European Space Thermal Engineering Workshop
18-20 October 2022

METHODOLOGY FOR ELECTRICAL HARNESS THERMAL MODELLING IN A GLOBAL SYSTEM THERMAL ANALYSIS

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AGENDA

1) Harness heat leak introduction
2) Methodology
3) Thermal test campaigns
4) Test results analysis
5) Harness modelling procedure
6) Conclusion

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1) HARNESS HEAT LEAK INTRODUCTION

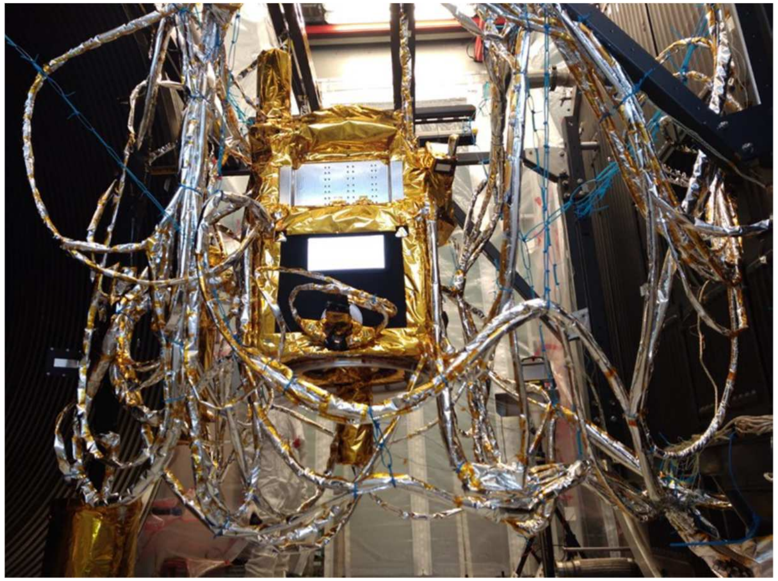
Significant for miniaturized systems

Thermal heat leaks through harnesses can lead to a **large uncertainty** in system thermal analysis

- Especially **significant for miniaturized system as nanosatellites or microsatellites** (with reduced harness lengths)
- In particular for **system with low heating power** available
- Concern for **both test and flight harnesses**

MICROSCOPE microsatellite

Nanosatellites



TARANIS microsatellite in TVAC

- Future systems will be **more and more power consuming** →more and more harness with high current/cross section.

1) HARNESS HEAT LEAK INTRODUCTION

Hard to simulate in a system thermal model

- A lot of various harnesses definition:
  - Material
  - Gauge
  - Shielding
  - Thermo-optical properties
  - Accommodation
  - Lengths
  - Strand
  - Mechanical mounting
  - …

- A lot of thermal configurations:
  - Radiative sink
  - Conductive sink
  - Heat transfers direction
  - With/without MLI/SLI
  - …

A lot of parameters and configurations + parasite heat leaks
→ thermal behavior hard to catch in a system thermal model

Conduction ?
Radiation ?
Both ?
Which ratio ?

Which model in my system analysis ?
Which meshing ?
Which parameters ?

Which uncertainty ?

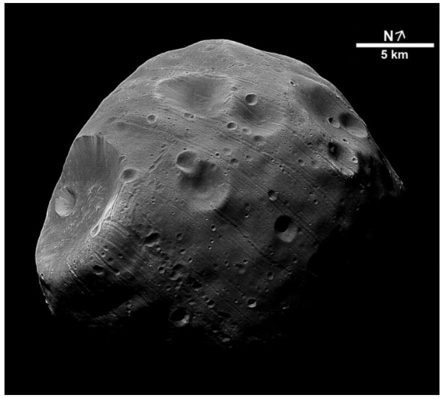
Objective of this study: identify a simple procedure to recommend a thermal modelling of the harness for a global system thermal analysis where a detailed thermal model of all harnesses is not possible (too much nodes, too much time consuming, …). This procedure doesn't concern the cryogenic temperatures.

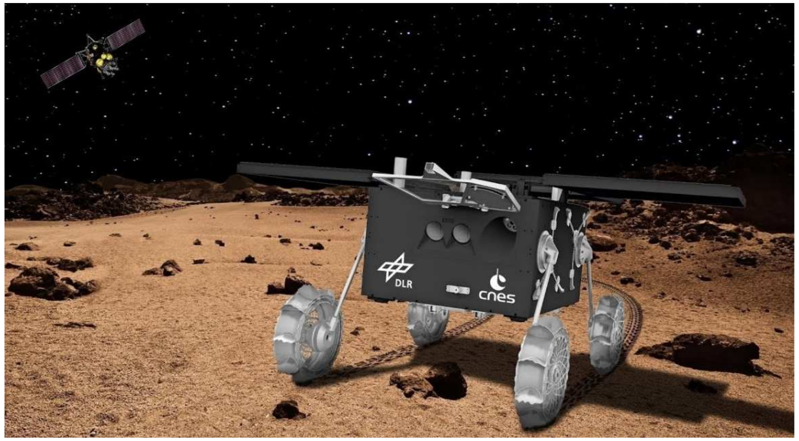
→ *Alternative to a classic meshing convergence study cost and time consuming*

1) HARNESS HEAT LEAK INTRODUCTION

In the frame of the MMX Rover CNES/DLR project

- Study performed in the frame of the **MMX rover CNES/DLR mission** where **heat leaks through harnesses are important**





- **MMX probe from JAXA (Mars Moons Exploration)** explores Deimos and Phobos (moons of Mars planet) and returns samples from Phobos to Earth
- Launch 2024
- CNES and DLR build a rover (**29 kg**) onboard this probe
- Rover is hitched to the probe until Phobos and jettisoned to the Phobos surface from a low altitude
- The **rover autonomously uprights and deploys itself** from a stowed position and **drive on Phobos**
- Objective of the rover is to perform a detailed observation, characterization and analysis of the Phobos soil (response to mechanical action of the rotation of the wheels, spectrometer, radiometer, cameras…)…
- **Low-cost** and **reduced development plan** (new space approach)
- **Thermal environment similar to Earth Moon (cold, dust, …)**
- Main thermal architecture:
  - Electronic box (30*30*15cm) with battery kept at room temperature insulated from the external and cold chassis box (**50*50*25 cm**)
  - Very limited in energy because far from the sun and no radioactive source (only solar panels) → very **small heating power**
  - **1 000 harnesses** with **small lengths** in **two thermal areas with large temperature differences** → heat leaks in harnesses is important

AGENDA

1) Harness heat leak introduction

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3) Thermal test campaigns

4) Test results analysis

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6) Conclusion

2) METHODOLOGY

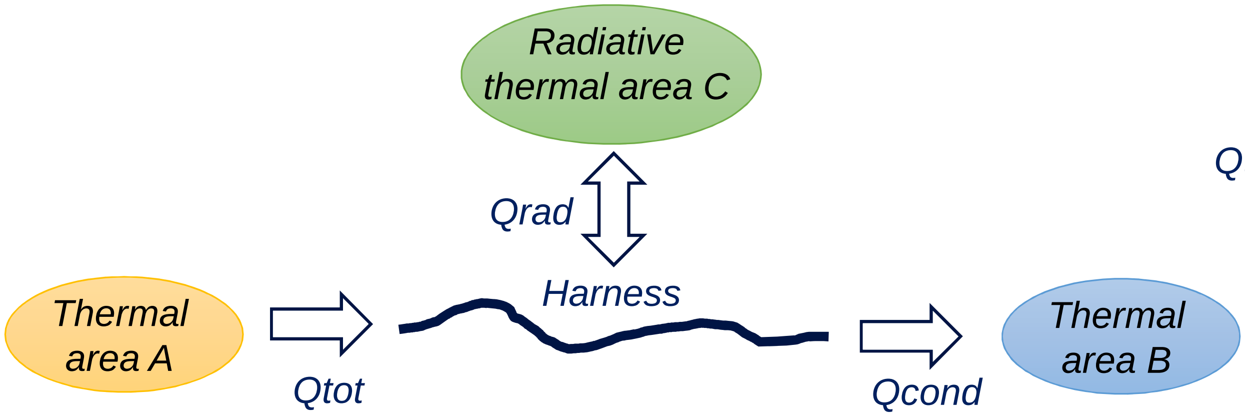
How to proceed ?

- **A** Test campaign — Perform a **test campaign** on some typical flight harnesses under various thermal configurations
- **B** Detailed model — **Detailed thermal model** of the harness in each configuration to catch heat transfers accuratly
- **C** Simplified model — **Simplification of the detailed models** to be compatible of a global nodal approach in a system analysis (driven by a precision objective)
- **D** Characteristic parameter — Identify a **key and unique parameter to catch the main heat transfer** involved: radiative, conductive, both (similar to Biot number)
- **E** Link with simplified model — Analyze the **influence between this parameter and the simplified thermal modelling**
- **F** Modelling procedure — **Provide the procedure as a recommendation** of a simplified thermal modelling for a global system thermal model

2) METHODOLOGY

Thermal modelling approach

Definition of the thermal system: an harness connects a thermal area A to another thermal area B in a thermal radiative area C



Qtot = Qrad + Qcond

Detailed thermal model:

- Detailed thermal model with both **Systema** or **NX Siemens** software and **analytical** resolution
- Used to **quantify heat fluxes**
- Able to **catch conductive and radiative** heat transfers accurately

Simplified thermal model:

- **Nodal approach** with less nodes (from 60 nodes for the detailed model until 2 nodes at minimum, one per connector)
- **Several meshing laws studied**: uniform, quadratic, exponential
- 2 performance indicators to identify the error of the simplified model relating to the detailed model (reference):
  - $Q_{tot}/Q_{tot,ref}$ ⇒ validate the total heat input involved in this system
  - $Q_{rad}/Q_{rad,ref}$ ⇒ validate the radiative heat flux (conductive is caught if both total and radiative are caught)
- Example of accuracy targeted is about 10% on the total heat input Qtot in the frame of MMX Rover Mission

2) METHODOLOGY

Characteristic number

Thermal modelling of harness depends on **2 main parameters:**

1) **Harness physical characteristics and mounting**: number of wires, accommodation, gauges, thermo-optical properties
2) **Thermal environment**: radiative sink temperature, conductive sink temperature, heat fluxes direction (who is hot and who is cold ?)

➢ **Need to define a dimensionless number** to characterise the entire thermal configuration (harness + thermal environment)

Temperature difference θ between ambiance T_a and harness T : $\theta = T_a - T$

For a hot source T_{hot} and a cold source T_{cold} the temperature difference θ at a position x of a harness of length L is given by

$$\theta(x) = C_1 \cdot e^{m\cdot x} + C_2 \cdot e^{-m\cdot x}$$

with
$$\begin{cases} C_1 = T_{hot} - C_2 \\ C_2 = \frac{T_{cold} - T_{hot}\cdot e^{m\cdot L}}{e^{-m\cdot L} - e^{m\cdot L}} \\ \boldsymbol{m^2} = 4 \cdot \varepsilon \cdot \sigma \cdot p \cdot T_a^3 / (\lambda \cdot S) \end{cases}$$

represents the ratio between radiative and conductive heat fluxes, relative to the harness length: : m² = (Φrad / Φcond)/L²

With radiative linearization:

$$\Phi_{rad} = \varepsilon \cdot \sigma \cdot p \cdot L \cdot (T_a^4 - T^4) \approx \varepsilon \cdot \sigma \cdot p \cdot L \cdot 4 \cdot T_{avg}^3 \cdot (T_a - T)$$

$$\Phi_{cond} = \frac{\lambda \cdot S}{L} \cdot (T_a - T)$$

$\Rightarrow$ **We define** $M = \frac{\Phi_{rad}}{\Phi_{cond}} = \frac{4 \cdot \varepsilon \cdot \sigma \cdot p \cdot L^2 \cdot T_{avg}^3}{\lambda_{eq} \cdot Seq}$

With T_{avg} the mean temperature of the thermal system

2) METHODOLOGY

Characteristic number

- The configuration (harness definition + thermal environment) is characterised using the dimensionless characteristic number **M** calculated based on user inputs

$$M = 4\cdot\varepsilon\cdot\sigma\cdot p\cdot L^2\cdot T_{avg}^3/(\lambda_{eq}\cdot S_{eq})$$

External IR emissivity of the strand [-]

Stefan-Boltzmann cst [$W.m^{-2}.K^{-4}$]

Strand external radiative perimeter [m]
(considering the actual strand shape after accommodation)

Harness length between connectors [m]

Average temperature of the system [K]

Equivalent strand thermal conductivity [$W.m^{-1}.K^{-1}$]

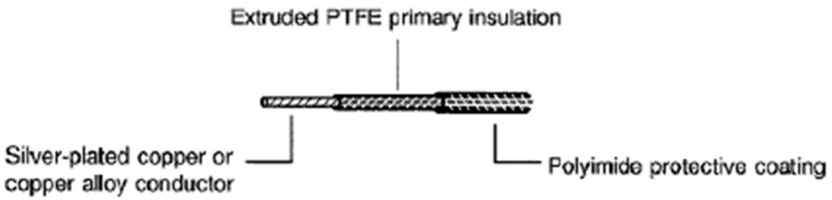
Equivalent strand cross-section [m^2]

The procedure will provide recommendations to adapt the thermal modelling for various M values depending on user configuration

2) METHODOLOGY

Characteristic number

Explanation of equivalent strand cross-section and conductivity



$$S_{eq} = S_{copper} + S_{PTFE} + S_{Polyimide}$$

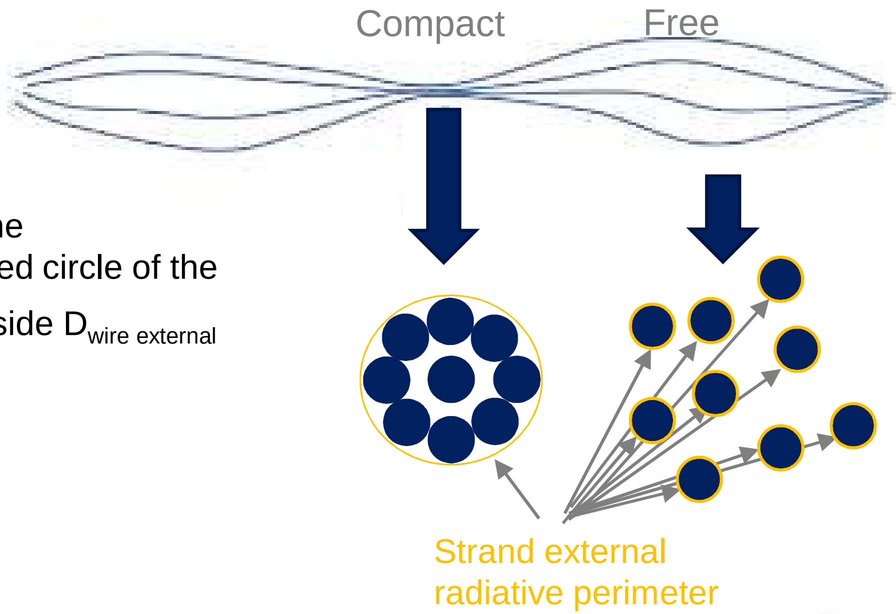
$$\lambda_{eq} = \frac{\lambda_{copper}\cdot S_{copper}+\lambda_{PTFE}\cdot S_{PTFE}+\lambda_{polyimide}\cdot S_{polyimide}}{S_{copper}+S_{PTFE}+S_{Polyimide}}$$

Explanation of strand external radiative perimeter

- Free geometry: $p = N_{wire} \cdot \pi \cdot D_{wire\ external}$
- Compact geometry: $p = \frac{2\cdot\pi\cdot D_{wire\ external}}{\sqrt{2-\sqrt{2}}}$
- Between compact and free: assumption that the evolution of *p* is linear

Radius of the circumscribed circle of the octagon of side $D_{\text{wire external}}$

Example of harness shape after mounting



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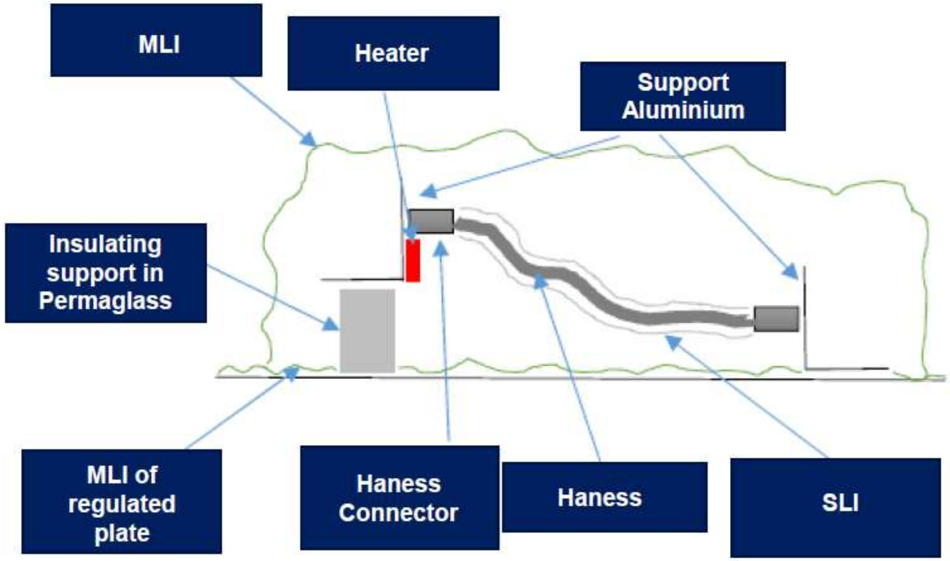
3) THERMAL TEST CAMPAIGNS

Test campaign n°1

- See ESTEW 2021 – 019 presentation “Characterization test of thermal heat leaks in electrical harnesses
- Test facility : 2m3 thermal chamber at CNES Toulouse. Test in June 2021



79 thermocouples
6 heating lines
2 weeks of testing

Test under vacuum
(P<10^{-5}hPa)

Harness definition (Flight heritage)

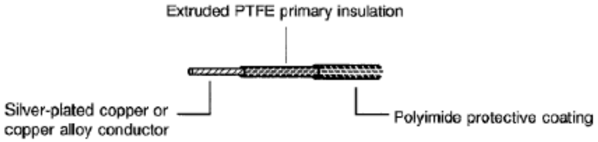
Harness n°1

9 single wires AWG26 (3901/013/02B)

Connector Micro-D MBM 3401-029 01 B 9 S FR112

- Copper Section: 9x 0.179mm^2
- PTFE Section: 9x 0.369mm^2
- Polyimid Section: 9x 0.053mm^2
- Polyimid IR emissivity: 0.9

Total lineic conductance =
6.42 10^{-4} W.m/K



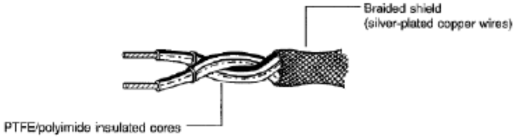
Harness n°2

12 shielded twisted pairs AWG26 (3901/013/41)

Connector Micro-D MBM 3401-029 01 B 25 S FR112

- Copper Section: 24x 0.179mm^2
- PTFE Section: 24x 0.369mm^2
- Polyimide Section: 24x 0.053mm^2
- Copper shielding: 12x 0.384mm^2
- Shielding IR emissivity: 0.2

Total lineic conductance =
23.07 10^{-4} W.m/K

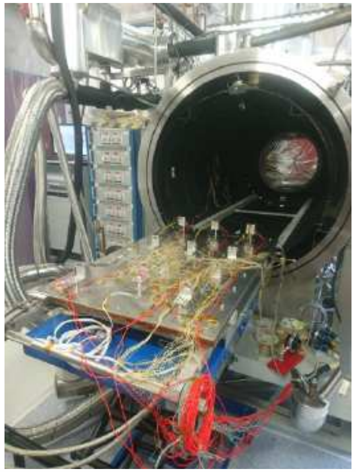


- **Total cross section 3.6 higher than n°1**

3) THERMAL TEST CAMPAIGNS

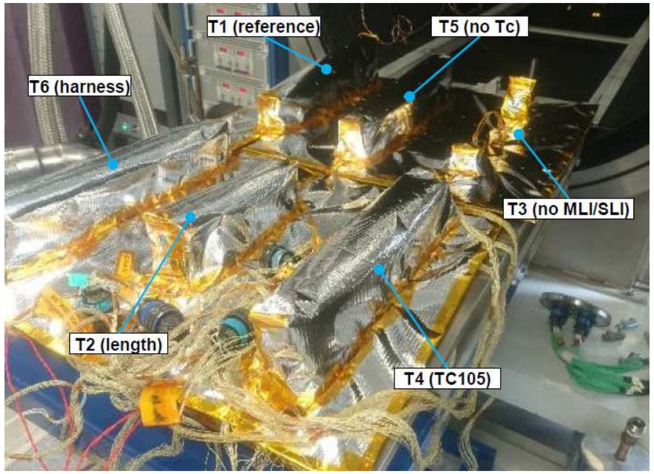
Test campaign n°1

Test article (TA)	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**
Name	**Reference**	**Length**	**No MLI/SLI**	**TC105**	**No Tc**	**Harness**
Harness	9 AWG 26 (ECSS 3901-013-02B) Flight heritage	9 AWG 26 (ECSS 3901-013-02B) Flight heritage	9 AWG 26 (ECSS 3901-013-02B) Flight heritage	9 AWG 26 (ECSS 3901-013-02B) Flight heritage	9 AWG 26 (ECSS 3901-013-02B) Flight heritage	**12 shielded twisted pairs AWG26 (ECSS 3901/013/041) Flight heritage**
Length	30 cm	**15 cm**	30 cm	30 cm	30 cm	30 cm
Accomodation / mechanical mounting	Direct between connectors	Direct between connectors	Direct between connectors	**With TC105 on the middle (15 cm)**	Direct between connectors	Direct between connectors
Connector	Micro D C&K 9S 340102901B 9SFR112 Flight heritage	Micro D C&K 9S 340102901B 9SFR112 Flight heritage	Micro D C&K 9S 340102901B 9SFR112 Flight heritage	Micro D C&K 9S 340102901B 9SFR112 Flight heritage	Micro D C&K 9S 340102901B 9SFR112 Flight heritage	**MDM connector 25 pins Flight heritage**
MLI + SLI	Yes	Yes	**No MLI / SLI**	Yes	Yes	Yes
Test harnesses	Heaters + Tc	Heaters + Tc	Heaters + Tc	Heaters + Tc	**Heaters** + **less Tc**	Heaters + Tc



Test chamber

Test article exemple (setup ongoing)



Test setup before testing

3) THERMAL TEST CAMPAIGNS

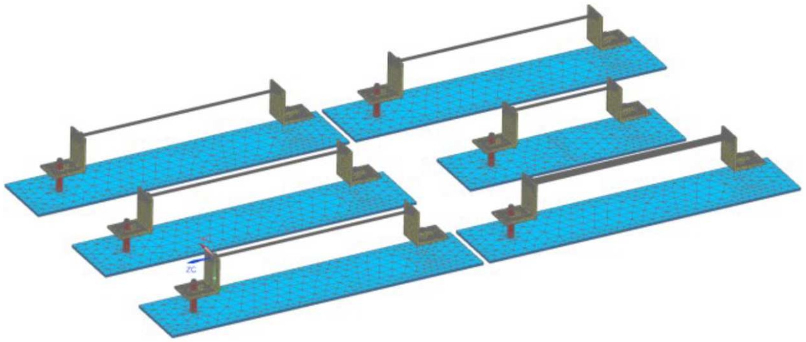
Test campaign n°1

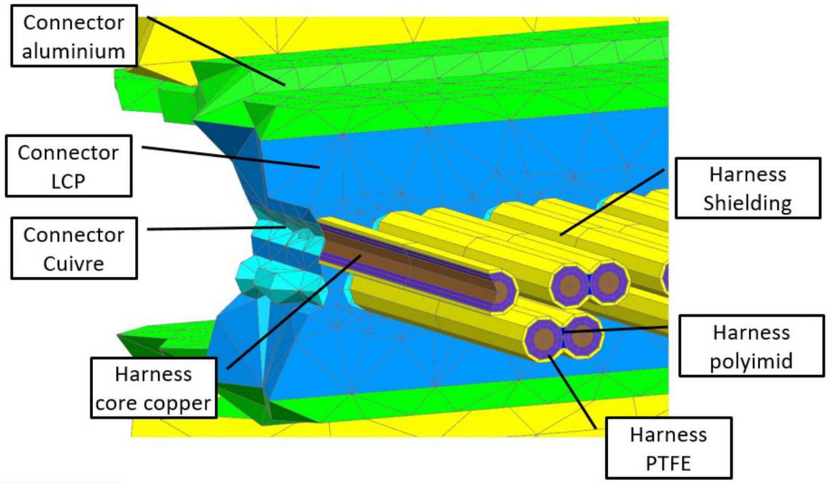
- Several thermal environments tested:
  - T_{env} = - 55 °C
  - T_{plate} = 20 °C (hot case) or T_{plate} = - 40 °C (cold case)
  - Heater power: 0.5 W, 0.75 W, 1 W and 1.5 W

- 6 test articles compared to study the influence of:
  - Harness lengths
  - Harness type
  - Radiative exchanges (MLI/SLI)
  - TC105 accommodation
  - Test thermocouples parasite leaks

- Detailed thermal model performed to correlated test results (NX Siemens) and analyze the thermal behavior

NX detailed thermal model





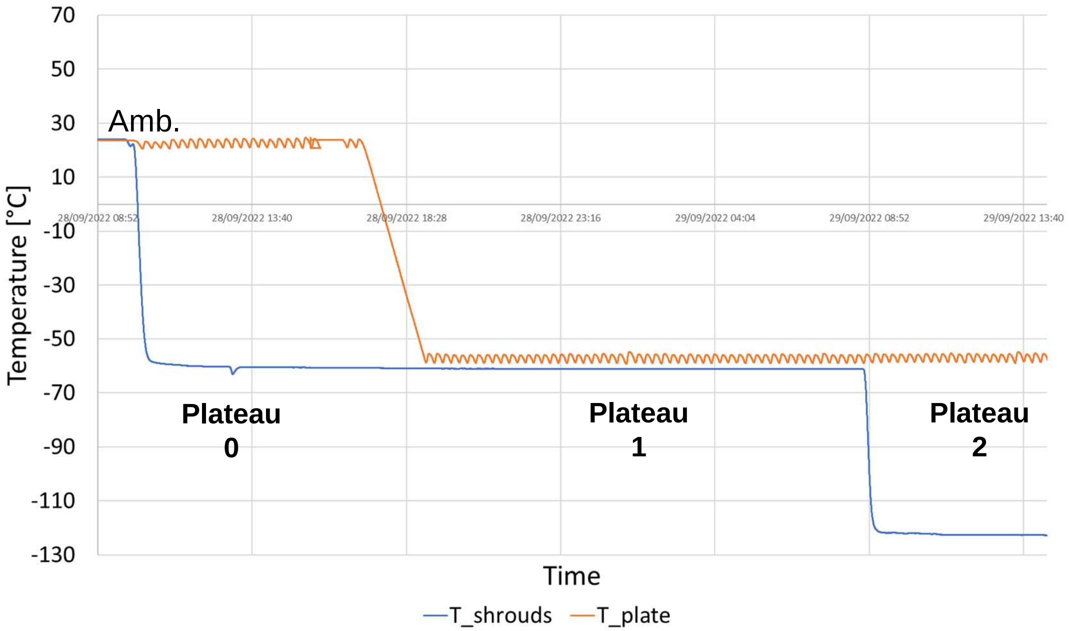
Main conclusions of test campaign n°1

A. **Radiative phenomenon can be one of the major heat transfer**
B. A **radiative/conductive ratio that drives the temperature difference** inside harness (equivalent to Biot number)
C. The precise behavior inside harness is **hard to catch in a system analysis**

3) THERMAL TEST CAMPAIGNS

Test campaign n°2

- **Same setup than n°1** but with **different harness definition and thermal environment** (more radiation)
- **Same test facility** : 2m3 thermal chamber at CNES Toulouse. Test in September 2022
- **6 new test articles** to study the influence of:
  - Harness accommodation (compact, spaced)
  - Emissivity
  - Harness length
- Several thermal balances in **various thermal configuration** with same order of magnitude of heating power than test campaign n°1



Plateau	$T_{shrouds}$ [°C]	T_{plate} [°C]
P0	-60	+23
P1	-60	-60
P2	-120	-60

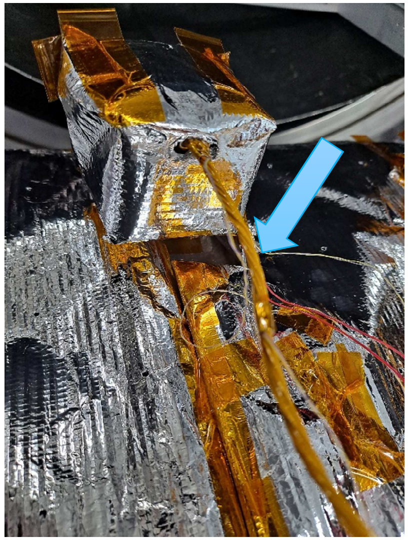
38 thermocouples
6 heating lines
1 week of testing

Test under vacuum
(P<10^{-5}hPa)

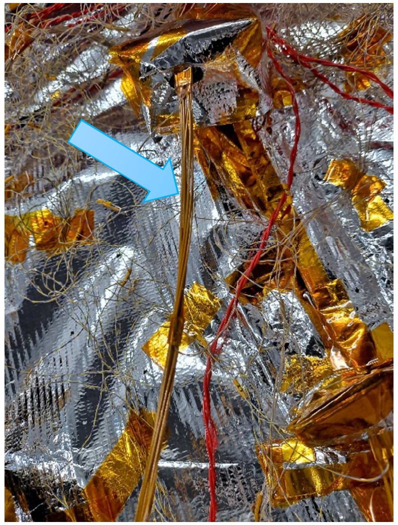
3) THERMAL TEST CAMPAIGNS

Test campaign n°2

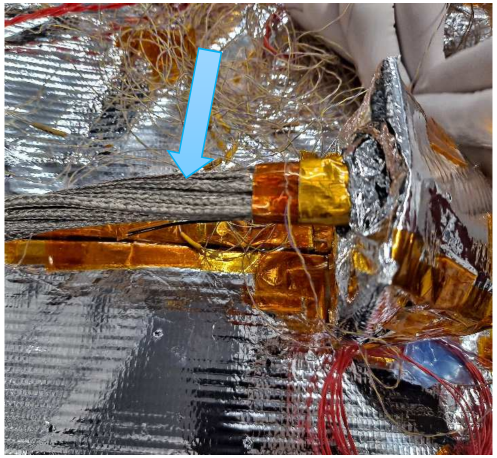
Test article (TA)	T7	T8	T9	T10	T11	T12
Name	**Compact**	**L45**	**L60**	**L15**	**Pinch middle**	**Emissivity**
Harness	9 AWG 26 (ECSS 3901-013-02B) Flight heritage	9 AWG 26 (ECSS 3901-013-02B) Flight heritage	9 AWG 26 (ECSS 3901-013-02B) Flight heritage	9 AWG 26 (ECSS 3901-013-02B) Flight heritage	9 AWG 26 (ECSS 3901-013-02B) Flight heritage	**12 shielded twisted pairs AWG26 (ECSS 3901/013/041) flight heritage**
Length	30 cm	**45 cm**	**60 cm**	**15 cm**	30 cm	30 cm
Accomodation	**Compact**	Spaced	**1 pinch every 15 cm**	Spaced	**1 pinch in the middle**	Spaced
Connector	Micro D C&K 9S 340102901B 9SFR112 Flight heritage	Micro D C&K 9S 340102901B 9SFR112 Flight heritage	Micro D C&K 9S 340102901B 9SFR112 Flight heritage	Micro D C&K 9S 340102901B 9SFR112 Flight heritage	Micro D C&K 9S 340102901B 9SFR112 Flight heritage	**MDM connector 25 pins Flight heritage**
MLI + SLI	Without	Without	Without	Without	Without	Without



Test article 7



Test article 8

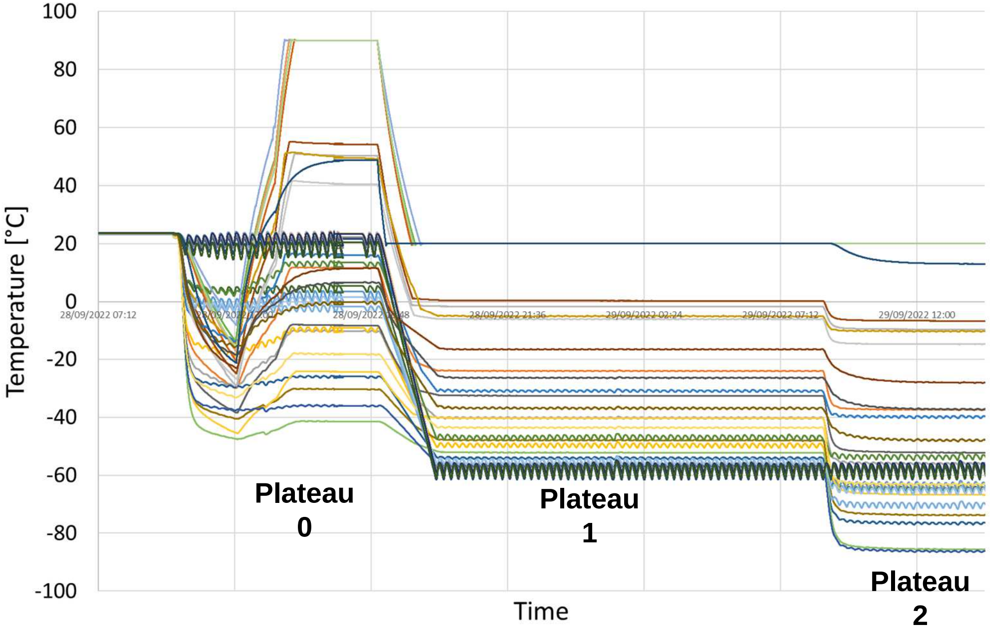


Test article 12

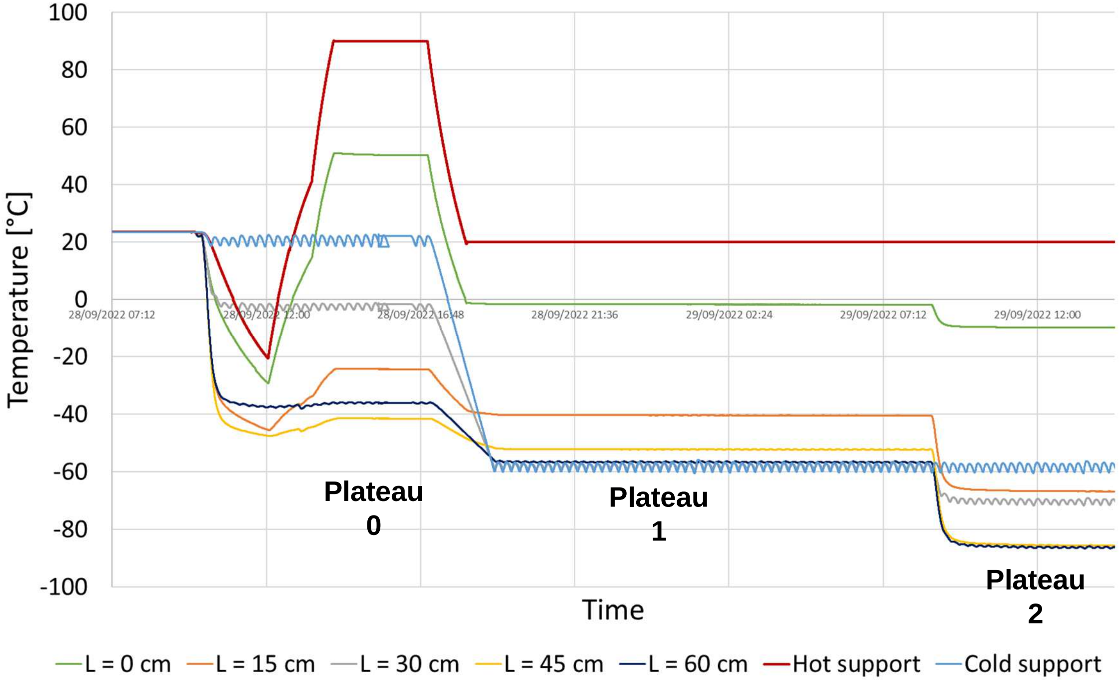
3) THERMAL TEST CAMPAIGNS

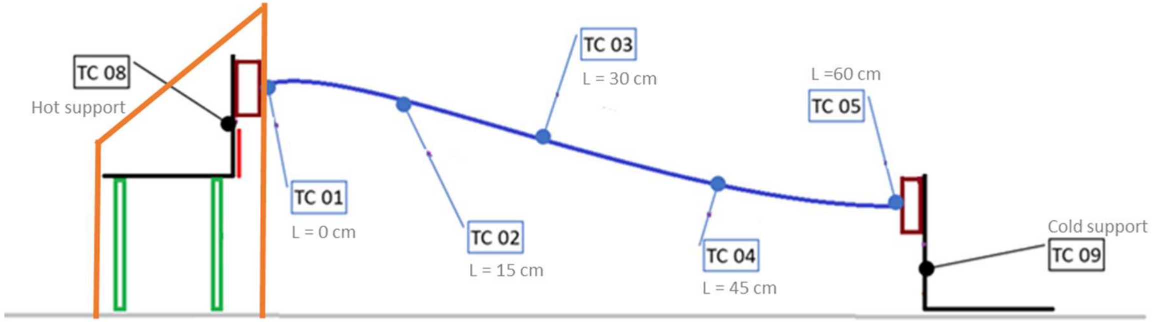
Test campaign n°2

- Time evolution of all temperatures of all harnesses TA7 to TA12



- Example of temperatures on TA9 at various lengths of the harness





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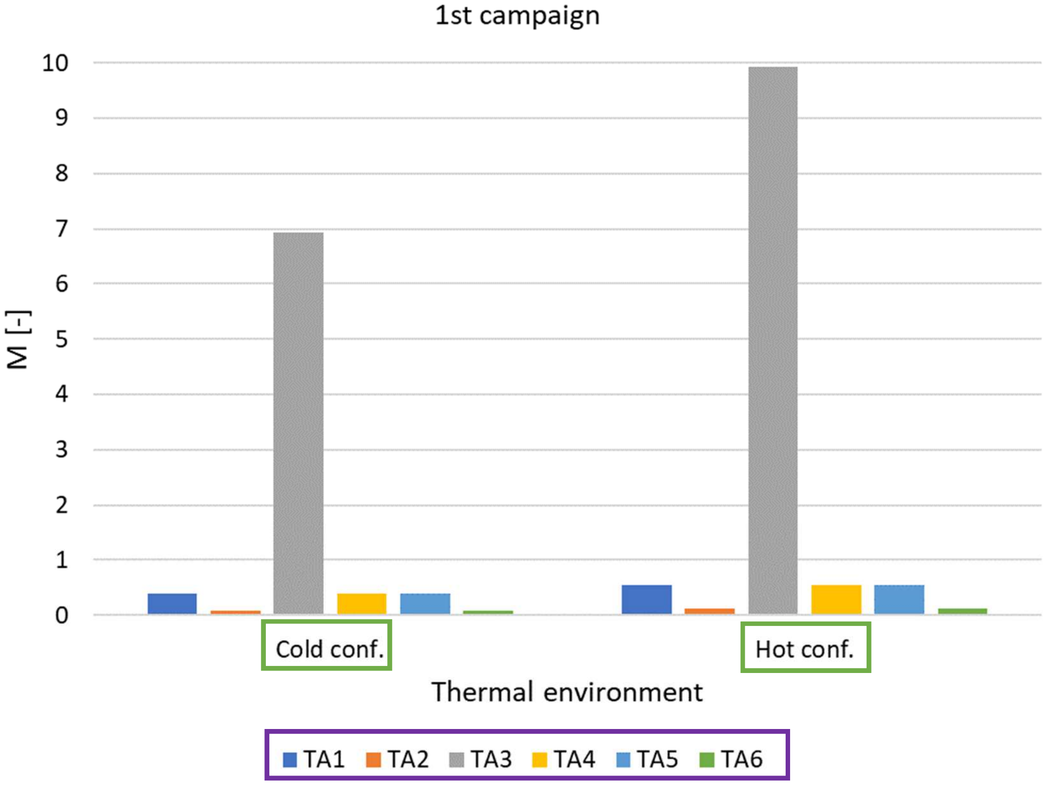
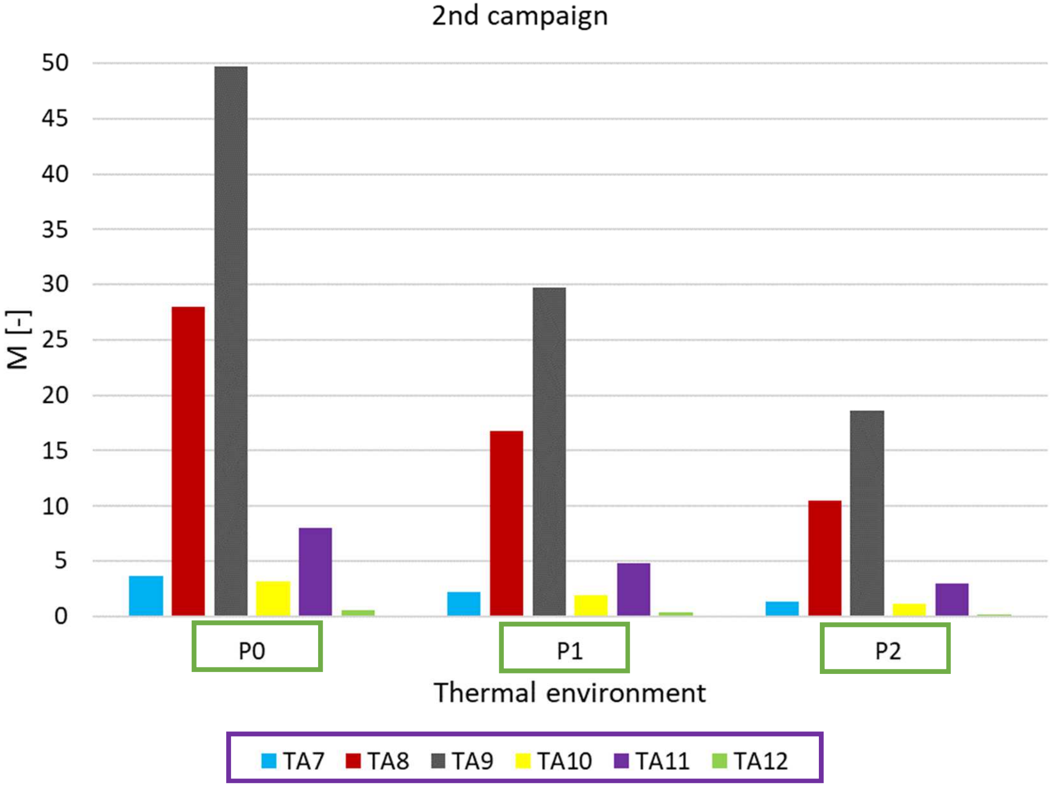
4) TEST RESULTS ANALYSIS

Characteristic number M

- With the 2 test campaigns, **30 configuration are tested**.
- The associated **M values are in the range 0.1 – 50**
- **Low M values means test articles driven by conduction** (high M values means more radiation)





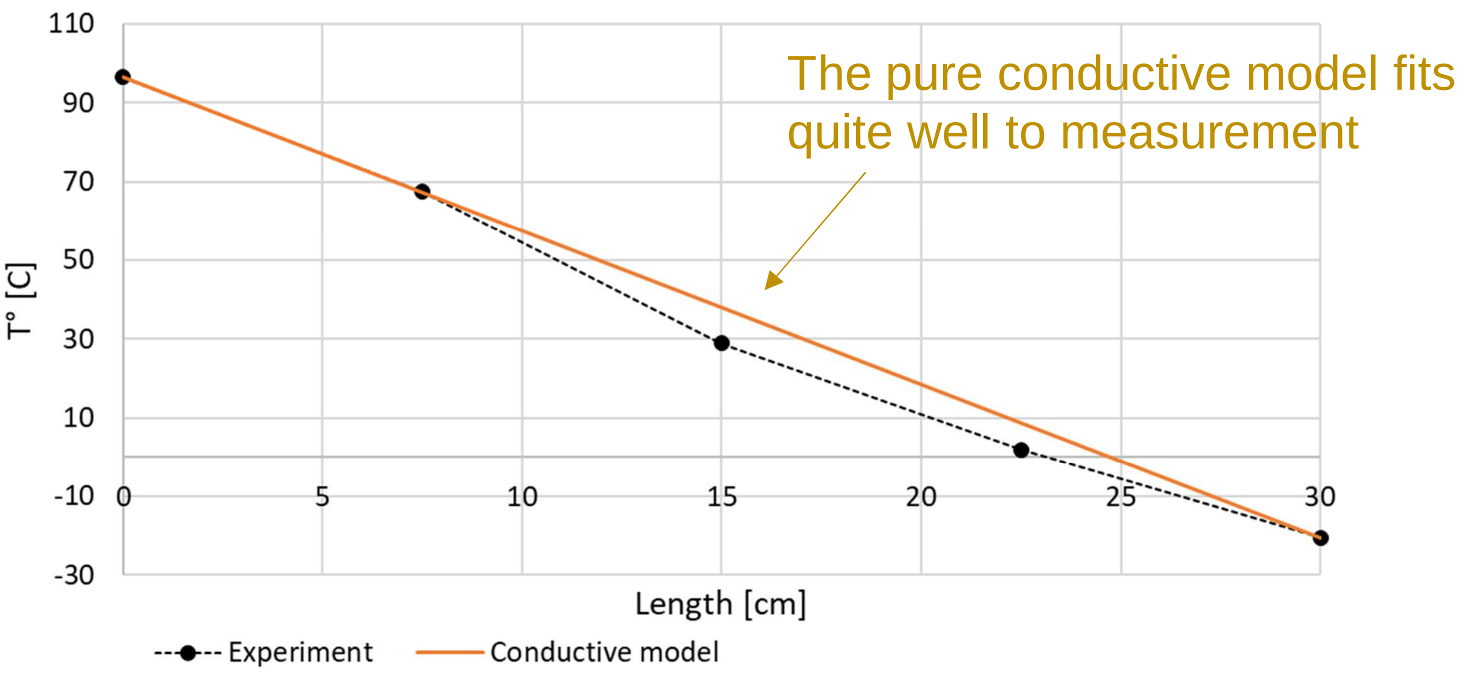
$$M = \frac{\Phi_{rad}}{\Phi_{cond}} = \frac{4 \cdot \varepsilon \cdot \sigma \cdot p \cdot L^2 \cdot T_{avg}^3}{\lambda_{eq} \cdot Seq}$$

4) TEST RESULTS ANALYSIS

Detailed thermal model

- For test campaign n°1, M < 1 for all situations except TA3 (6 < M < 14)
- **Test articles more driven by conduction** → a pure **conductive thermal model** fits quite well.

1st test campaign TA1: M = 0.4



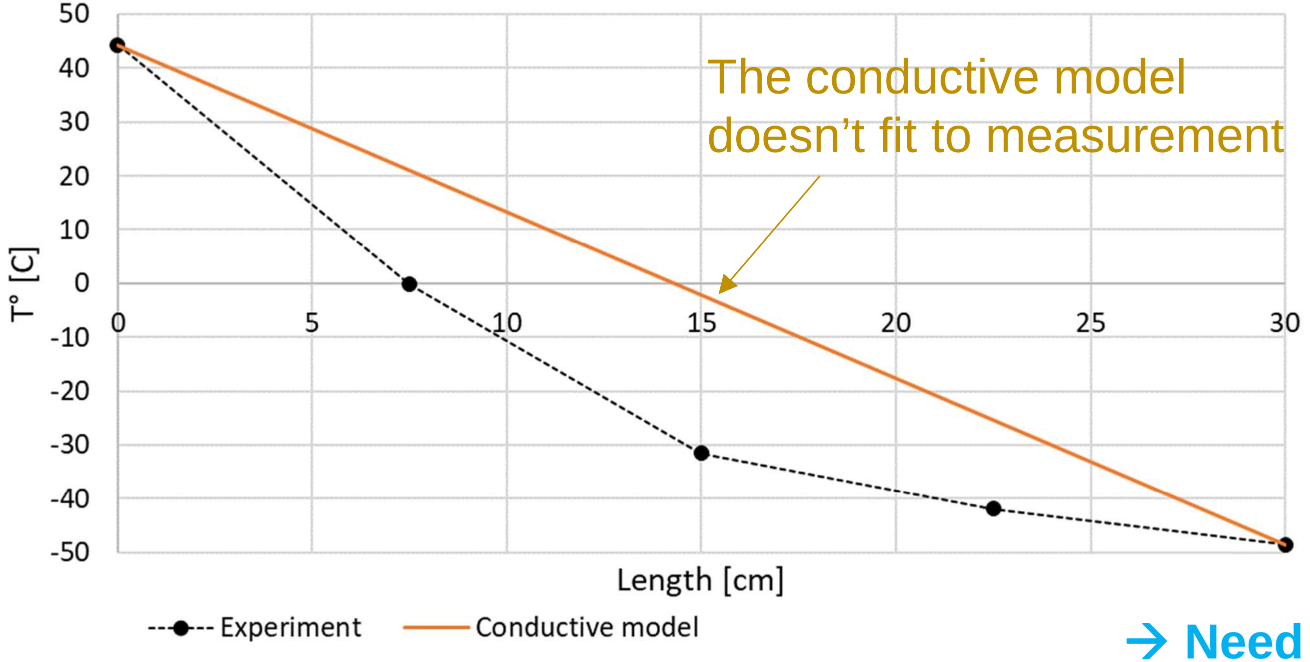
The pure conductive model fits quite well to measurement

4) TEST RESULTS ANALYSIS

Detailed thermal model

- For test campaign n°1, TA3 (6 < M < 14) is more driven by radiation
- **With a pure conductive model the error is important**→ does not fit experiment

1st test campaign TA3: M = 6.9



The conductive model doesn’t fit to measurement

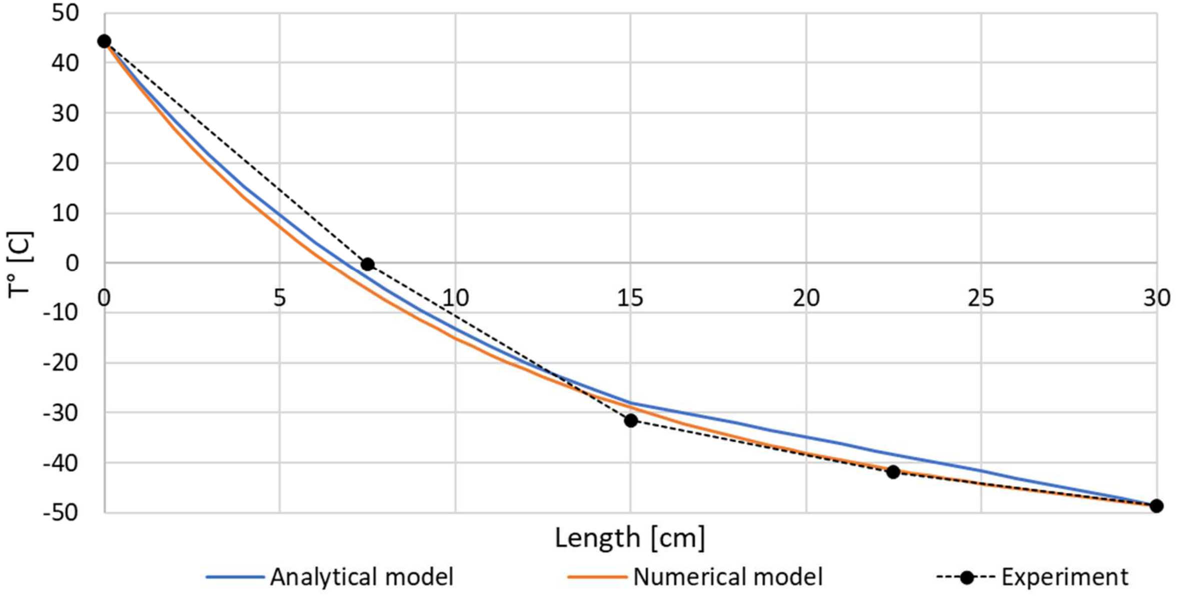
→ Need to use conductive-radiative model for higher M values

4) TEST RESULTS ANALYSIS

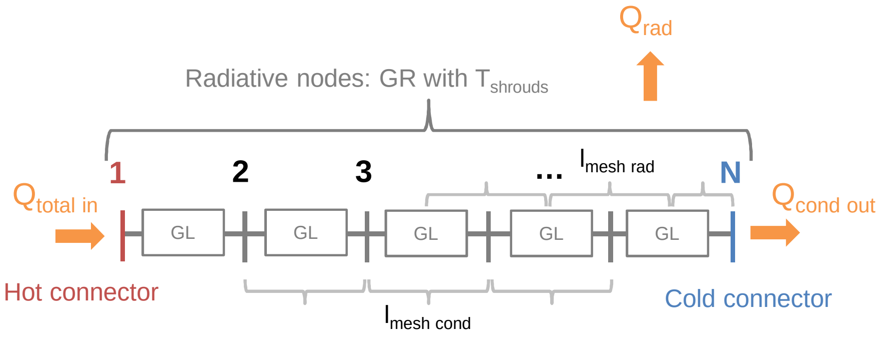
Detailed thermal model

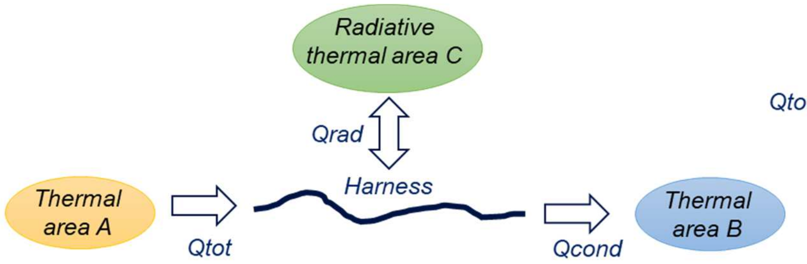
Example of the 1st test campaign TA3

- **TA3 (6 < M < 14)** with a **conductive-radiative thermal modelling**
- Nodes number is increased until convergence of the result (=meshing convergence study)
- The 60 nodes mesh numerical model fits both to **experimental temperatures** and analytical model (error is same order as metrology error)



1st test campaign TA3: M = 6.9





Qtot = Qrad + Qcond

- Heat fluxes computed with this detailed correlated model are taken as reference for the thermal model simplification.
- The accuracy evaluation of this simplification is based on Qtot and Qrad (conductive heat flux Qcond is caught if Qtot and Qrad are caught)

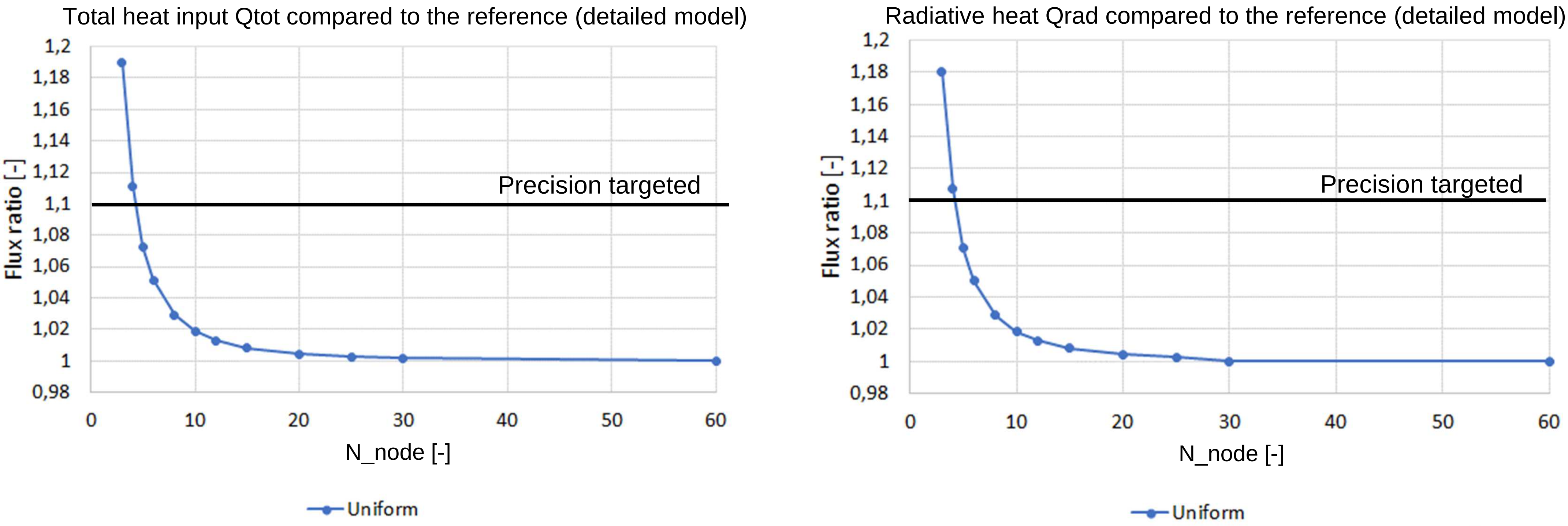
4) TEST RESULTS ANALYSIS

Thermal model simplification

Example of the 1st test campaign TA3

- **Detailed model is simplified reducing nodes number** and results are compared to the detailed model (=reference).
- For a **target precision of 10%, 5 nodes** are sufficient

1st test campaign TA3: M = 6.9



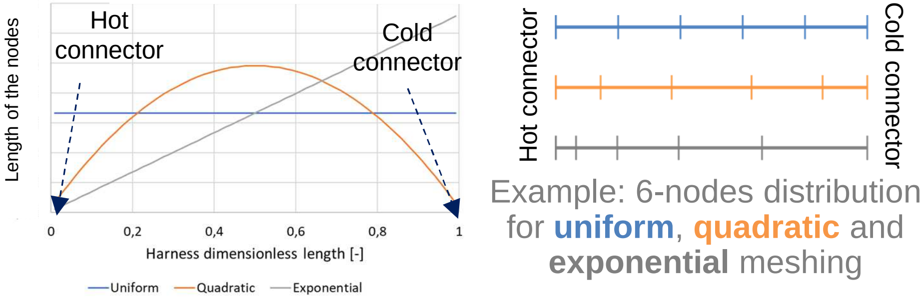
4) TEST RESULTS ANALYSIS

Thermal model simplification

Example of the 1st test campaign TA3

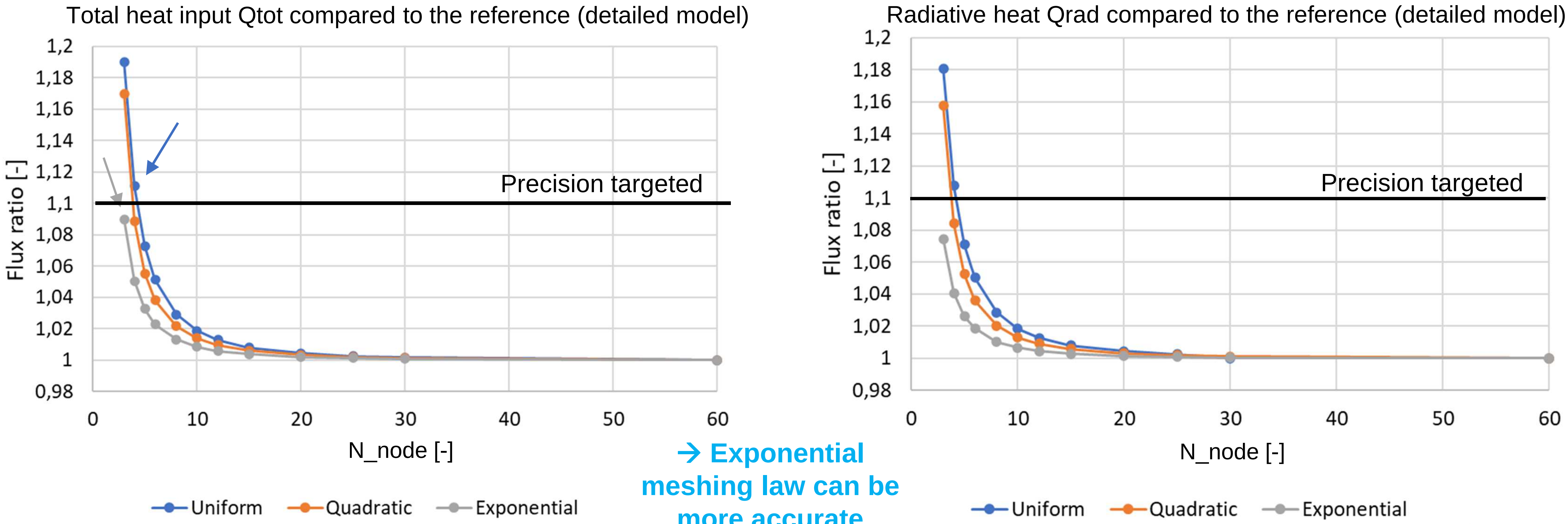
- **Detailed model is simplified reducing nodes number** and results are compared to the detailed model (=reference).
- For a **target precision of 10%, 5 nodes** are sufficient
- With an **exponential meshing (instead uniform), 3 nodes** are sufficient

Explanation of meshing distribution laws



Example: 6-nodes distribution for **uniform**, **quadratic** and **exponential** meshing

1st test campaign TA3: M = 6.9



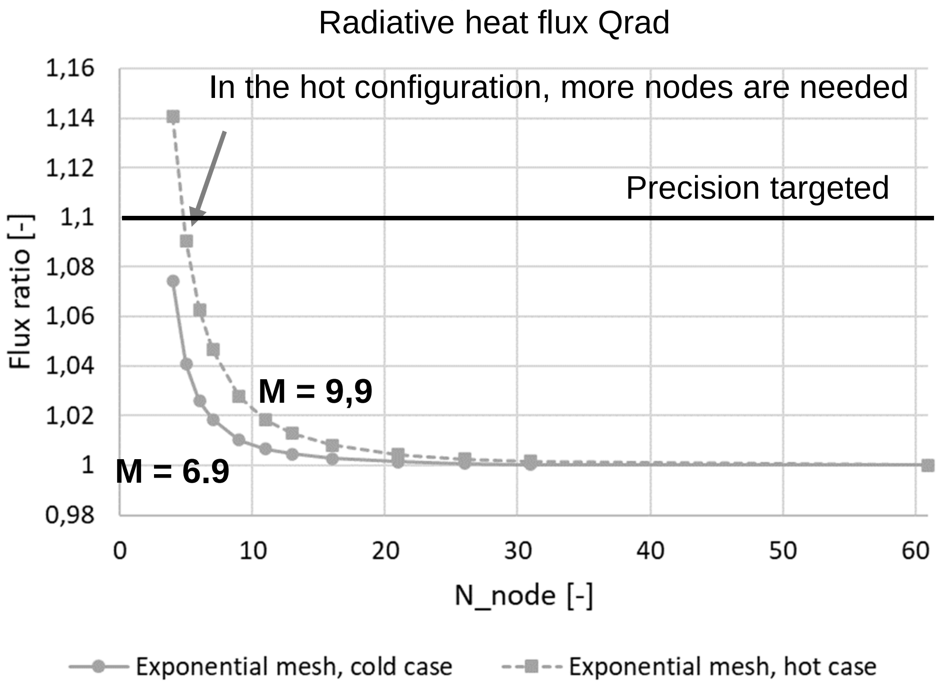
→ Exponential meshing law can be more accurate

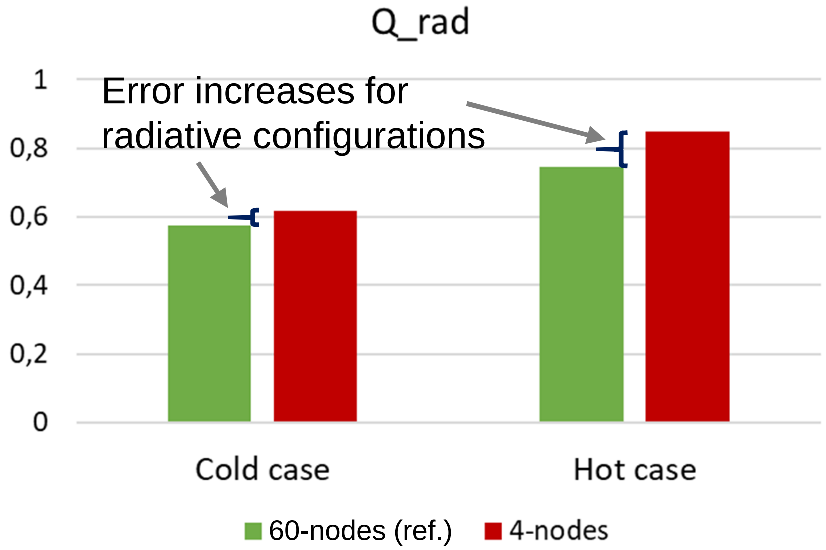
4) TEST RESULTS ANALYSIS

Link with M number

- **Influence of the thermal environment** comparing cold (M = 6.9) vs hot (M = 9.9) thermal configurations
- To catch an hot thermal configuration (more driven by radiation), more nodes are needed

1st test campaign TA3: M = 6.9 (cold) and M = 9.9 (hot)





Number of nodes required ↗ for warmer environments

→ N_{nodes} ↗ with M

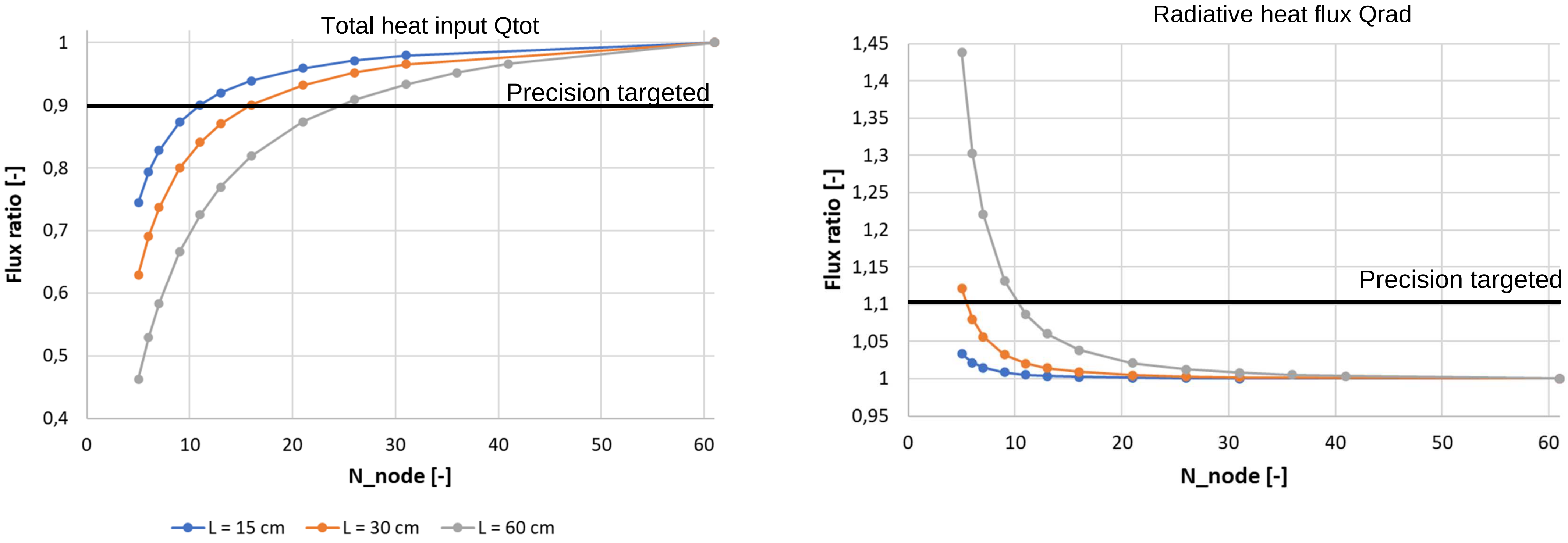
4) TEST RESULTS ANALYSIS

Link with M number

- **Influence of the harness length**
- With a uniform meshing

Number of nodes required ↗ for longer harnesses
→ **N_{nodes} ↗ with M**

2nd test campaign TA9 TA10 & TA11



TA10: L15, M = 1.8 → 11 nodes
TA11: L30, M = 4.7 → 16 nodes
TA9: L60, M = 29 → **26 nodes**

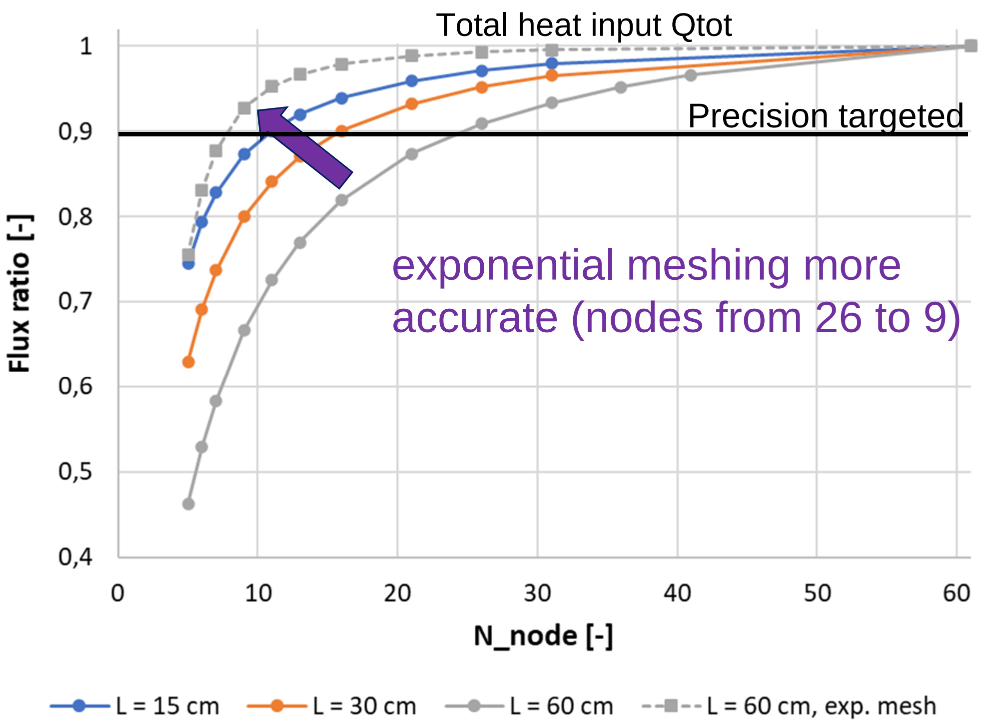
Too much nodes for a system analysis !

4) TEST RESULTS ANALYSIS

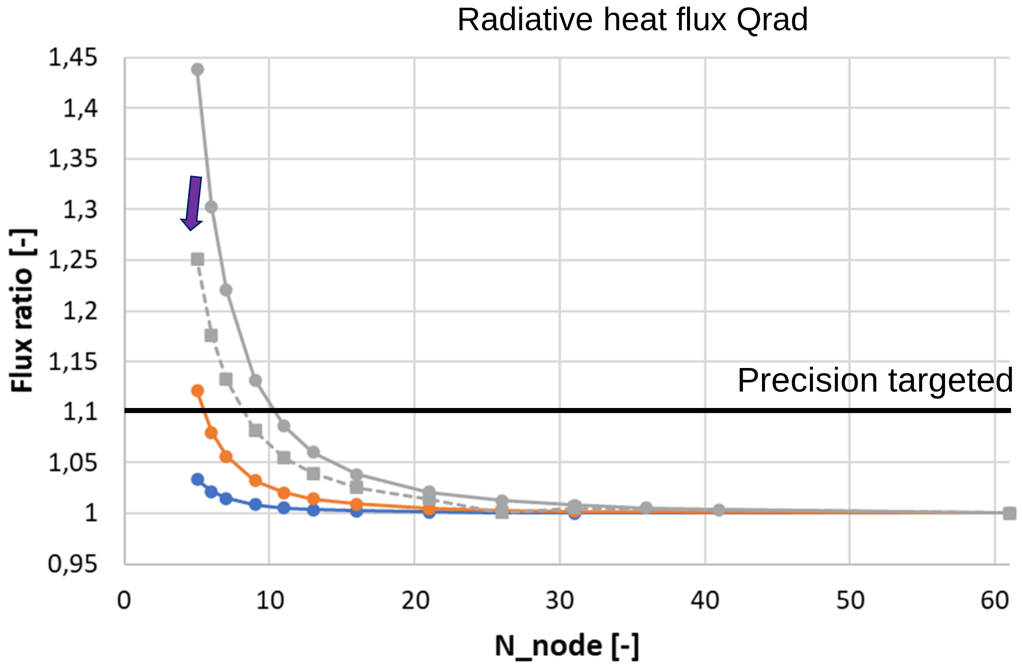
Link with M number

- **Influence of the harness length**
- With a uniform meshing

2nd test campaign TA9 TA10 & TA11



exponential meshing more accurate (nodes from 26 to 9)



Need to use exponential meshing law

→ N_{nodes} ↗ with uniform meshing

4) TEST RESULTS ANALYSIS

Synthesis of the test observations

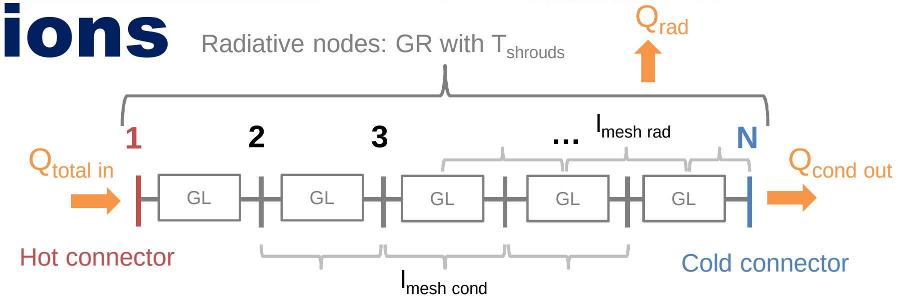
- **Harness length:** number of nodes required ↗ for longer harnesses
- **Thermal environment:** number of nodes required ↗ for hotter thermal environments
- **Harness geometry:** number of nodes required ↗ for free geometries (higher radiative perimeter)
- **Emissivity:** number of nodes required ↗ for higher ε

$$N_{nodes} \nearrow \text{ when } M \nearrow$$

- Mesh complexity increases when radiative heat transfer becomes dominant (quite intuitive)
- Exponential meshing distribution reduces number of nodes for high M values

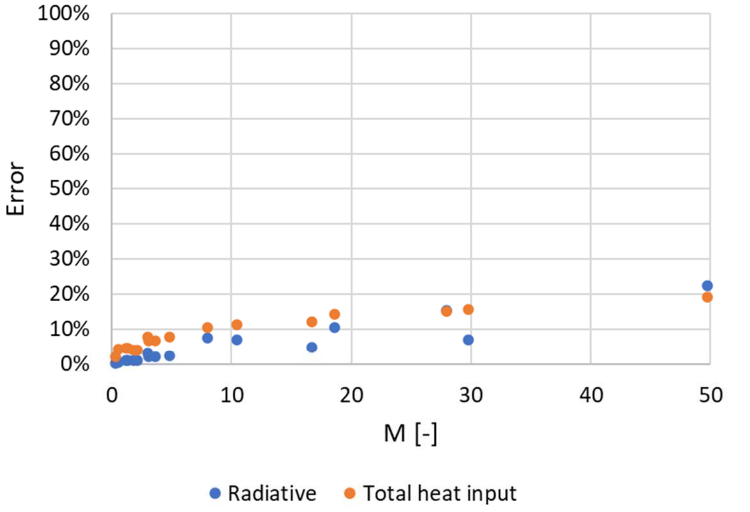
➢ **M number allows to anticipate an appropriated meshing for global system thermal analysis**

Synthesis of the test observations

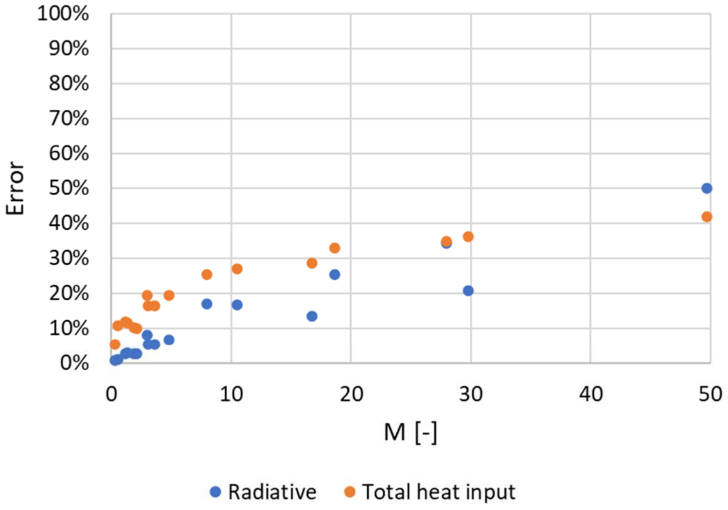


- Comparison of 6-nodes, 4-nodes and 3-nodes meshing to the reference (60 nodes) to evaluate the error on the heat fluxes

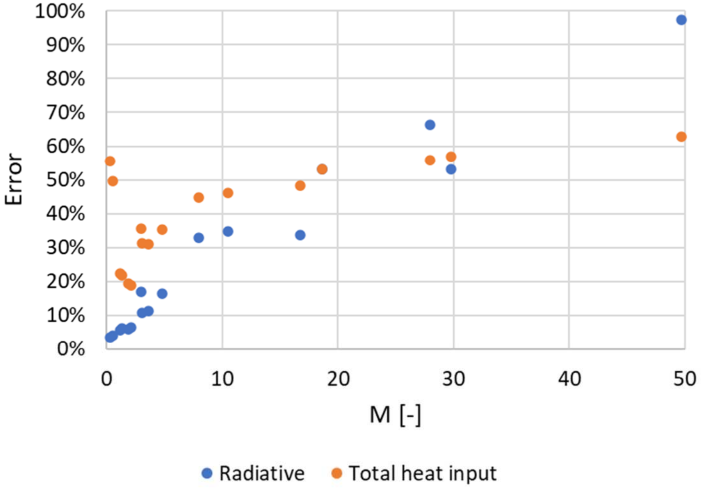
6 nodes



4 nodes



3 nodes



- **With 6-nodes, all M lead to error < 25%** and **if M < 20 then error < 15%** *But 6-nodes can be difficult in a system thermal model…*

- **With 4-nodes, all M lead to error < 50%** and **if M < 6 then error < 20%.**

- **With 3-nodes, all M lead to error < 100%** and **if M < 20 then error < 60%.** *Conductive-radiative model inappropriate to evaluate conductive harnesses (M <<) with 3 nodes*

Remark: meshing with 2 nodes for harnesses with M > 1 lead to error >> 100%

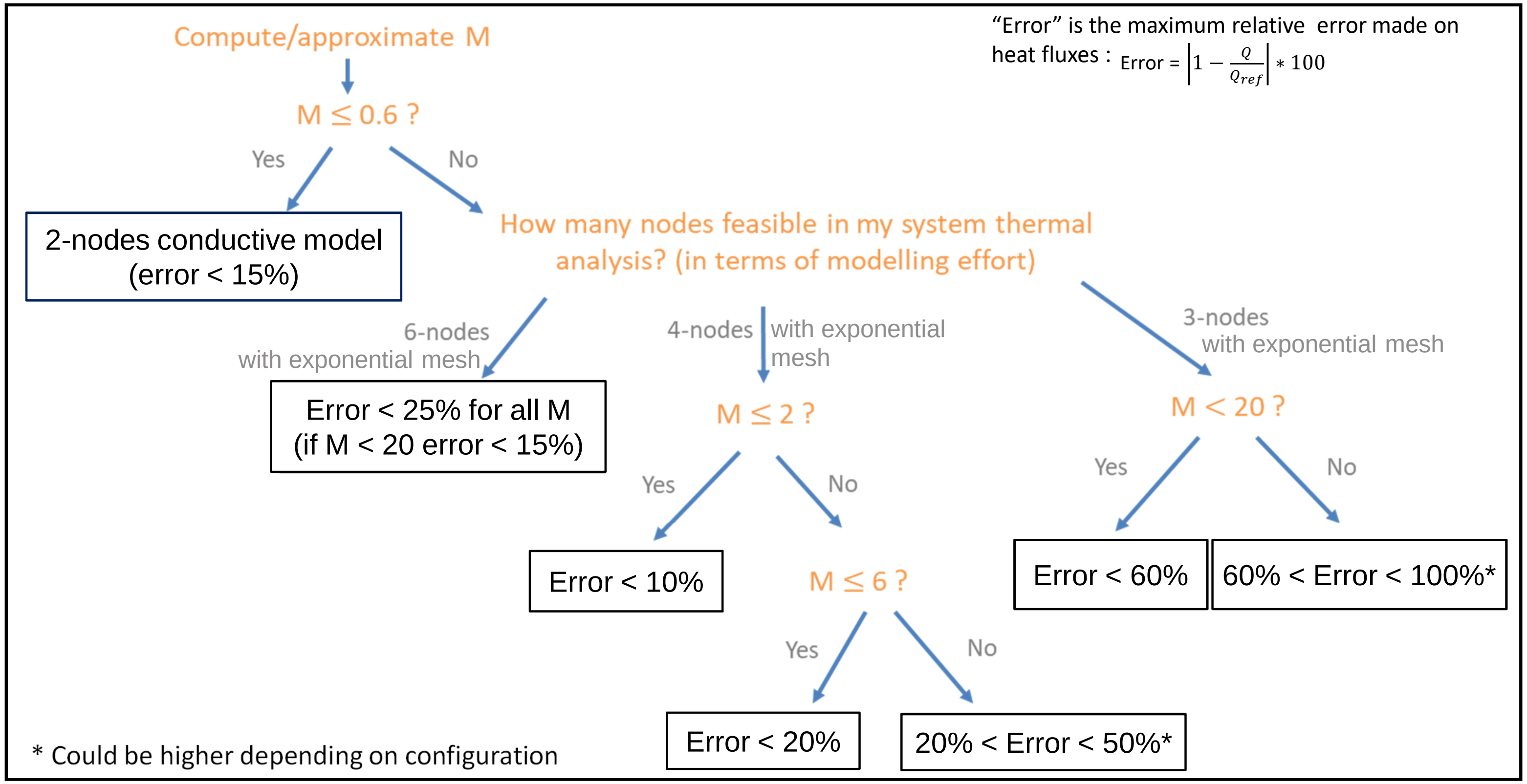
AGENDA

1) Harness heat leak introduction
2) Methodology
3) Thermal test campaigns
4) Test results analysis
5) **Harness modelling procedure**
6) Conclusion

5) HARNESS MODELLING PROCEDURE

Procedure (=recommendation)

Methodology not applicable for cryogenic temperature range



"Error" is the maximum relative error made on heat fluxes : $\text{Error} = \left|1 - \frac{Q}{Q_{ref}}\right| * 100$

Compute/approximate M

$M \leq 0.6$?

Yes

2-nodes conductive model (error < 15%)

No

How many nodes feasible in my system thermal analysis? (in terms of modelling effort)

6-nodes with exponential mesh

Error < 25% for all M (if M < 20 error < 15%)

4-nodes with exponential mesh

$M \leq 2$?

Yes

Error < 10%

No

$M \leq 6$?

Yes

Error < 20%

No

20% < Error < 50%*

3-nodes with exponential mesh

$M < 20$?

Yes

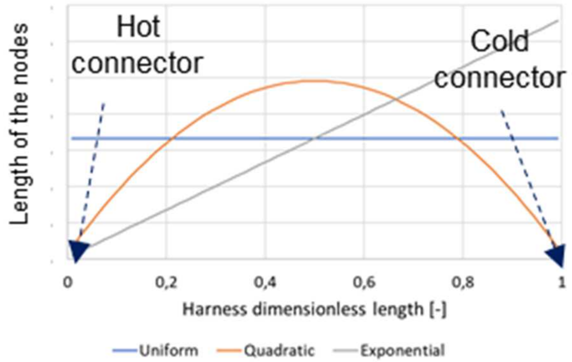
Error < 60%

No

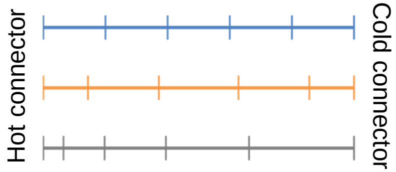
60% < Error < 100%*

* Could be higher depending on configuration

Meshing distribution laws



Example: 6-nodes distribution for **uniform**, **quadratic** and **exponential** meshing



$$M = 4 \cdot \varepsilon \cdot \sigma \cdot p \cdot L^2 \cdot T_{avg}^3 / (\lambda_{eq} \cdot S_{eq})$$

External IR emissivity of the strand [-]

Stefan-Boltzmann cst [W.m^{-2}.K^{-4}]

Strand external radiative perimeter [m]
(considering the actual strand shape after accommodation)

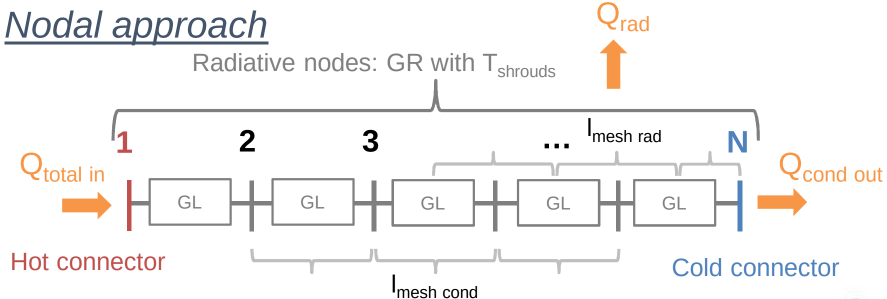
Harness length between connectors [m]

Average temperature of the system [K]

Equivalent strand thermal conductivity [W.m^{-1}.K^{-1}]

Equivalent strand cross-section [m^2]

Nodal approach

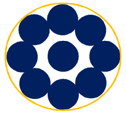


5) HARNESS MODELLING PROCEDURE

Example of application

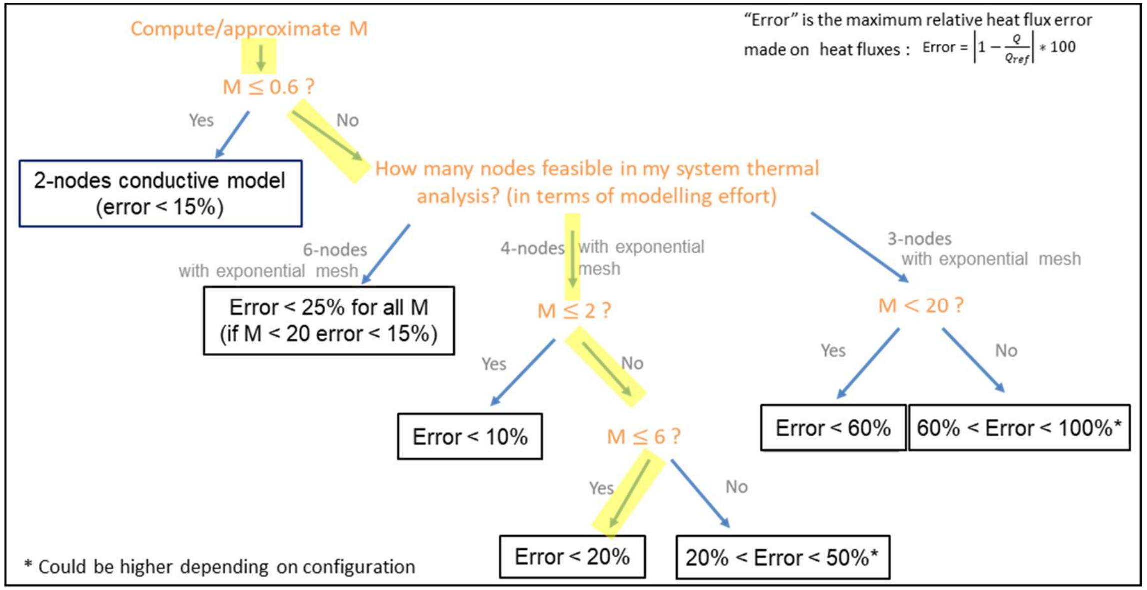
<u>Application on TA7 plateau 0</u>

- Length 30 cm
- 9 single-wires AWG26: $(\lambda \cdot S)_{eq} = 6.42\ 10^{-4}$ W·m/K (see p14)
- Compact geometry → $p = \frac{2 \cdot \pi \cdot D_{wire}}{\sqrt{2-\sqrt{2}}} = 7.22$ mm



- No MLI, no SLI → $\varepsilon = 0.95$
- Environment:
  - o $T_{radiative}$ sink = -60°C / $T_{conductive\ sink}$ = +23°C
  - → $T_{mean} = -19^{o}C$

$$M = 4 \cdot \varepsilon \cdot \sigma \cdot p \cdot L^2 \cdot T_{mean}^3 / (\lambda \cdot S)_{eq} = 3.6$$



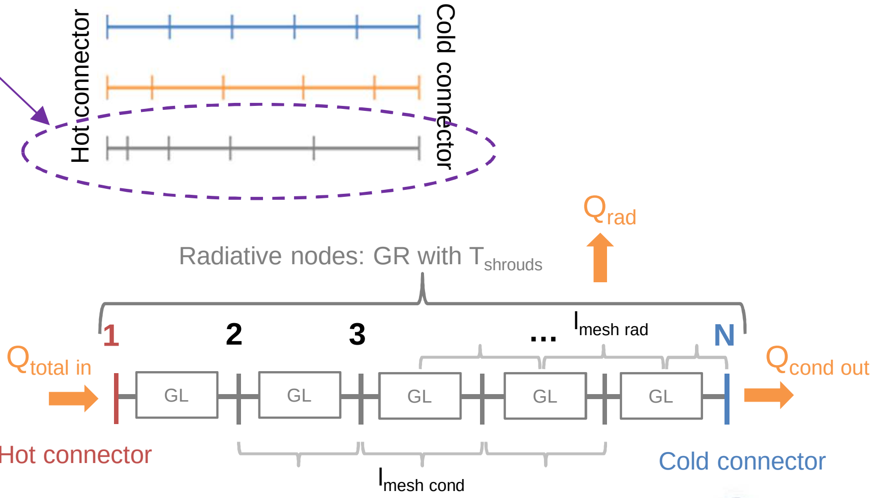
"Error" is the maximum relative heat flux error made on heat fluxes : $\text{Error} = \left|1 - \frac{Q}{Q_{ref}}\right| * 100$

* Could be higher depending on configuration

➢ Solution: **Thermal modelling with 4 nodes (exponential meshing) is adapted to my system thermal model in terms of modelling efforts. It will leads to an error < 20% on heat fluxes**. With 3 nodes, the error should be < 60%.

Exponential mesh

$l_{mesh\ cond}$ [cm]	GL = $(\lambda \cdot S)_{eq} / l_{mesh\ cond}$	$l_{mesh\ rad}$ [cm]	GR = $p \cdot \varepsilon \cdot l_{mesh\ rad}$
4.92	GL(1,2) = 0.012970	2.46	GR(1,env) = 0.0001688
9.96	GL(2,3) = 0.006406	7.44	GR(2,env) = 0.0005105
15.12	GL(3,4) = 0.004219	12.54	GR(3,env) = 0.0008607
		7.56	GR(4,env) = 0.0005189



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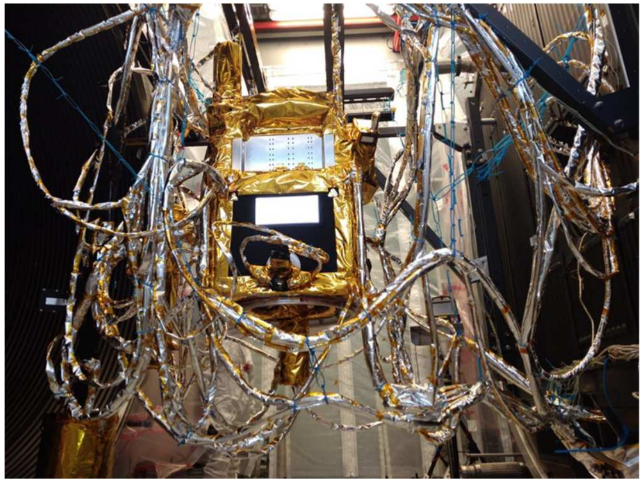
6) CONCLUSION

Lessons learned



- **Thermal heat leaks by harnesses can lead to a large uncertainty** in system thermal analysis (especially **for miniaturized system**)
- This study provides **recommendations for thermal modelling based on characteristic number M** to catch radiation/conduction heat transfers (see p33)
- These recommendations are **based on testing on 30 configurations**
- The thermal model can be mathematical or geometrical
- With this methodology, the thermal model fits better to reality and the **system thermal model correlation post thermal balance is better/easier/faster**
- This methodology is **implemented in Rover MMX project** (similar 3 nodes approach) but a complementary activity will be performed to optimize this modelling on most influential harnesses following this procedure

Next steps

- Evaluate impact of **connectors**
- Study the influence of the **current (joule effect)**
- Evaluate what's happens for **harnesses in external environment**
- Perform **more test campaigns** to gather more configurations (quadratic mesh can be benefits in some situations)
- Make an **evaluation of this methodology on a system thermal test** (today done at element level).

Thank you for your attention

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