Appendix I

TMRT Module Software
Use on an Industrial Application

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Abstract

Reduction thermal model activity is a recurrent activity on a majority of space program. The reduction is usually done manually. This activity can also take a lot of time if the DTMM (Detailed Thermal Mathematical Model) to be reduced has a lot of nodes and thermal couplings. Moreover, the fact that the reduction is done manually increases the error risk on the RTMM (Reduced Thermal Mathematical Model) and so increases therefore the difficulty of the correlation activity between DTMM and RTMM. In order to optimize reduction activity, an initial module software (so called TMRT, Thermal Model Reduction Tool) has been developed by Airbus Defence & Space (ADS) and Thales Alenia Space (TAS) under ESA contract. This module has been afterward implemented in TAS Thermal Internal Software (E-THERM) and several evolutions have been done under TAS self-funding, in order to implement typical ESATAN-TMS parameters and functions and so to permit the reduction of an ESATAN-TMS DTMM. The objectives of the presentation are to :

- describe briefly the TMRT Module of E-THERM
- define limits and constraints of TMRT module for an ESATAN-TMS DTMM reduction
- present the reduction results obtained on an industrial application.


ESA 28th European Space Thermal Analysis Workshop
WE LOOK AFTER THE EARTH BEAT
TMRT (Thermal Model Reduction Tool)
APPLICATION ON ESATAN-TMS DETAILED THERMAL MATHEMATICAL MODEL
14th - 15th October 2014
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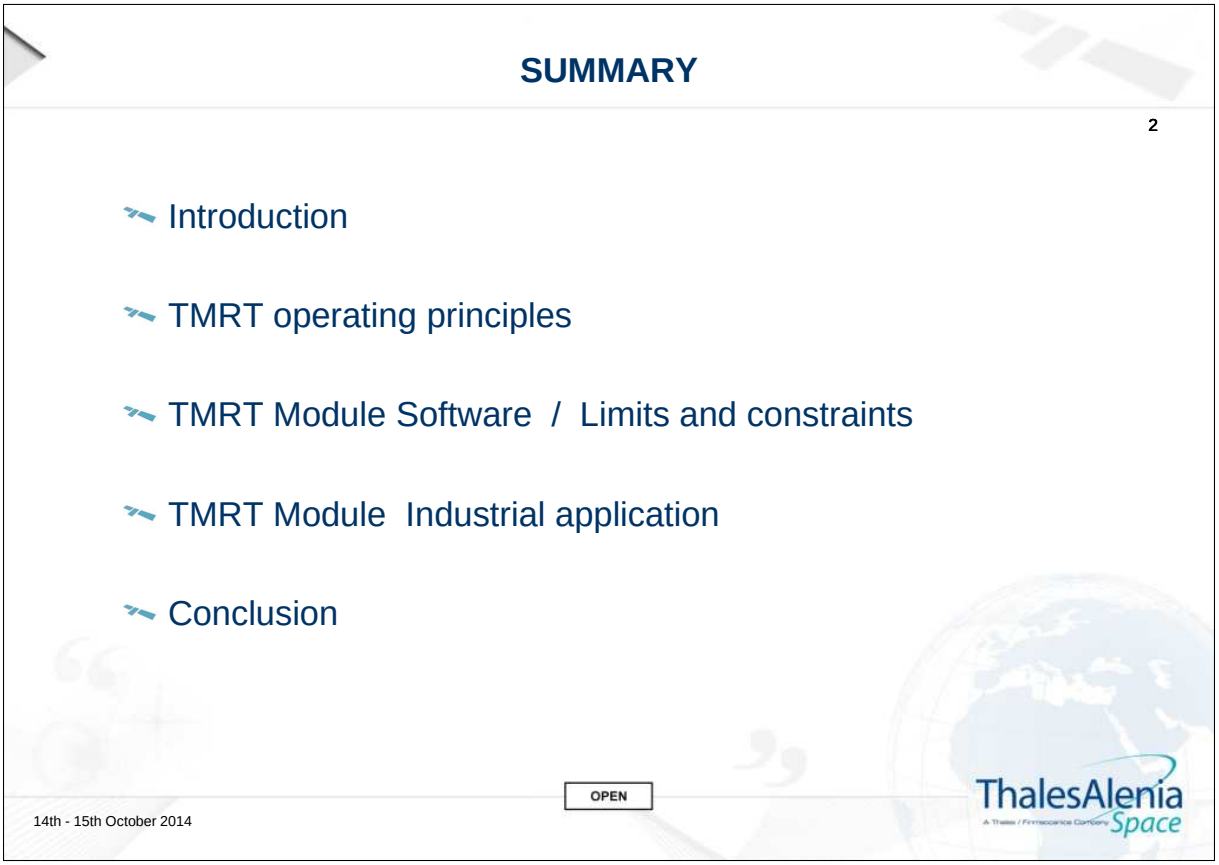
SUMMARY
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Introduction
TMRT operating principles
TMRT Module Software / Limits and constraints
TMRT Module Industrial application
Conclusion
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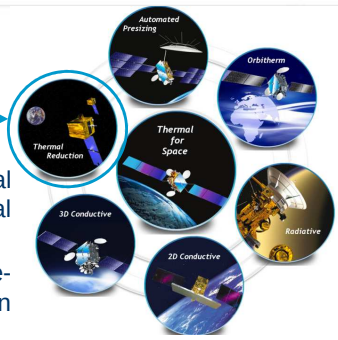
INTRODUCTION

- TMRT = Thermal Model Reduction Tool
  - Module of e-Therm Software
- TMRT permits :
  - to reduce the number of nodes of an initial Detailed Thermal Mathematical Model (DTMM) (nodal model) by generating a final Reduced Thermal Mathematical Model (RTMM).
  - to handle with two thermal model formats : ESATAN-TMS and e-Therm, for both input (DTMM) and output (RTMM). Crossing between formats is possible.
- Initial development made by Thales Alenia Space (TAS) & Airbus Defence&Space (ADS) under ESA contract.
- TMRT Module Software (included in e-Therm v1.4 software) for DTMM reduction *ESATAN-TMS → ESATAN-TMS* firstly used on TAS HR Satellite Export program and on sub-systems of CSO program



TMRT Module Software developed for use at System Level

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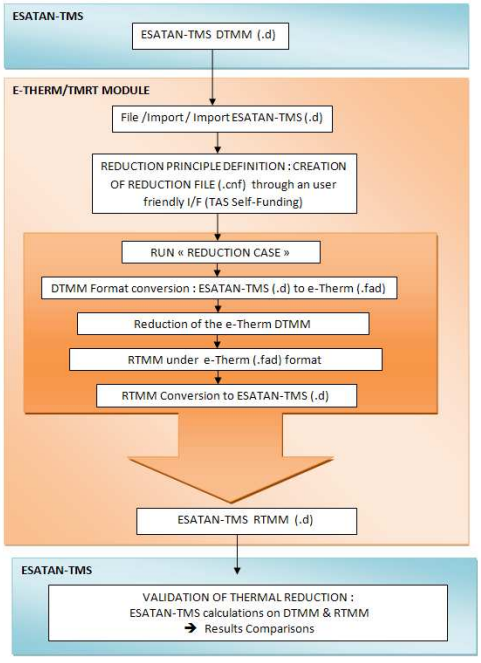
ESATAN-TMS DTMM REDUCTION : TMRT PRINCIPLE



- Reduction limited to DTMM (Mathematical)
- "Physical" reduction taking into account non-linear radiative couplings, source terms and capacitances
- No reduction of DTGM (Geometrical) for ESATAN-TMS DTMM Reduction
  - Manual activity on the base of DTGM in order to create RTGM if needed.
  - *Nota: In the case of an e-Therm DTMM reduction, reduction of DTGM is possible (but reduction is limited to nodes – no reduction of number of faces)*

Thermal Reduction on e-Therm model format

Conversion ESATAN-TMS <-> e-Therm

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TMRT Constraints on ESATAN-TMS DTMM (TMRT Input) (1/2)

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TMRT ESATAN-TMS DTMM RECOGNIZED PARAMETERS & FUNCTIONS		
PARAMETERS & FONCTION	INITIAL VERSION OF TMRT	DEVELOPED VERSION (TAS SELF-FUNDING)
Node Label	YES	YES
Node Initial Temperature (T)	YES	YES
Node Area (A)	YES	YES
Node Capacitance (C)	YES (limited to numerical value)	YES (numerical value and calculated value with Esatan « variables »)
Node type (D, B, X)	YES (except X type)	YES
Internal dissipation (QI)	NO	YES (numerical value and time dependency value)
Radiative Couplings (GR)	YES (limited to numerical value)	YES (numerical value and calculated value with Esatan « variables »)
Conductive Couplings (GL)	YES (limited to numerical value)	YES (numerical value and calculated value with Esatan « variables »)
T(℃) dependency variable	NO	YES (for instance : tempe rature dependency of thermal conductivity)
Constant External fluxes QE Earth / QA Albedo /QS Solar	NO	YES
Time Dependency External fluxes QE Earth / QA Albedo /QS Solar	NO	YES (under conditions : a specific ESATAN-TMS format shall be apply)
Thermostatic Regulation Lines (THRMST function / QR)	NO	YES (under conditions : a specific ESATAN-TMS format shall be apply)
Fortran boucle “FOR” for nodes & conductors definition	NO	YES
§INCLUDE Function	NO	YES

TAS TMRT Developed version able to recognize & treat the main parameters of an ESATAN-TMS DTMM

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TMRT Constraints on ESATAN-TMS DTMM (TMRT Input) (2/2)

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- TMRT ESATAN-TMS DTMM unrecognized parameters & functions :
  - Nodes label with accent
  - Nodes coordinates (= ESATAN-TMS r5 outputs) : *FX = -0.887000, FY = -0.329500, FZ = 0.244750*
  - Convective conductors
  - Function LOG
  - All ESATAN-TMS functions and fortran subroutines not listed in the previous slide
- ESATAN-TMS DTMM Size :
  - TMRT can’t import the ESATAN-TMS DTMM when this latter is too big (typically for a thermal model with conductors number > 400 000).
  - *Actual by-passing solution* = Conductive and radiative couplings reduction is done step by step (= creation of several DTMM as inputs for TMRT: one for instance with only conductive couplings and the other with only radiative couplings). A fusion activity shall also be done on the base of RTMM models issued from TMRT.

Some restrictions exist on ESATAN-TMS DTMM input format

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TMRT Reduction Methodology

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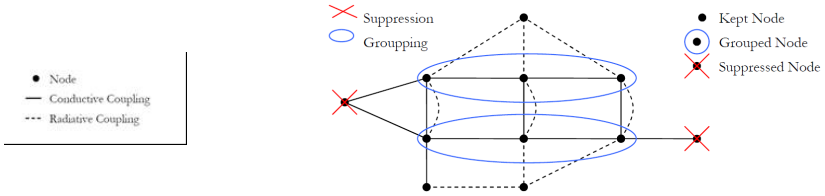
- STEP 1 : Generating RTMM node list starting from the RTMM one and performing combinations of DTMM nodes :
  - Kept nodes = Nodes present in DTMM and in RTMM with the same characteristics.
  - Average nodes = Grouping of nodes where the weights of all grouped nodes are either proportional to their areas or their thermal capacitances (depending on users will).
  - Suppressed nodes = Nodes removed from RTMM nodes list. Theirs characteristics are also reallocated on « kept nodes »



- STEP 2 : Run reduction case

TMRT Reduction philosophy based on combination of DTMM nodes

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TMRT Reduction Constraints

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- On combinations of DTMM nodes:
  - A DTMM node which has a radiative coupling with another node can't be suppressed in the reduction (= can't be a "SUPRESSED" node).
  - DTMM "KEPT " nodes can't be renumbered in RTMM through TMRT
  - The capacitance of a DTMM node which has the "SUPRESSED" status can't be attributed to an "AVERAGE" node of the RTMM. It can be attributed only to a " KEPT " node.
- On generated RTMM ESATAN-TMS:
  - Some renumbering shall be done manually (due to restriction listed hereafter)
  - Outputs definition shall be redefined manually with RTMM nodes list.
  - Comparison between DTMM & RTMM results shall be done through ESATAN-TMS calculation in order to validate the RTMM.

Some restrictions exist on TMRT reduction under ESATAN-TMS format

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TMRT Industrial Application (1/8)

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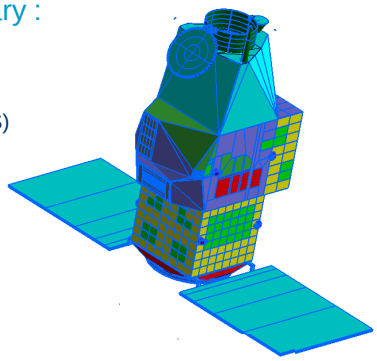
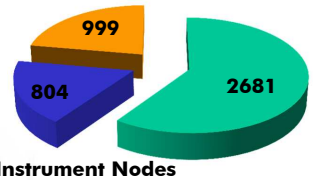
- HR Export Satellite Detailed Thermal Model Summary :
  - Software : ESATAN-TMS r4
  - Global Satellite Thermal Model is composed by :
    - **1** External Radiative Model (External DTGM – ESATAN-TMS)
    - **13** Internal Radiative Models (Internal DTGM)
    - **3** Conductive Models (e-Therm & ESATAN-TMS)
    - **1** Mathematical Thermal Model (DTMM – ESATAN-TMS)
  - Satellite DTMM nodes number = **4484** nodes
  - Satellite Thermal Regulation lines number = **53**





Instrument Nodes
MMS Nodes
PF Nodes

MMS = Mission Module Service
PF = Platform

Instrument Regulation Lines
MMS & PF Regulation Lines

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TMRT Industrial Application (2/8)

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- Satellite Reduction objectives :
  - RTMM nodes number < **400**
  - Temperature objectives (Difference between reduced & detailed Models):
    - for structural nodes : **ΔT(°C) < 3°C**
    - for MLI nodes : **ΔT(°C) < 10°C**
  - Consumption objectives(Difference between reduced & detailed Models):
    - **ΔP(W) < 5%** for :
      - Global heating power consumption of Satellite
      - Global heating power consumption of EOPL subsystem
      - Global heating power consumption of PF+MMS subsystem
    - **ΔP(W) < 15%** for line with an heating power consumption > 5W
    - **ΔP(W) < 0.5W** for line with an heating power consumption > 5W
  - Thermal cases validation number : **2**
    - Hot nominal Case
    - Safe Case

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TMRT Industrial Application (3/8)

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- Software version used : e-Therm 1.4b / TMRT Module
- Node Reduction Synthesis :
  - RTMM nodes number = **340** → Reduction **factor** is closed to **13 :**
    - 249 structural nodes (140 for EOPL / 109 for PF+MMS)
    - 89 MLI nodes
    - 1 Boundary node (Space node) / 1 Inactive node (X)
- Reduction Synthesis (Temperature) :
  - Hot Nominal Case **:**
    - **98%** of SATELLITE RTMM structural nodes have $\Delta T_{(DTMM/RTMM)} < 3℃$
    - **98%** of SATELLITE RTMM MLI nodes have $\Delta T_{(DTMM/RTMM)} < 10℃$
  - Cold Safe Case **:**
    - **93%** of SATELLITE RTMM structural nodes have $\Delta T_{(DTMM/RTMM)} < 3℃$
    - **97%** of SATELLITE RTMM MLI nodes have $\Delta T_{(DTMM/RTMM)} < 10℃$
  - *Note 1: Calculation of average temperature is made classically and not in proportion of MCP for structure or area for MLI. For the few nodes not in tolerance criteria, the calculus in proportion of area or mCp gives better results.*
  - *Note 2: At Instrument Level, 100% (resp. 99%) of RTMM structural nodes have $\Delta T_{(DTMM/RTMM)} < 3℃$ in hot nominal case (resp. in cold safe case).*

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TMRT Industrial Application (4/8)

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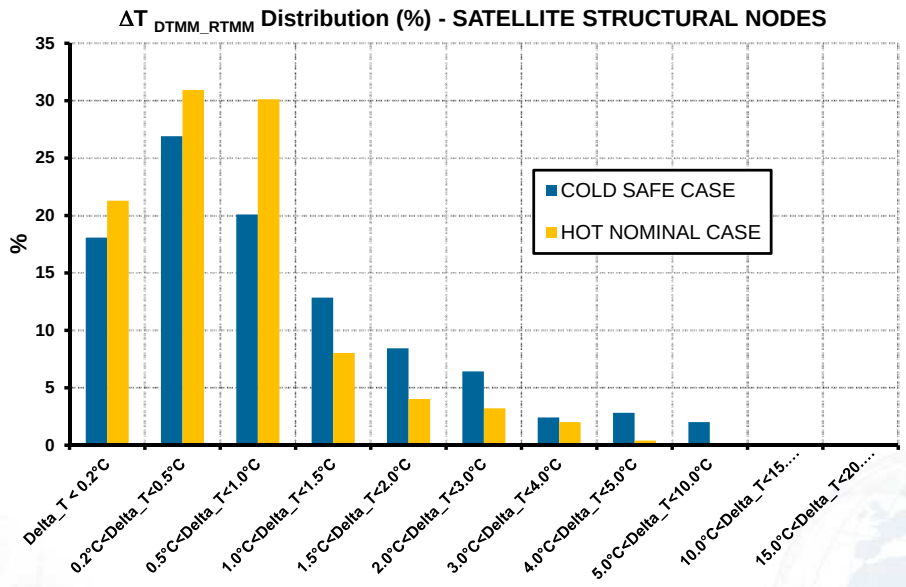

Good Representativeness of Structural Nodes Temperature

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TMRT Industrial Application (5/8)

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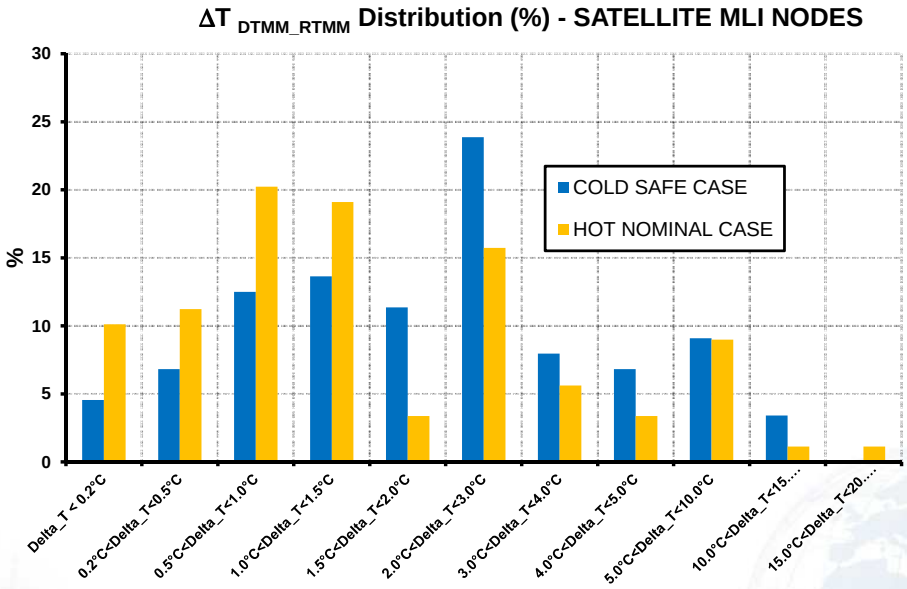

Good Representativeness of MLI Nodes Temperature

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TMRT Industrial Application (6/8)

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- Reduction Synthesis (Heating Power Consumption) :
  - Hot Nominal Case :
    - $\Delta P_{(DTMM/RTMM)}$ **= -0.9 %** on Satellite Global heating power consumption
    - $\Delta P_{(DTMM/RTMM)}$ **= -0.6 %** on EOPL Global heating power consumption
    - No heating power consumption on PF/MMS in hot case.
  - Cold Safe Case :
    - $\Delta P_{(DTMM/RTMM)}$ **= 0.9 %** on Satellite Global heating power consumption
    - $\Delta P_{(DTMM/RTMM)}$ **= 1.1 %** on EOPL Global heating power consumption
    - $\Delta P_{(DTMM/RTMM)}$ **= 2.8 %** on PF/MMS Global heating power consumption

$\Delta P_{(DTMM/RTMM)} < 5\ \% \rightarrow$ Good representativeness of heating power consumption

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TMRT Industrial Application (7/8)

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GLOBAL SATELLITE ATC CONSUMPTION HOT NOMINAL CASE	DTMM	RTMM	ΔP (W)	Δ (%)	REDUCTION STATUS VS OBJECTIVES
GLOBAL SATELLITE ATC CONSUMPTION (W)	63.2	62.6	-0.6	-0.9	OK
CTA EOPL CONSUMPTION					
DETECTION UNIT AREA	19.0	18.6	-0.4	-2.2	OK
BACK CAVITY AREA	18.6	18.7	0.1	0.5	OK
FONT CAVITY AREA	9.7	9.0	-0.7	-6.9	OK
M2 AREA	10.0	9.9	-0.1	-0.7	OK
M1 AREA	5.7	6.4	0.7	11.9	OK
TOTAL	63.0	62.6	-0.4	-0.6	OK
CTA PF+MMS CONSUMPTION					
PCU	0.0	0.0	0.0	/	NO ATC CONSUMPTION
VPU	0.0	0.0	0.0	/	
CSFU	0.0	0.0	0.0	/	
ZONE PDHT (*)	0.2	0.0	-0.2	/	
CRYPTO TURK	0.0	0.0	0.0	/	
TANK	0.0	0.0	0.0	/	
PF -X PANEL	0.0	0.0	0.0	/	
BATTERY	0.0	0.0	0.0	/	
-Zinf RWs	0.0	0.0	0.0	/	
+Zinf RWs	0.0	0.0	0.0	/	
+Zsup TTC	0.0	0.0	0.0	/	
Pan -Y PCDU	0.0	0.0	0.0	/	
Pan +Y SMU	0.0	0.0	0.0	/	
CSS	0.0	0.0	0.0	/	
TOTAL	0.2	0.0	-0.2	/	OK
(*) Incluant OMUX/ Crypto TMI / MOD et EPC					

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TMRT Industrial Application (8/8)

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GLOBAL SATELLITE ATC CONSUMPTION COLD SAFE CASE	DTMM	RTMM	ΔP (W)	Δ (%)	REDUCTION STATUS VS OBJECTIVES
GLOBAL SATELLITE ATC CONSUMPTION (W)	316.8	319.8	3.0	0.9	OK
CTA EOPL CONSUMPTION					
DETECTION UNIT AREA	70.8	70.8	0.0	0	OK
BACK CAVITY AREA	35.8	34.8	-1.1	-3	OK
FONT CAVITY AREA	17.4	16.0	-1.3	-8	OK
M2 AREA	14.9	15.1	0.2	1	OK
M1 AREA	10.4	11.0	0.6	6	OK
TOTAL	149.3	147.6	-1.6	-1.1	OK
CTA PF+MMS CONSUMPTION					
PCU	1.9	4.1	2.2	/	OK
VPU	0.0	0.0	0.0	/	OK
CSFU	0.0	0.0	0.0	/	OK
ZONE PDHT (*)	84.6	80.5	-4.1	-5	OK
CRYPTO TURK	0.0	0.1	0.1	/	OK
TANK	2.2	2.6	0.3	/	OK
PF -X PANEL	43.3	49.3	6.0	14	OK
BATTERY	23.8	22.1	-1.7	-7	OK
-Zinf RWs	0.0	0.0	0.0	/	OK
+Zinf RWs	0.0	0.0	0.0	/	OK
+Zsup TTC	0.0	0.0	0.0	/	OK
Pan -Y PCDU	0.0	0.0	0.0	/	OK
Pan +Y SMU	0.0	0.0	0.0	/	OK
CSS	11.7	13.5	1.8	15	OK
TOTAL	167.5	172.2	4.7	2.8	OK
(*) Incluant OMUX/ Crypto TMI / MOD et EPC					

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CONCLUSION

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- TMRT Module Software allows to :
  - Reduce a DTMM at ESATAN-TMS format
  - Reduce a DTMM in shorter time than “classical manual method”.
  - Limit “manual” user actions (= reduction of human errors)
  - Create RTMM with an excellent representativeness of DTMM
- TMRT Module Software has been validated on industrial cases and will be used on future programs.
- Discussion on-going to update TMRT Module Software :
  - Increase the TMRT capacity on conductors number (radiative & conductive)
  - Limitate constraints on TMRT DTMM combinations nodes

Benefit to use TMRT

Update of software functionalities identified

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Thank you for your attention

Any questions?

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