$

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