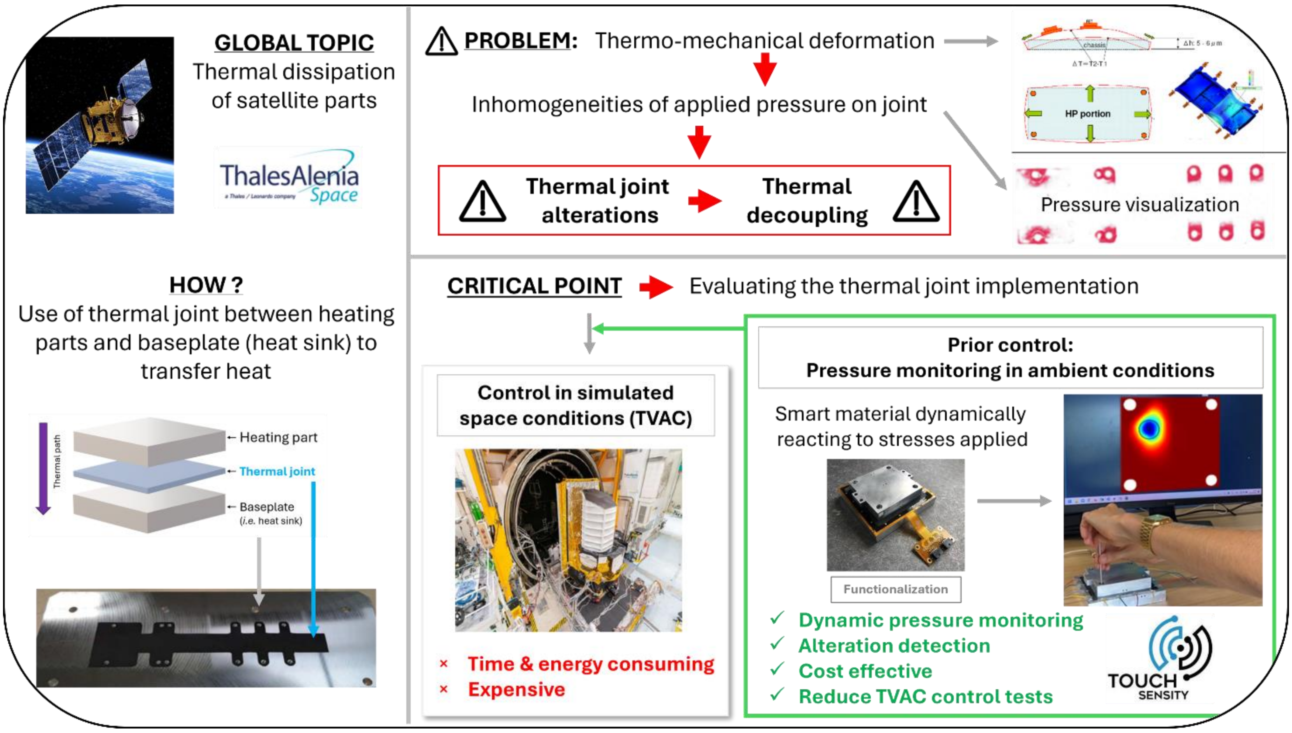

Sustainable thermal joint workmanship validation by smart material

Executive Summary Report

Early Technology Development

Channel: Open Discovery Ideas Channel

Affiliation(s): TOUCH SENSITY (TS), THALES ALIENA SPACE - FRANCE (TAS-F)

Activity summary:
Thermal dissipation is a recurrent issue in systems and a real concern in satellite thermal joints for space companies such as Thales Aliena Space (TAS). This problem is addressed with time-consuming and costly tests under simulated space conditions (using TVAC). This study aimed to implement Touch Sensity (TS) solution to detect eventual thermal decoupling in thermal joints via pressure monitoring in order to enhance joint workmanship validation process. Functionalizing joints with TS sensing device enabled a pressure distribution visualization at the interface. This implementation provided repeatable and consistent results under ambient and space conditions.

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0. Abbreviations

PROJECT CONTRIBUTORS	
TAS(-F)	THALES ALENIA SPACE (FRANCE)
TS	TOUCH SENSITY
PROJECT TERMS	
OSIP	Open Space Innovation Platform
WP	Work Package
TECHNICAL TERMS	
GRR	Global Relative Response
TVAC	Thermal VAcuum Chamber

1. Introduction

This OSIP activity results from a collaboration between Thales Alenia Space – France (TAS-F) and Touch Sensity (TS) on the following subject: a sustainable method to validate the workmanship on thermal joint (from TAS) with smart material (from TS).

TAS, specialized in the construction of satellites, is looking for a new solution to improve significantly thermal interface knowledge and validation, answering the increasing power and reduced size of satellite payloads and units.

The existence of this OSIP project was motivated by a time-consuming step encountered by TAS: the validation of thermal joint workmanship. The thermal joint and the overall assembly (equipment/joint/panel) are subjected to mechanical and thermal stresses during and after tightening. These stresses can induce the apparition of defects in the thermal joint (*e.g.* lack of contact, weak contact, bubbles or over-thickness), and thus, induce a degradation of the thermal efficiency. Evaluating the implementation of the thermal joint becomes critical.

Among the existing control parameters, one of the interests for this project is the thermal contact. The current way to validate thermal joint workmanship is by testing the parts in function and under its working conditions. For satellites, it means to run tests on mocks-up, and with flight configurations in simulated space environment, to highlight underlying issues. These conditions are achieved in vacuum chambers (TVAC), making the experiments expensive, time consuming and energy intensive.

A prior control to identify thermal decoupling is through the monitoring of the pressure applied at the thermal joint, in ambient conditions. In this context, TAS and Touch Sensity (TS) have collaborated to propose a technological breakthrough improve TAS resilience, competitiveness and carbon footprint.

TS proposed its innovative technology allowing monitoring mechanical stresses (as pressure) applied on a material: a sensing device integrated at the thermal interface to dynamically map the distribution of pressure applied on the joint. This sensing device could thus increase the knowledge of the thermal interface and enhance TAS workmanship validation process.

This breakthrough would thus have a major impact on industrial process:
- Reducing mock-ups iterative tests
- Reducing time and costs of vacuum equipment thermal joint validation,
- Easing thermal joint qualification process,
- Easing possible future design rules evolution.

This report aims to document TS monitoring solution evaluation and to demonstrate a functional application of the TS technology to thermal joints and its response in typical environmental conditions (ambient conditions, under vacuum, change of temperature).
To do so, the objectives of this activity were the following:

1. Establish the requirements and thermal properties expected,
2. Apply TS technology to thermal joints:
    - Functionalizing TAS thermal joints with TS sensing device,
    - Evaluating risks and determining the boundary conditions,
3. Install the functionalized thermal joints on TAS equipment,
4. Realize tests under different conditions,
5. Analyze, summarize and critic the experiments done.

2. Project Background

In order to enhance the thermal path, a thermal joint is inserted between two components by filling as much as possible the space in between. Heat dissipation is the main application, in which the thermal joint is inserted between a heat-producing device (heat source) and a heat-dissipating device (heat sink), as illustrated below:

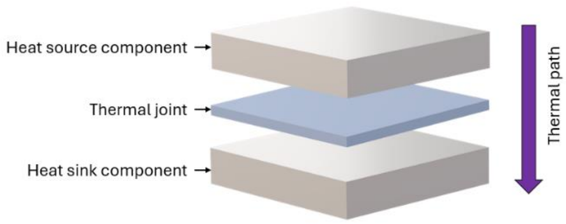


Figure 1: Graph of a thermal joint configuration. Joint maximizes the thermal path between both parts.

TAS uses custom thermal joints to help the thermal dissipation of some satellite components. Once in conditions, mechanical distortions on the components (mounting, vibrations, space conditions) induce alterations in the joints. These alterations affect its thermal efficiency and so, the assembly's. Evaluating the thermal joint implementation between two parts therefore becomes critical.

The thermal contact was the main control parameters of interest in this study. It can be validated through temperature measurements placed at the interfaces. These measurements must be done in space environmental conditions, delivered by TVAC. Figure 2 display a TVAC from ESA, similar to the ones used by TAS.

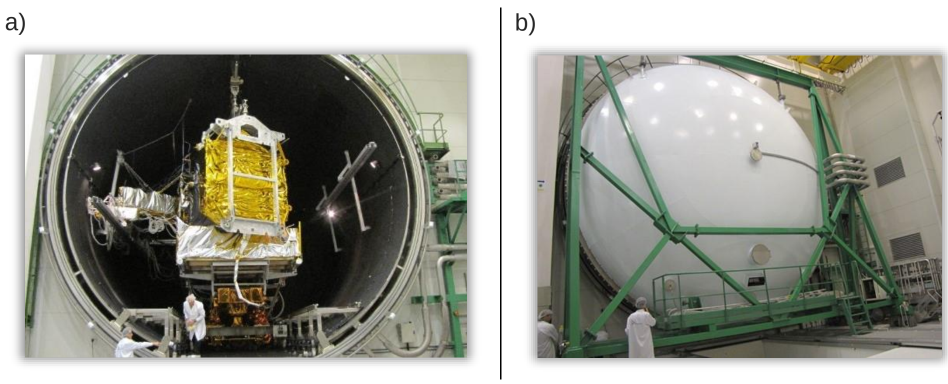


Figure 2: a) Satellite Alphasat inside the Intespace Simmer vacuum chamber. b) The chamber is closed and sealed, before a two-month test campaign on Alphasat. Credits: a) © Astrium, b) © Astrium.

Testing in such facilities is expensive, time-consuming and energy intensive. So to minimize the invoking of such tests, prior preparation can be conduct: identifying thermal decoupling is through the thermal joint pressure monitoring, in ambient conditions. In this context, TS proposed its technology, the Sensity Tech ®, to meet TAS needs.

The Sensity Tech® makes materials sensitive to mechanical and thermo-mechanical stresses such as pressure. The information is then represented as a mapping of the part's behaviour and deterioration.

Here, the TAS thermal joint was functionalized with the TS sensing material, as illustrated in the Figure 3:

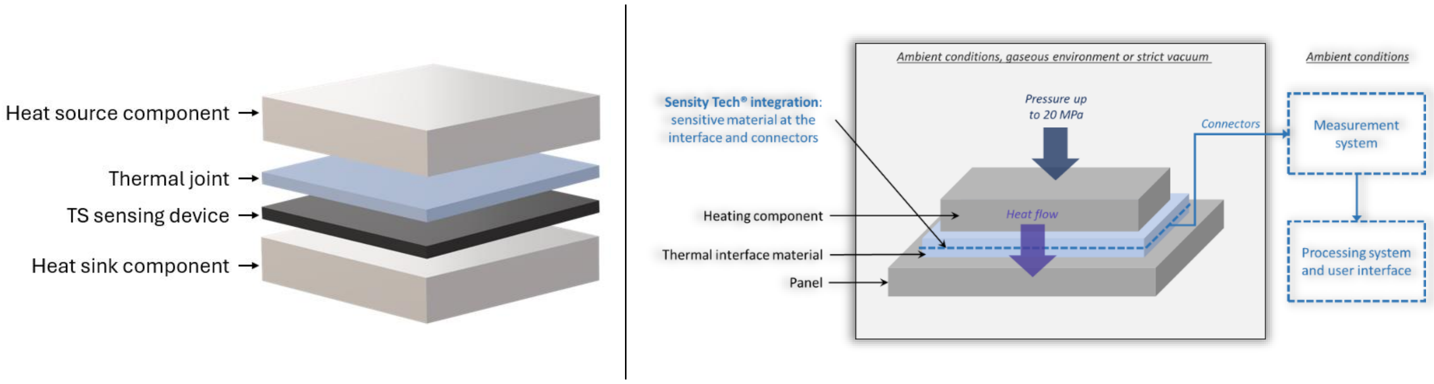


*Figure 3: Sensity Tech ® integration in TAS configuration. The top component size is 12cm*12cm. The sizes of thermal joint, sensing device and bottom component are 14cm*14cm.Sensing area is is 12cm*12cm.*

To validate the solution's compatibility, TAS established a list of requirements to reach. Two test campaigns were organized in accordance with this list:

- A preliminary campaign in ambient conditions, with pressure and temperature tests,
- A campaign in space environmental conditions, using TVAC.

The test campaigns are described in the section3. Methodology. The test campaigns results are presented in section 4. Key Findings.

3. Methodology

This OSIP project is organized in two major WP:

- WP2000, covering all the preliminary preparations before the space conditions tests in TVAC,
- WP3000, covering the TVAC space conditions tests, the results and the conclusions of the project.

WP2000 - Preliminary study before space conditions testing in TVAC

The early steps were to establish states of art TAS of thermal joints and TS solution. To evaluate the TS technology monitoring and also the compatibility with their equipment, TAS provided a list of requirements. The following ones were the most critical:

1. Defect detection:
   - ability to detect the target defect size,
   - ability to localize the defect in the equipment with the targeted accuracy.
2. Measurement precision at low pressure:
   need to assess low or lacking contact between thermal interface material (TIM) and parts (loss of thermal efficiency).
3. Preservation of thermal joints properties:
   - no impact from TS technology on the joints physical properties.

The TS technology was evaluated on two criteria:

1. **The assessment of the global applied pressure.** To detect it, the GRR Sensity Tech® feature is used, representing the global material response in percent throughout time. This feature was evaluated through compression tests at 20°C and at 60°C.

2. **The assessment of pressure distribution and the detection of defect**. The Sensity Tech® provides a 2D mapping of the alterations the functionalized thermal joint has been subject to. This feature was evaluated through compression tests on flawless joints and with introduction of defects in the joints (hole).

These experiments also tested the Sensity Tech® robustness to high pressure and temperature.

WP3000: Space conditions testing in TVAC

Once the WP2000 was reached and a final configuration chosen, additional tests were performed in TAS facilities. Table 1 displays the synoptic of the space conditions testing in TVAC.

Table 1: TVAC space conditions testing synoptic.

STEPS	OUTPUT	DURATION
1: Ambient pressure and 60°C	Ability to withstand temperature	2 hours
2 : Vacuum and 20°C	Ability to withstand vacuum	16 hours
3 : Vacuum and 60°C	Ability to withstand vacuum and temperature	6 hours
4 : Pressurex film comparison	Comparison of Pressurex film* and TS mapping	1 hour

*A Pressurex film is a tool that reacts to the pressure and gives its distribution on a specific range. After test, colors appear according to the pressure applied. The Pressurex film will be inserted below the sensing device.

4. Key Findings

Results: WP2000 - Preliminary study before vacuum testing

Assessment of the global applied pressure

For this test, the Figure 3 setup was put under compression cycles. The sensing device response was monitored in real time through the GRR. A GRR is displayed in Figure 4, put against the applied value pressure through time:

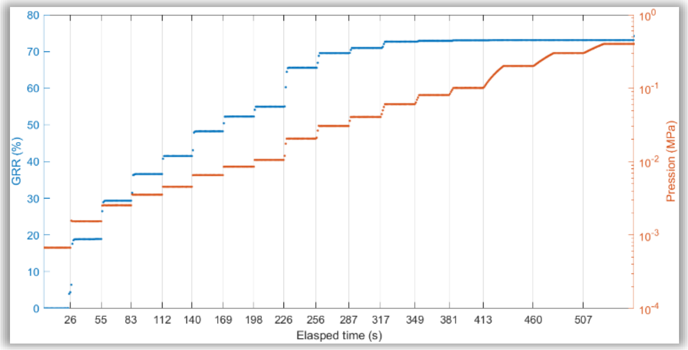
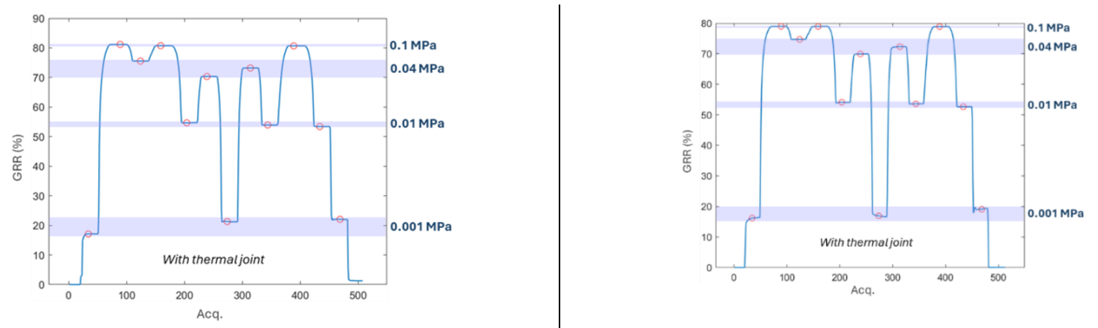


Figure 4: Example of GRR (blue line – left y-axis) behaviour to pressure evolution (orange line - right y-axis).

On Figure 4, the GRR increased instantaneously with pressure and displayed distinct stages for each pressure value. Above around 0.1 MPa, GRR steps reduce and then saturate. Below 0.1 MPa, distinct values of GRR can be associated to applied pressure values. The experiment was reproduced 3 times on 3 different specimens, at 20°C and at 60°C.
To ensure reversibility, experiments were realized with mixed stages of increasing and decreasing pressure.



Specimen #1 Specimen #2

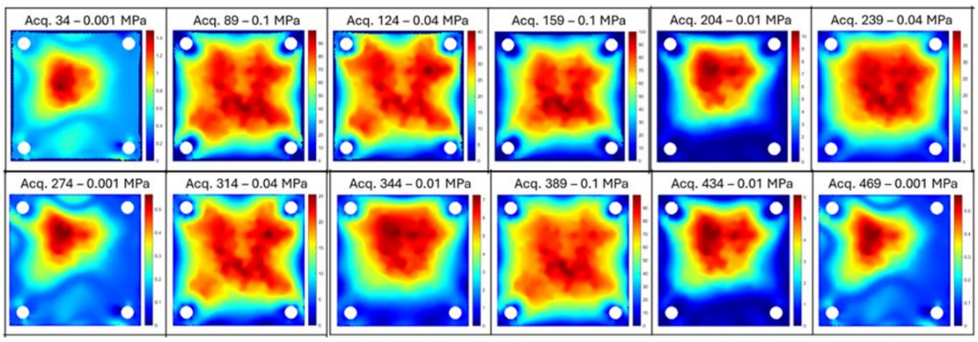
Figure 5: Sensing device GRR of two specimens over pressure variations. Violet stripes highlight the GRR range for similar pressure stages. The x-axis shows the elapsed acquisitions during the cycle.

The GRR followed the pressure alterned stages without significant hysteresis. Furthermore, the GRR variations go in the same way for all specimens.

Assessment of the pressure distribution

The 2D mapping allows monitoring the pressure distribution, highlighting the alterations in the joint. Table 2 displays the mapping computed using the data from Figure 5 at different acquisition number (represented by red circles in Figure 5).
For a given pressure value but different times, cartographies are similar. For pressure below 0.01MPa, the bottom or bottom right corner seem less compressed (blue zone), confirmed later by further investigations. Over 0.04MPa, the cartographies show a squared compressed area. Cartographies were reproducible and repeatable, highlighting similar modified area.

*Table 2: Cartographies at different values of pressure. The local color scale represents a modification rate (in %), in a 12cm*12cm area.*



Defect detection

This step encounter difficulties with the current thermal joints. As an intermediate step, a thermal joint D was introduced. Joint D presents more controlled features, which reduces the chances of misinterpretations. Adjustments were also made to the Sensity Tech® settings.

From here, results were obtained with joint D in the setup. The defects (holes of various diameters) in joint D were introduced manually. Resulting cartographies are displayed in Figure 6:

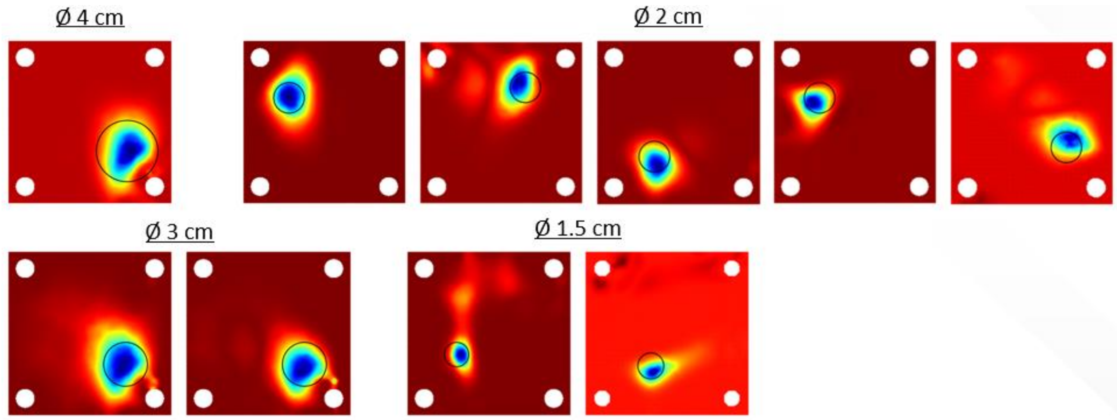


*Figure 6: Sensity Tech® defect cartographies. The defects are identified by a clear blue stain. A black circle indicates the location and size of the defect in the joint during each test (1 image = 1 test). The images represent a 12cm*12cm area.*

Defects are identified by a blue stain. This stain is well located and consistent with the defect size.

WP2000 conclusion

The TS sensing device shown promising results for the pressure evaluation (through GRR feature) and the pressure distribution mapping at the interface. Considering the consistent results with the joint D, the incoming tests in space conditions were carried out with the joint D.

Results: WP3000 - Vacuum testing

This section presents the vacuum testing results realized in TVAC in TAS facilities.

STEP 1: Ambient pressure conditions and 60°C temperature

This step aim was to evaluate the sensing device behaviour under 60°C at ambient pressure. Figure 7 shows the GRR (left) regarding the TVAC temperature rise (right). Its behaviour is coherent with the temperature cycle: the data fluctuated as the temperature rises,then remained stable during the 60°C stage.

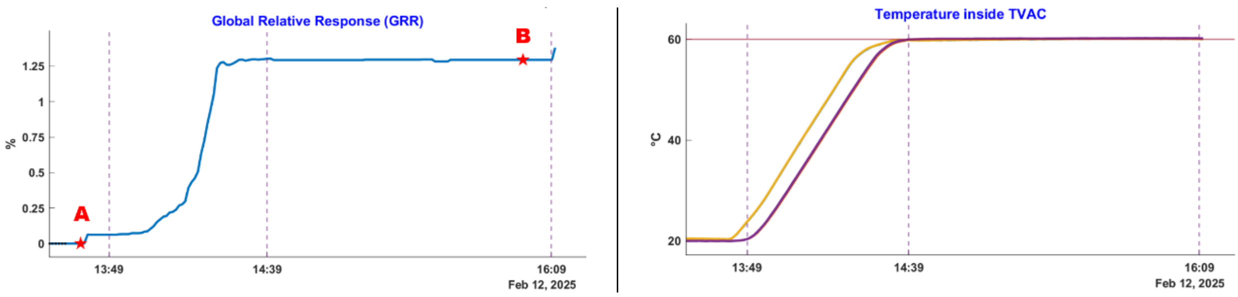
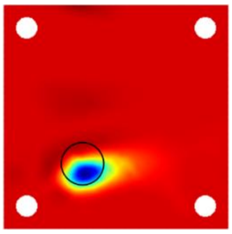
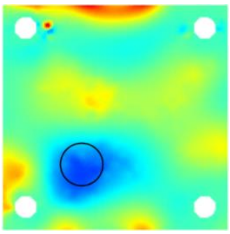


Figure 7: GRR (left) of sensing device regarding the TVAC temperature rise (right).

The letters in the bottom plot refer to the timestamps processed to obtain the defect cartographies in Table 3:

Table 3: Defect cartographies (local scale) at 20°C (left) and 60°C (right) in TVAC. Note: cartographies color scales are local and thus, not cross-matchable.

Timestamp marker	**A** Before temperature rise	**B** Before end of 60°C stage
T°	20°C	60°C
Pressure	ambient	ambient
Cartography		

- Image A is similar to cartographies exposed in Figure 6**Erreur ! Source du renvoi introuvable.**, (same conditions). The defect is well located and well sized.
- Image B shows fluctuations induced by the temperature rise. The defect remains visible and well located. The disturbances affect mainly the size of the defect, less sharp than in A. These fluctuations were also observed step 3 (see Table 4).

STEPS 2-3: Vacuum conditions under 20°C and 60°C temperatures

In these consecutive steps, the objectives were to evaluate the ability of TS technology to withstand:
- The vacuuming process and environment,
- The temperature rise in these vacuum conditions.

Figure 8 (a.) presents the sensing device GRR regarding the TVAC pressure drop and temperature rise (b.). The GRR behaviour is coherent with the cycles.

Anew, the letters in the Figure 8 bottom plot refer to the timestamps processed to obtain the defect cartographies in Table 4:

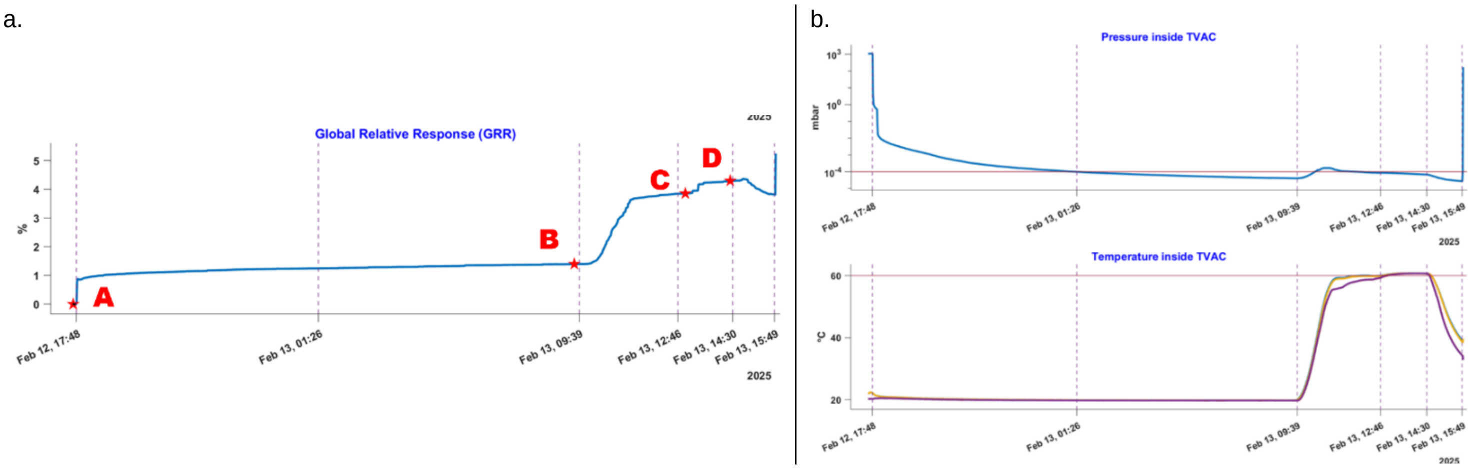
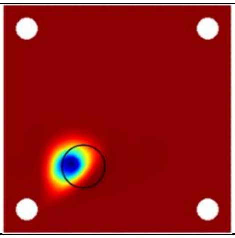
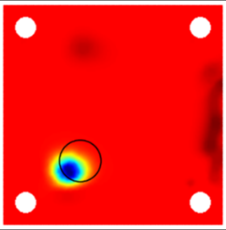
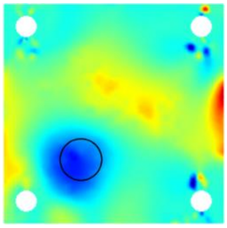
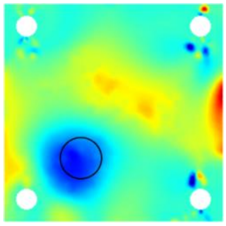


Figure 8: GRR of sensing device (left) regarding the TVAC pressure drop and temperature rise (right).

Table 4: Defect cartographies in various conditions of pressure and temperature, managed by the TVAC. Note: cartographies color scales are local and thus, not cross-matchable.

Timestamp marker	**A** Before vacuuming process	**B** Before temperature rise	**C** Temperature reached	**D** Before end of 60°C stage
T°	20°C	20°C	60°C	60°C
Pressure	Ambient	Vacuum	Vacuum	Vacuum
Cartography				

- Image A: the defect is still well located and well sized.
- Image B presents the defect cartography after the vacuuming process (14 hours). The location and size of the defect have been lightly modified, but the vacuuming did not induce any major disturbance.
- Images C and D: the defect remains visible and well located, despite the temperature induced disturbances (same nature than Table 3), affecting mainly the defect size (less sharp).

STEP 4: Ambient temperature and ambient pressure conditions - Pressurex film comparison

The objective here was to compare the resulting TS cartography with the Pressurex film (inserted below the sensing device) pressure mapping in ambient conditions

Figure 9 presents a) a photo of Pressurex film mapping and b) the resulting TS cartography. A superposition is presented on Figure 9 c). As observed, the defect is visible and well located on the TS cartography, and coherent with the Pressurex film mapping.

a) Pressurex film - TAS b) TS cartography c) Superposition

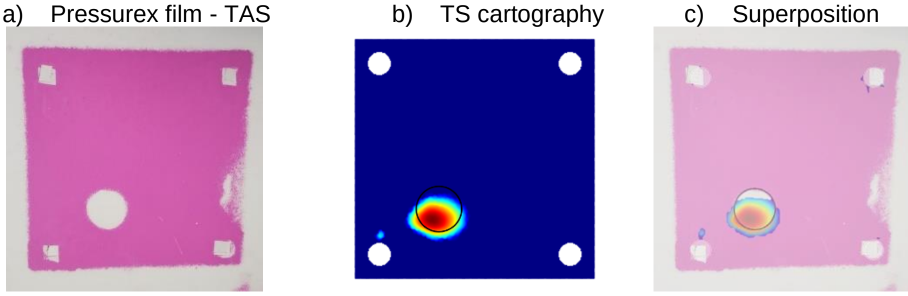


Figure 9: Comparison between Pressurex film and TS cartography.

WP3000 conclusion

The objectives were to progressively expose the TS sensing device to an extreme environment. The device withstood all the imposed pressure and temperature conditions, providing coherent cartographies of the defect. The most influential condition appears to be the temperature rising, affecting mostly the defect shape. TS technology was barely affected by the vacuuming process.

5. Conclusion

This project main goals were the integration of TS sensing device into a TAS typical configuration and the validation of TS technology response through its abilities:

- to assess the strains the thermal joints endure,
- to withstand space environmental conditions.

In the early steps of the project, several configurations were evaluated on the following criteria:

a) evaluation of the global applied pressure,
b) cartography of interface pressure distribution,
c) resistance to high pressure and temperature,
d) defect cartography.

After a preliminary study, a sensing device have been approved in combination with the thermal joints A and C, providing repeatable and consistent responses.

Further investigations were successfully conducted to improve the defect cartography, implying some adjustments (the use of joint D and a specific Sensity Tech ® calibration). The sensing device was able to detect and locate defects close to the target size, with repeatability and consistency. Considering these results, the evaluation under space conditions were done with these adjustements, as a first step.

The tests in TVAC machine have shown that the TS technology withstood all the imposed space conditions, providing coherent cartographies of the defect.

6. Future Work

To conclude this document and this project, the following Table 5 summarizes the technical limitations encountered their vectors of improvement to be investigated in future work.

Table 5: Encountered technical barriers (left) and their vectors of improvement (right)

Encountered technical barriers/ limitations	Vectors of improvement
Defect cartography of joint A, B, C	- Identifying joints features that obstruct TS technology. - Adjust the joints in consequences, still with the objective of maximizing thermal conductance
	Testing other thermal joints.
Defect detection: - Lower the detection minimum size - Adress the case of over-thickness	Adaptation of data processing.
	Tuning sensing device to improve sensitivity.
Pressure distribution and defect detection: provide absolute value of pressure.	Using Pressurex films to calibrate the cartographies and establish confidence metrics.
	R&D to establish absolute value of pressure.
Thermal impact evaluation: - Current sensing device - Device integrated in thermal joint	Study thermal conductance of the sensing device according to the temperature.
	Tuning the sensing device to improve thermal efficiency.
Precisions on pressure measurements at medium/high pressure.	Tuning the sensing device to raise the saturation upper value.
Widen perimeter of application.	Implementation on larger configurations.

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