# ESA RFP 3-15938 - EMBEDDED THERMAL CONTROL OF A TRANSMIT ACTIVE ANTENNA USING 3D PRINTING

FINAL REVIEW– 30TH OF AUGUST 2023

ISSUE 03_OPEN

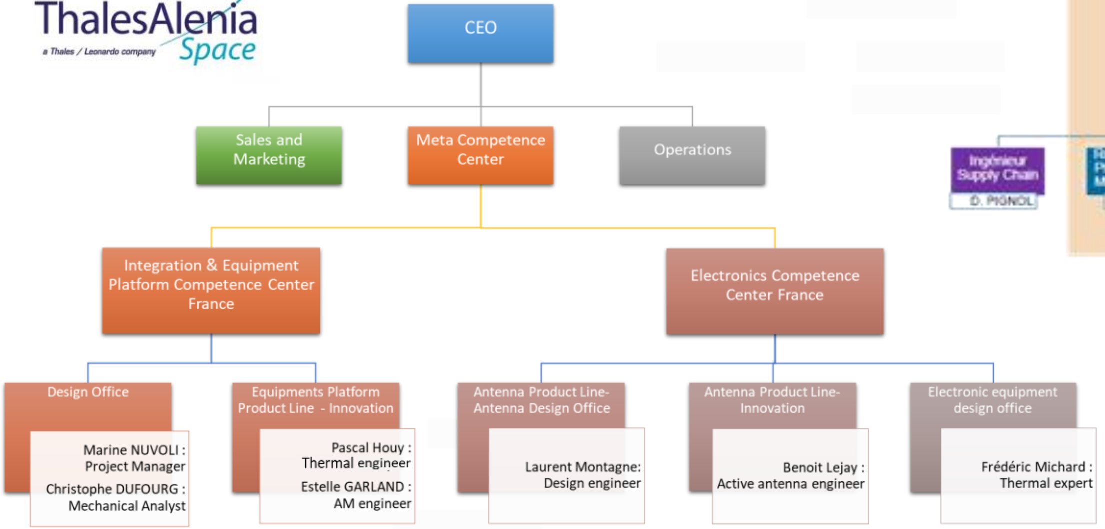

**Date:** 30/08/2023
**Ref:** 0005-0010124745
**Template:** 83230347-COM-TAS-EN-012

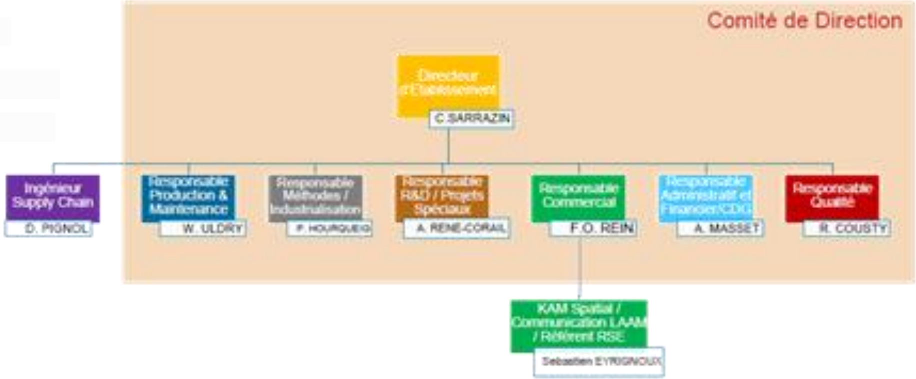
# AGENDA

# 1. PROJECT CONSORTIUM

# PROJECT CONSORTIUM

- ESA / Thales Alenia Space as prime contractor / Lisi Aerospace Additive Manufacturing as partner
- LAAM is a TAS historical and preferred partner for R&D studies
- Collaborative project with teams from TAS-Cannes and TAS-Toulouse






Date:

Ref: Not referenced

Template: 83230347-COM-TAS-EN-012

PROPRIETARY INFORMATION



THALES ALENIA SPACE OPEN

# 2. PROJECT OBJECTIVES


**Date:** 30/08/2023
**Ref:** 0005-0010124745
**Template:** 83230347-COM-TAS-EN-012

# PROJECT OBJECTIVES

**→ Development of a new active antenna structure, made by additive manufacturing, with embedded thermal control connected to the satellite MPL**

/// Using additive manufacturing technology could improve performances of an active antenna for several reasons :

- Structure : Improvement of stiffness thanks to topology optimization
- Thermal management : Enhancing of global heat transfer (decrease of the number of thermal interfaces, direct embedded thermal control connected to MPL)
- RF performances : Possible use of active antennas with high thermal dissipation thanks to a more efficient thermal management
- Integration : Limitation of assembly components and time
- Multi-functions : Structure with mechanical & thermal functions

/// The breadboard has been representative of a real antenna in terms of global antenna behavior but not dimensions. Its mechanical and thermal performances predicted by the numerical models have been compared to the experimental performance of the breadboard.

→ To validate a methodology for both the design and models construction that can be applied to any type of active antenna.

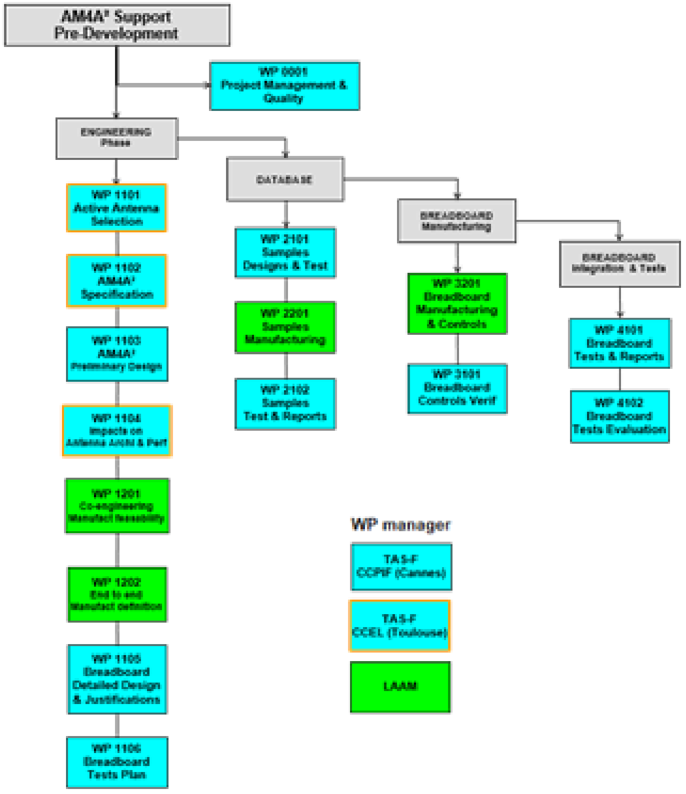

Date: 30/08/2023
Ref: Not referenced
Template: 83230347-COM-TAS-EN-012

# 3. STRUCTURE AND SCHEDULE OF STUDY

# STRUCTURE AND SCHEDULE OF STUDY

## Project flow chart

| Phase | WP n° | WP Title | Entity Responsible | Department Responsible | WP Responsible |
|---|---|---|---|---|---|
| | | | | | |
| | 0001 | Project Management & Quality | TAS | CCPIF | M. Nuvoli |
| | | | | | |
| ENGINEERING Phase | 1101 | Active Antenna Selection | TAS | CCEL | B. Lejay |
| | 1102 | AM4A$^2$ Specification | TAS | CCEL | B. Lejay |
| | 1103 | AM4A$^2$ Preliminary Design | TAS | CCPIF | M. Nuvoli |
| | 1104 | AM4A$^2$ Impacts on Antenna Architecture & Performances(included costs, mass, planning) | TAS | CCEL | L. Montagne |
| | 1201 | Co-engineering - Manufacturing feasability vs proposed design | LAAM | CCPIF | E. Garland |
| | 1202 | Definition of the end to end manufacturing scenario | LAAM | CCPIF | E. Garland |
| | 1105 | AM4A$^2$ Breadboard Detailed Design & Justifications | TAS | CCPIF | M. Nuvoli |
| | 1106 | AM4A$^2$ Breadboard Tests Plan | TAS | CCPIF | M. Raynaud |
| | | | | | |
| DATABASE | 2101 | Samples - Designs & Tests Plan | TAS | CCPIF | E. Garland |
| | 2201 | Samples Manufacturing | LAAM | CCPIF | E. Garland |
| | 2102 | Samples - Tests & Reports | TAS | CCPIF | E. Garland |
| | | | | | |
| BREADBOARD Manufacturing & Controls | 3201 | AM4A$^2$ Breadboard Manufacturing & Controls | LAAM | CCPIF | E. Garland |
| | 3101 | AM4A$^2$ Breadboard Controls verification | TAS | CCPIF | M. Nuvoli |
| | | | | | |
| BREADBOARD Integration & Tests | 4101 | AM4A$^2$ Breadboard Tests & Reports | TAS | CCPIF | M. Raynaud |
| | 4102 | AM4A$^2$ Breadboard Tests Evaluation | TAS | CCPIF | M. Nuvoli/ P. Houy |

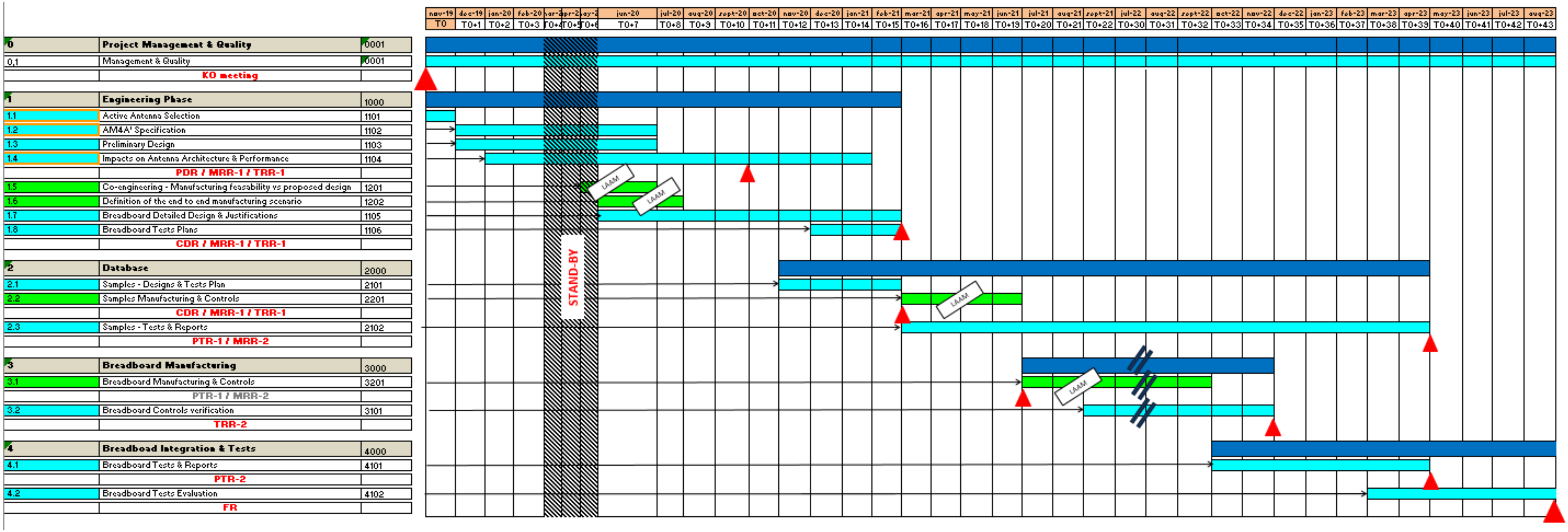




Date: 30/08/2023
Ref: Not referenced
Template: 83230347-COM-TAS-EN-012

# STRUCTURE AND SCHEDULE OF STUDY

## Project Gantt chart






Date: 30/08/2023

Ref: Not referenced

Template: 83230347-COM-TAS-EN-012

PROPRIETARY INFORMATION



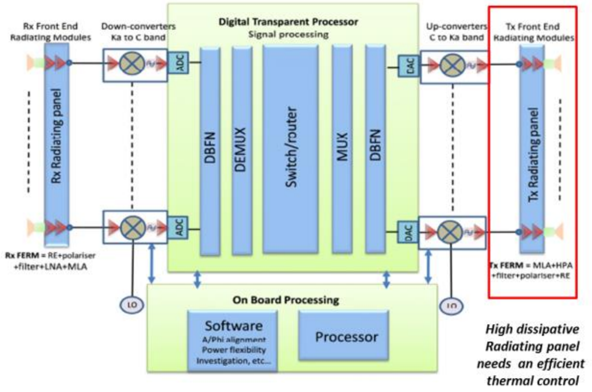
THALES ALENIA SPACE OPEN

# 4. REMINDER OF THE USE CASE RETAINED FOR THIS STUDY

# MISSION AND PAYLOAD SELECTION

- In recent years the commercial satellite market has been evolving rapidly. Satellite operators now recognize that the high degree of in-orbit coverage flexibility provided by active array antennas is an enabler for their business models, providing the service flexibility needed to adapt to changing commercial conditions and to seize new business opportunities.
- At the same time, there is a strong drive towards :
  - lowering the cost of satellite capacity in orbit,
  - leading to the emergence of Very High Throughput Systems for broadband multimedia mission featuring large numbers of beams .

- The Payload chosen answering geostationary broadband multimedia missions is a Ka-Band digital payload associated with :
  - Digital Transparent Processor providing frequency flexibility,
  - high capacity and dissipative transmit active antenna.





Date: 30/08/2023
Ref: 0005-0010124745
Template: 83230347-COM-TAS-EN-012

# ACTIVE ANTENNA SELECTION

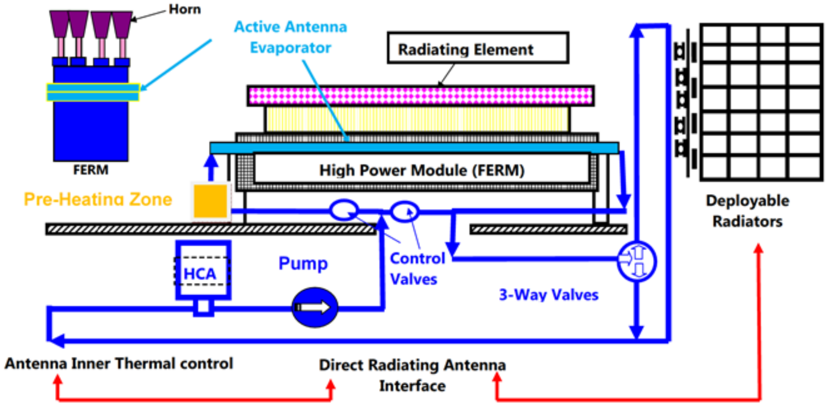
- Direct Radiating phased array Antenna presents several advantages :
  - DRAs for both Rx and Tx antennas are very well suited for generating numerous agile beams over a earth field of view.
  - DRA offers a full-power exchange among beams, a functionality not at reach when considering focused as well as off-focus arrays facing reflector.
  - As a consequence of a high number of feeds contributing to each beam, DRA offers a very low RF degradation versus active chains failure and then no redundancy needs, a functionality not at reach when considering focused as well as off-focus arrays facing reflector.
  - DRA offers low side-lobe level and isolation improving the capacity of the system.
  - DRA offers a solution to have a high density integration and then improves RF performances thanks to stringent minimization of insertion loss between the HPA and the free space.
  - DRA offers an accommodation on the Earth panel and facility of the thermal control.

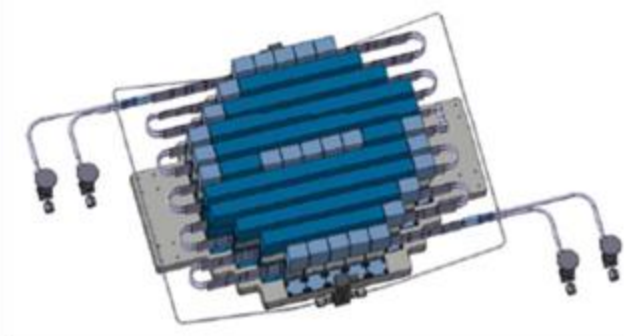
- Direct Radiating Array is selected for the active antenna case study for all these reasons.


Date: 30/08/2023
Ref: 0005-0010124745
Template: 83230347-COM-TAS-EN-012

# ANTENNA THERMAL CONTROL SELECTION

- Two Phase Mechanically Pumped Loop (2Ø-MPL) is the most effective of the high dissipative antenna thermal control) :
  - Very high heat transfer coefficients achievable,
  - Very high power transport capability on long distance,
  - High level of the quasi-isothermal capability,



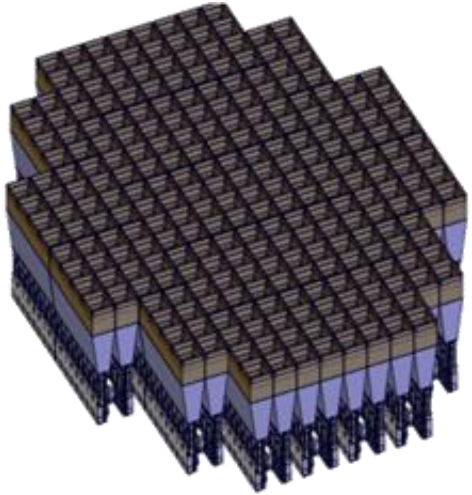



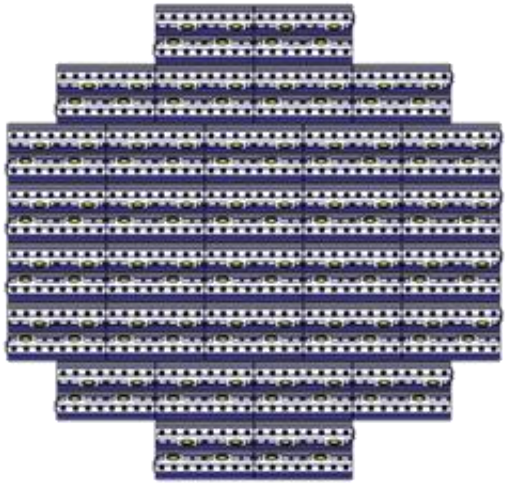

Date: 30/08/2023
Ref: 0005-0010124745
Template: 83230347-COM-TAS-EN-012

# 5. OVERVIEW OF TRANSMIT ACTIVE ANTENNA RETAINED FOR THIS STUDY

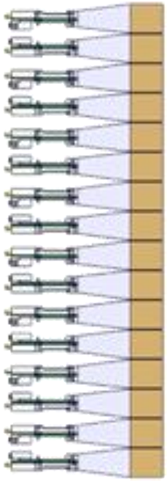
# TRANSMIT RADIATING PANEL ARCHITECTURE OVERVIEW

- Reference document : TN1 Active antenna definition and critical parameters for the embedded thermal control using 3D printing, ref : 0005-0011545687 issue 02
- The transmit radiating panel of the Direct Radiating Array (DRA) active antenna to consider in this study is composed of several Front-End Radiating Module (FERM) dual polarization, mounted on the earth panel of the satellite.

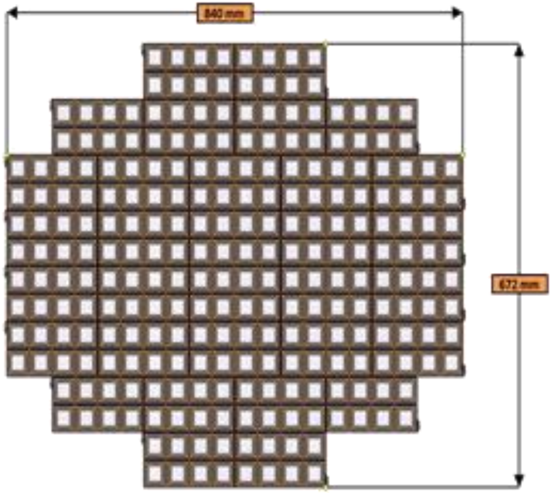




(Bottom view)



(side view)



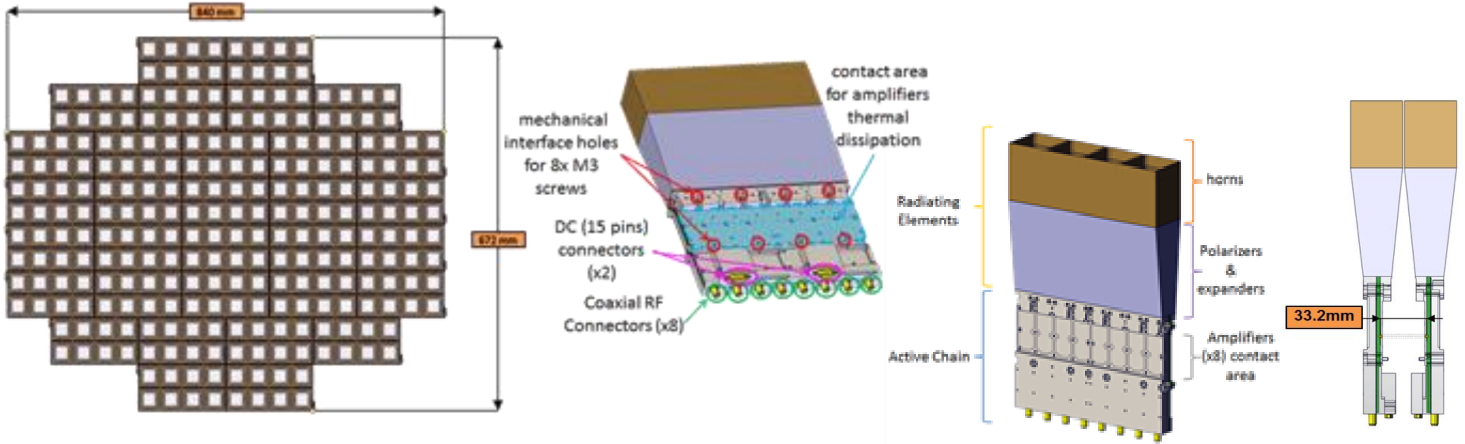

- This DRA is composed of **256 Radiating Elements**

**-> 64 Quad FERM modules dual polarization**


Date: 30/08/2023
Ref:
Template: 83230347-COM-TAS-EN-012

# TRANSMIT RADIATING PANEL ADAPTATION TO DEFINE BASELINE ARCHITECTURE

- Based on this heritage, the following characteristics have been considered to define the antenna baseline architecture.
- 256 Radiating Elements : 64 identical "Quad FERM"
  - Array antenna lattice : 42mm (avoid grating lobes in the earth coverage)
  - Distance between two face to face Quad FERM is 33,2mm
  - Heat pipe network is replaced by evaporator to be compatible with Two Phase Mechanically Pumped Loop -> mechanical structural supports will have to be considered in that case, in order to avoid stress on welds of the evaporator.
  - Mechanical, RF and electrical interfaces as defined in the view hereafter:

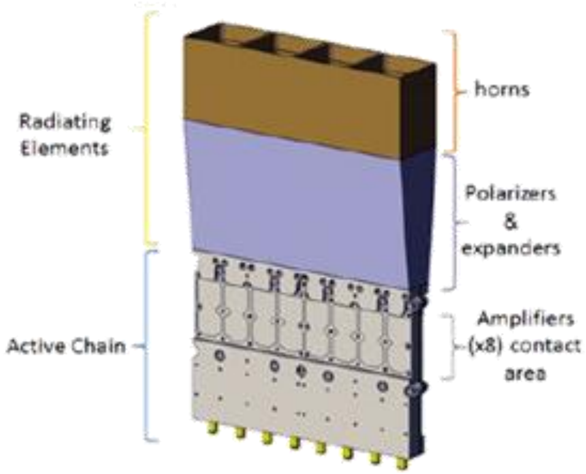


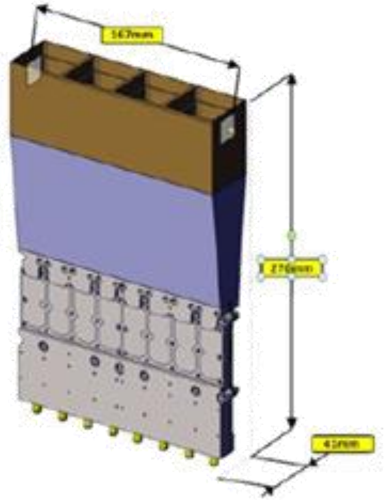


Date: 30/08/2023
Ref: Not referenced
Template: 83230347-COM-TAS-EN-012

# QUAD FERM DESCRIPTION

- The Quad FERM has the following characteristics :
  - The Radiating Output Section is an assembly of 4 horns (whose size was adapted to lattice definition), 4 polarizers (to separate R&L polarizations) and 8 expander waveguides to adapt with Front End and active chains spacing.
  - Two amplifiers (one per polarization) are used for each RF chain, so a Quad module has 8 amplifiers located on a common PCB card with embedded copper coins (thermal link with contact area).

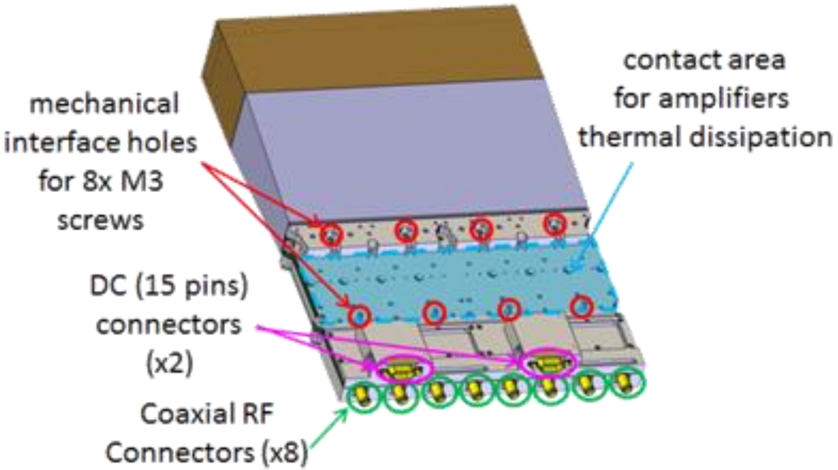


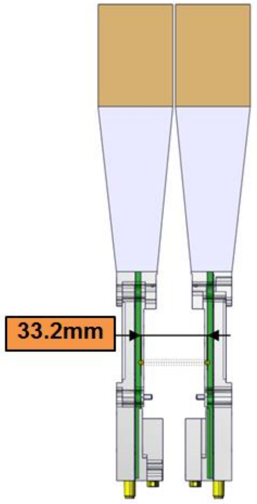




Date: 30/08/2023
Ref:
Template: 83230347-COM-TAS-EN-012

# QUAD FERM RF, DC, MECHANICAL AND THERMAL INTERFACES

- The following RF, DC mechanical and thermal interfaces have to be designed :
  - Each Quad FERM will be mounted to the supporting structure with 8x M3 CHC screws
  - A thermal contact area for thermal dissipation of active chains amplifiers towards the evaporator of the satellite Mechanically Pumped Loop (MPL).
  - Two DC Sub-D connectors (15 pins) are used for feed 8 active chains.
  - Eight RF SMP connectors to interface with payload by coaxial cables.
  - The distance between two face to face Quads FERM is 33,2mm



*spacing*

# TRANSMIT PHASED ARRAY ANTENNA DISSIPATED POWER BUDGET

- Amplitude taperisation (0,3 and 6dB) to achieve good RF isolation :
  - 3 class of High Power Amplifier
  - Central area 16 quad FERM : dissipated power 57W per Quad FERM
  - Middle area : 24 quad FERM : dissipated power 28W per Quad FERM
  - Edge area : 24 quad FERM : dissipated power 14W per Quad FERM

- Antenna dissipated power operational mode : 7.7 kW

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | | | | | | |
| | | | | | | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | | | | | | |
| | | 14 | 14 | 14 | 14 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 14 | 14 | 14 | 14 | | |
| | | 14 | 14 | 14 | 14 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 14 | 14 | 14 | 14 | | |
| 14 | 14 | 28 | 28 | 28 | 28 | 57 | 57 | 57 | 57 | 57 | 57 | 57 | 57 | 28 | 28 | 28 | 28 | 14 | 14 |
| 14 | 14 | 28 | 28 | 28 | 28 | 57 | 57 | 57 | 57 | 57 | 57 | 57 | 57 | 28 | 28 | 28 | 28 | 14 | 14 |
| 14 | 14 | 28 | 28 | 28 | 28 | 57 | 57 | 57 | 57 | 57 | 57 | 57 | 57 | 28 | 28 | 28 | 28 | 14 | 14 |
| 14 | 14 | 28 | 28 | 28 | 28 | 57 | 57 | 57 | 57 | 57 | 57 | 57 | 57 | 28 | 28 | 28 | 28 | 14 | 14 |
| 14 | 14 | 28 | 28 | 28 | 28 | 57 | 57 | 57 | 57 | 57 | 57 | 57 | 57 | 28 | 28 | 28 | 28 | 14 | 14 |
| 14 | 14 | 28 | 28 | 28 | 28 | 57 | 57 | 57 | 57 | 57 | 57 | 57 | 57 | 28 | 28 | 28 | 28 | 14 | 14 |
| 14 | 14 | 28 | 28 | 28 | 28 | 57 | 57 | 57 | 57 | 57 | 57 | 57 | 57 | 28 | 28 | 28 | 28 | 14 | 14 |
| 14 | 14 | 28 | 28 | 28 | 28 | 57 | 57 | 57 | 57 | 57 | 57 | 57 | 57 | 28 | 28 | 28 | 28 | 14 | 14 |
| | | 14 | 14 | 14 | 14 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 14 | 14 | 14 | 14 | | |
| | | 14 | 14 | 14 | 14 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 28 | 14 | 14 | 14 | 14 | | |
| | | | | | | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | | | | | | |
| | | | | | | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | | | | | | |


Date: 30/08/2023
Ref:
Template: 83230347-COM-TAS-EN-012

# 6. PRESENTATION OF PROPOSED TECHNICAL SOLUTION


Date: 30/08/2023
Ref:
Template: 83230347-COM-TAS-EN-012

# REMINDER OF MAIN REQUIREMENTS AND DRIVERS OF DESIGN

**Design / Assembly drivers**

- /// Compatibility with antenna dimensions and layout of RF elements
- /// Feasible design in AM which can be easily integrated despite low accessibility
- /// Embedded thermal control connected to MPL
- /// Compliant with alignment tolerances requirement
- /// Total mass of structure + thermal control < 35% of the whole antenna mass
- /// …

**Mechanical requirements**

- /// First frequency > 60 Hz with clamped interfaces
- /// Positive safety margins for applied loads

**Thermal & RF requirements**

- /// Capability to manage high dissipating power (≈ 9kW in localized areas)
- /// Temperature of RF elements interfaces in the range -25°C/+85°C
- /// Thermal gradient < 15°C (peak to peak) between all amplifying chains of quad FERM
- /// ...

**Cost / Planning drivers**

- /// Cost competitive and competitive manufacturing and AIT total lead time

# GLOBAL CONCEPT DESCRIPTION OF THE ANTENNA : MECHANICAL & THERMAL MODULES

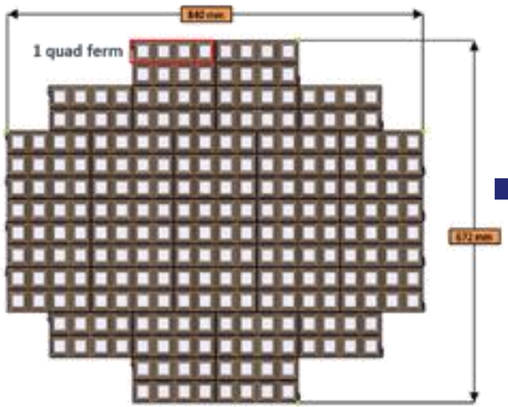
- Big dimensions of the antenna + low accessibility

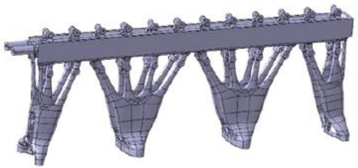
Architecture of the antenna =
challenging aspect

✗ Single bloc AM structure

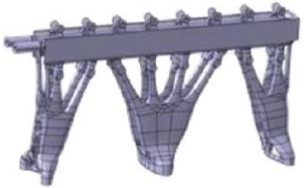
✓ Assembly of a small number of « modules » on an antenna baseplate

- A M&T module = AM structure in AlSi07Mg with embedded thermal control connected to MPL + all fixations for the quads FERM and the satellite

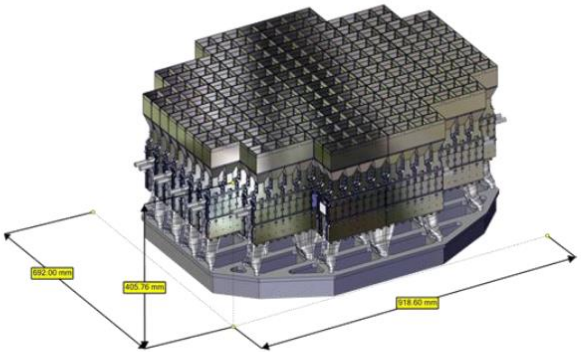


« 6 quads » M&T module



« 4 quads » M&T module

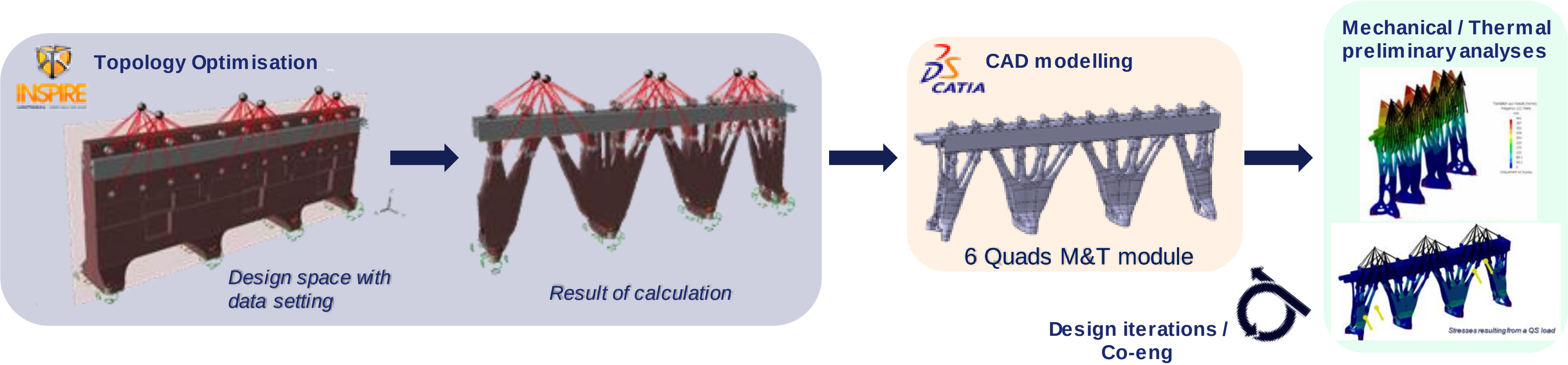





Date: 30/08/2023
Ref: Not referenced
Template: 83230347-COM-TAS-EN-012

# DESIGN OF THE ANTENNA MECHANICAL STRUCTURE

- **Breadboard = 6 quads M&T module** → Best compromise project budget / antenna representativeness (lowest edge effect and no thermal impact thanks to individual assembly)
- Mechanical structure design resulting from **topology optimisation** → Best stiffness / mass ratio
- Main parameters of data setting : clamped interfaces, QS loads, objective : max stiffness, constraint : F1> 60 Hz
- Performed steps : Topology optimisation / Surface reconstruction / Mechanical pre-sizing and preliminary thermal analysis to validate the concept → Thermal control optimized through design iterations

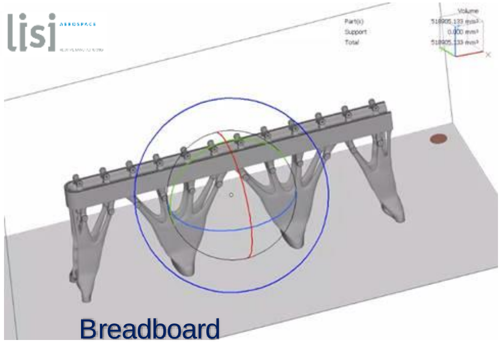




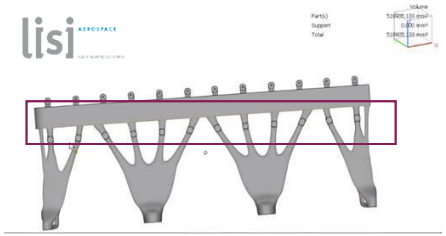
Date: 30/08/2023
Ref:
Template: 83230347-COM-TAS-EN-012

# CO-ENGINEERING TAS / LAAM

- Co-engineering TAS / LAAM : Validation of the quad M&T module design feasability and manufacturing risk mitigation
- Several aspects have been addressed :
  - **Best orientation** in the manufacturing batch in CONCEPT LASER XLINE2000R




→ The least risky / the least of supports
→ Tilt angle to avoid too sudden change of section





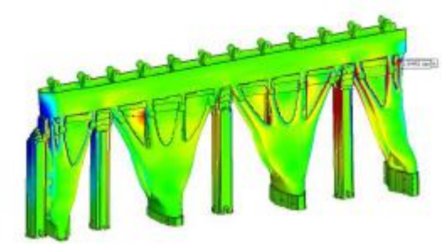
- Supporting structure : some modifications recommended by LAAM
  - **Reduction** of supports quantity
  - **Suppression** of supports in inaccessible areas for removing

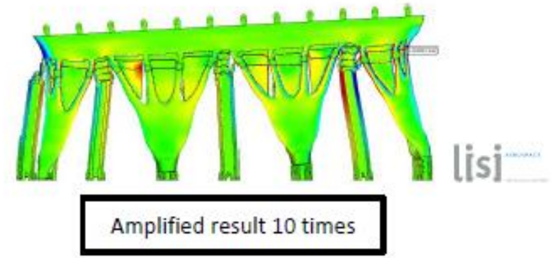

Date: 30/08/2023
Ref:
Template: 83230347-COM-TAS-EN-012

ThalesAlenia Space

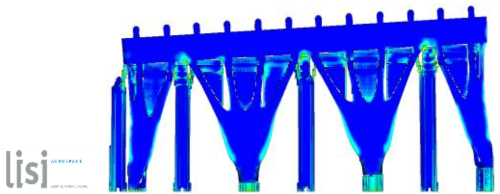
# CO-ENGINEERING TAS / LAAM

- **Simulation analysis** performed on 6 Quads M&T module
  - Surface deviation : Risk of deformation identified by LAAM and confirmed by simulation






→ Corrective actions proposed by LAAM : Local modifications of design




- No stress accumulation leading to risk of breakage or failure in production

- **Channel unpowdering :** Risk identified by LAAM
  - An in-depth cleaning procedure

- **Machining :**
  - Risk identified due to very tightened tolerances + raw part deformation

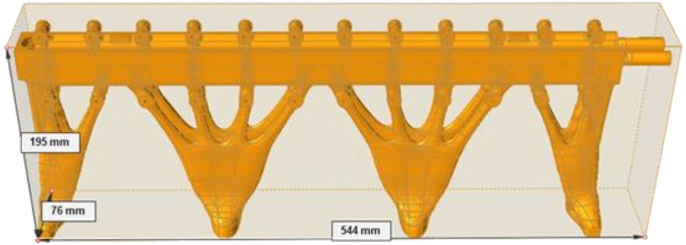

Date: 30/08/2023
Ref:
Template: 83230347-COM-TAS-EN-012

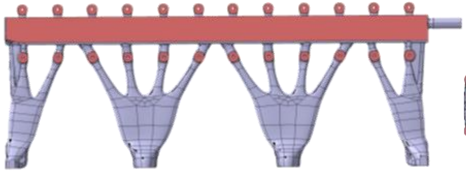
# BREADBOARD 6 QUADS M&T MODULE DETAILED DESIGN

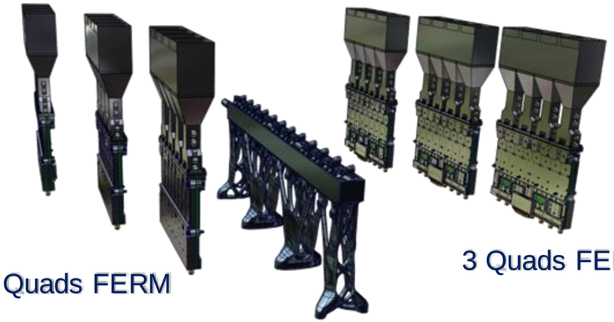
- 3D model + 2D drawing finalized in accordance with supplier and mechanical analyst recommendations :
  - Minor modifications of design to limit surface deviation and ease machining :
    - Addition of walls of matter to substitute supports of manufacturing
    - Addition of areas for positioning and referencing of the raw part
    - …
  - Modification of the RF equipment interface fixation diameter following the link sizing analysis
  - Adaptation of the 2D drawing to such a part geometry to ease the machining :
    - Enlarged tolerances
    - Adaptation of the functional dimensioning
    - Consolidation of machining process

# BREADBOARD 6 QUADS M&T MODULE DETAILED DESIGN

- Recap of the finalized breadboard :
  - Mass : 1.5kg
  - Overall dimensions : 544x195x76mm
  - Functional areas (machined) :
    - Interfaces with antenna baseplate
    - Interfaces with quad FERM
    - Thermal interfaces



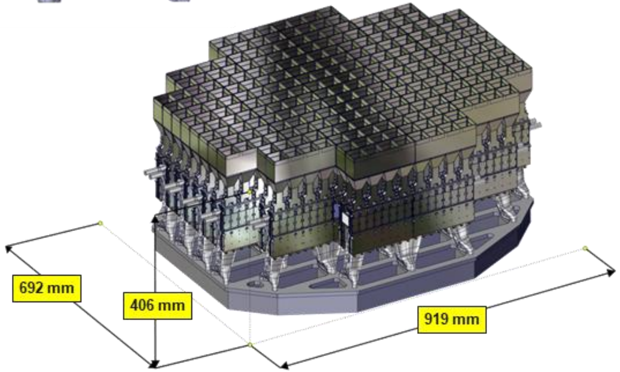





3 Quads FERM

3 Quads FERM

6 Quads M&T module






Date: 30/08/2023
Ref:
Template: 83230347-COM-TAS-EN-012

# OVERVIEW OF TECHNICAL SOLUTION : DESIGN DRIVERS

- The proposed solution for the whole antenna meets several requirements of design :

  - Compatibility with big dimensions and architecture of the antenna
  - Robust design to variations of antenna architecture
  - Feasible design in additive manufacturing + compatibility with dimensions of AM machines
  - Easy assembly with a small number of modules on a baseplate
  - Accessibility for welding of the embedded thermal control and connection to MPL
  - Possible machining of tightened tolerances to meet alignement requirement + high thermal contact conductance

6 Quads M&T module

# OVERVIEW OF TECHNICAL SOLUTION :

## /// Design impacts on RF chains

- Only minor modifications required on the Quad FERM design without impact on RF performances and mass

## /// Antenna mass budget impact

- Total mass of M&T AA structure ≈ 33 % of the antenna total mass < 35 % (TAS heritage) → no impact on active antenna total mass and may even lead to a slight mass saving

## /// Cost and schedule impacts

- Cost analysis performed on recurrent manufacturing and assembly of the antenna M&T structure : a little more expensive regarding manufacturing costs but some solutions of cost reduction identified. However, this solution also appears to be cost advantageous from a satellite / antenna AIT point of view thanks to its modularity and the grouping of all the elementary components into a small number of M&T quad modules.
- No impact on test sequence schedule because equivalent mechanical and thermal test sequence for both solutions. Significant impact on manufacturing, assembly integration & test schedule total lead time because it was estimated to be several weeks less than the baseline solution

For more details, see slides in the confidential appendix document.


Date: 28/09/2020
Ref:
Template: 83230347-COM-TAS-EN-012

ThalesAlenia
a Thales / Leonardo company Space

# 7. MECHANICAL AND THERMAL JUSTIFICATION OF 6 QUADS M&T MODULE DESIGN

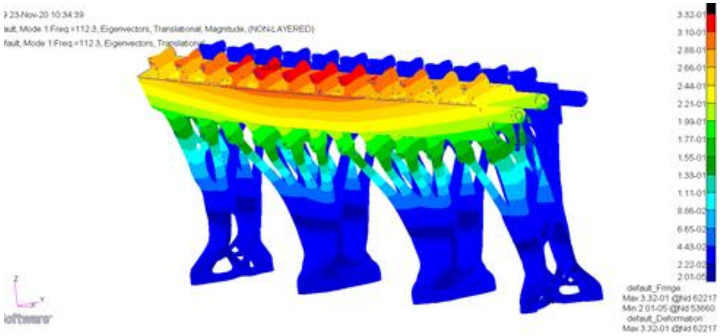
# MECHANICAL JUSTIFICATION OF 6 QUADS M&T MODULE DESIGN

## Modal analysis

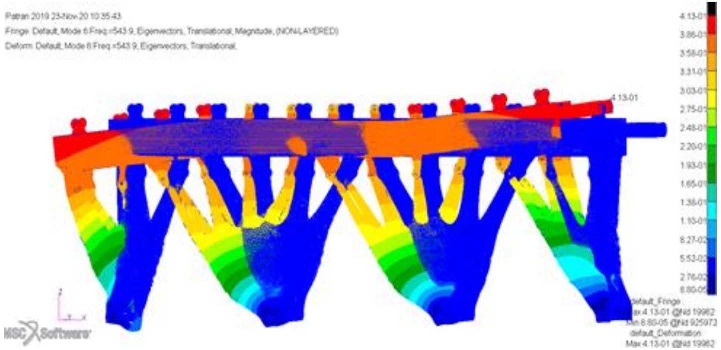
| | | Effective mass (kg) | | | | | |
|---|---|---|---|---|---|---|---|
| Mode | Freq (Hz) | T1 | % | T2 | % | T3 | % |
| 1 | **112,30** | 0,000 | 0% | 5,231 | 77% | 0,000 | 0% |
| 2 | 158,34 | 0,000 | 0% | 0,001 | 0% | 0,000 | 0% |
| 3 | 260,69 | 0,000 | 0% | 0,007 | 0% | 0,000 | 0% |
| 4 | 492,00 | 0,000 | 0% | 0,423 | 6% | 0,000 | 0% |
| 5 | 525,35 | 0,000 | 0% | 0,000 | 0% | 0,000 | 0% |
| 6 | **543,90** | 6,301 | 93% | 0,000 | 0% | 0,000 | 0% |
| 7 | 627,29 | 0,000 | 0% | 0,005 | 0% | 0,000 | 0% |
| 8 | 635,46 | 0,000 | 0% | 0,622 | 9% | 0,000 | 0% |
| 9 | 819,40 | 0,070 | 1% | 0,000 | 0% | 0,000 | 0% |
| 10 | 828,23 | 0,000 | 0% | 0,000 | 0% | 0,025 | 0% |
| 11 | 941,56 | 0,000 | 0% | 0,002 | 0% | 0,000 | 0% |
| 12 | 1017,36 | 0,000 | 0% | 0,000 | 0% | 0,000 | 0% |
| 13 | 1310,86 | 0,157 | 2% | 0,000 | 0% | 0,003 | 0% |
| 14 | **1349,07** | 0,000 | 0% | 0,000 | 0% | 6,256 | 92% |
| tot | | 6,532 | | 6,457 | | 6,556 | |
| % of rigid mass | | | 96% | | 95% | | 97% |

Modes and effective mass

Specification = 1st mode > 60Hz → Compliant



Mode 1 : 112.3 Hz
Main mode along Y axis
(Transverse mode)



Mode 6 : 543.9 Hz
Main mode along X axis
(Longitudinal mode)

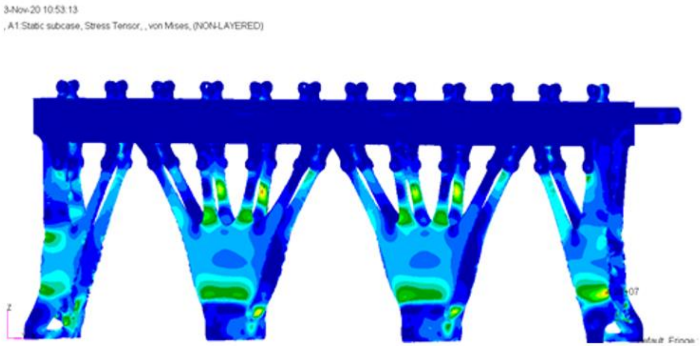

Date: 30/08/2023
Ref:
Template: 83230347-COM-TAS-EN-012

# MECHANICAL JUSTIFICATION OF 6 QUADS M&T MODULE DESIGN

- Quasi-Static analysis
  - Specification : 24 combined cases + pressure

| L/C | X sat (g) | Y sat (g) | Z sat (g) | Internal Pressure (bars) |
|---|---|---|---|---|
| Case 1 | ±17.8 | ±3.8 | ±2.1 | 13.5 |
| Case 2 | ±8.5 | ±15.3 | ±2.1 | |
| Case 3 | ±1.8 | ±9.1 | ±10.4 | |

  - Stress : MOS is 1.88 → OK
  - Link sizing :
    - IFs with Quad modules : MOS sliding & gapping > 0 → OK
    - IFs with the baseplate : MOS sliding & gapping > 0 → OK

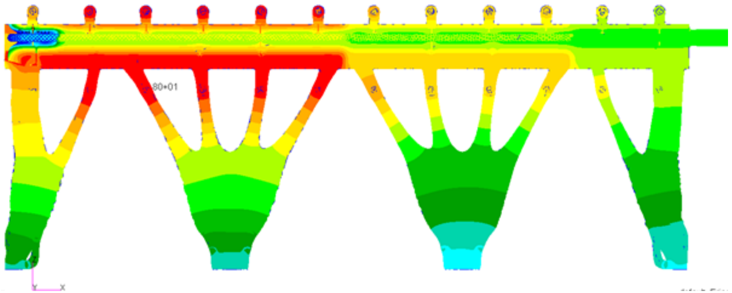




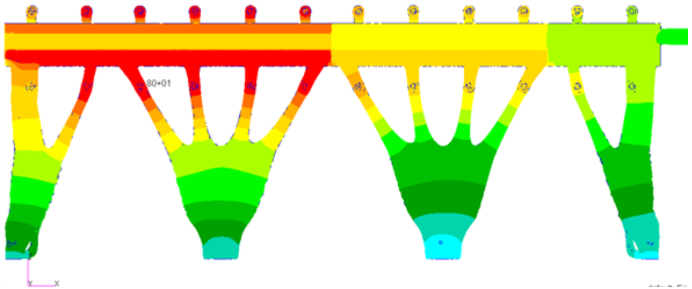
Date: 30/08/2023
Ref:
Template: 83230347-COM-TAS-EN-012

# MECHANICAL JUSTIFICATION OF 6 QUADS M&T MODULE DESIGN

- Thermo-elastic analysis



**Thermal mapping in the tubing (cross section view)**



**Thermal mapping outside the part**

- Stress : MOS is 0.84 → OK

- Link sizing :
  - IFs with quad modules : MOS sliding & gapping > 0 → OK
  - IFs with the baseplate : MOS sliding & gapping > 0 → OK

***Distribution of the stress in the part***

***Distribution of the stress in the part***

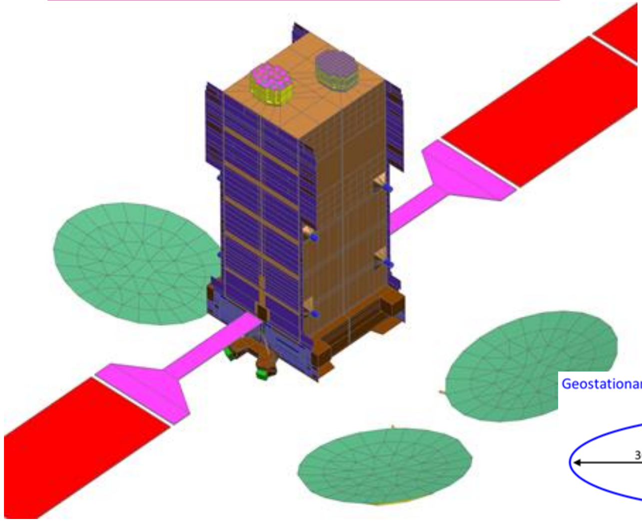


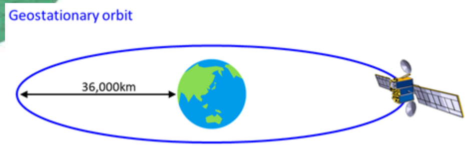
Date: 30/08/2023
Ref:
Template: 83230347-COM-TAS-EN-012

# THERMAL JUSTIFICATION OF 6 QUADS M&T MODULE DESIGN

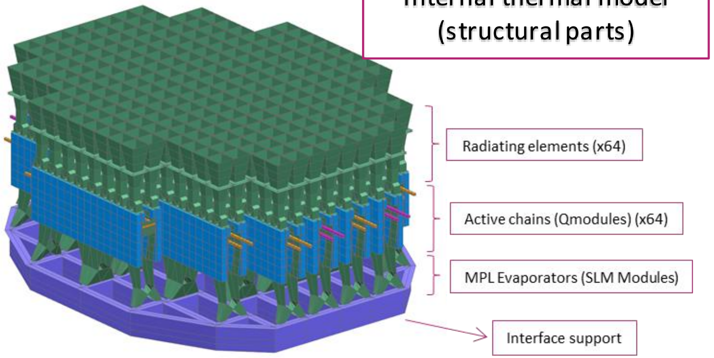
- Thermal justification of 6 Quads M&T module has been done with antenna thermal analysis
- DRA antenna thermal model and thermal control description
  - Based on Two Phase Mechanically Pumped Loop

Implementation of the DRA antenna on the earth panel of a NEO satellite

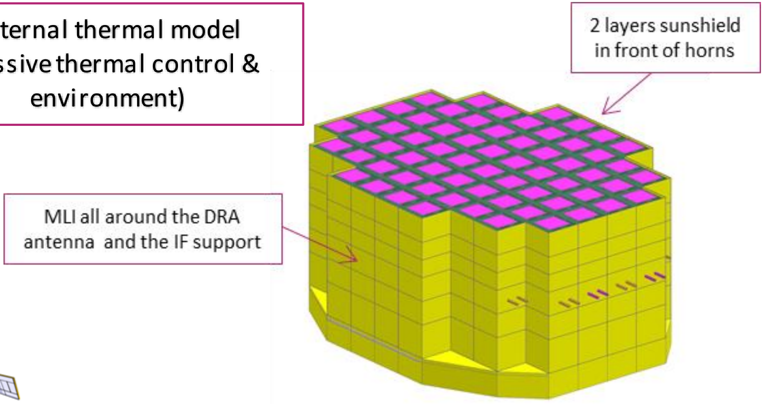





Internal thermal model (structural parts)




External thermal model (passive thermal control & environment)





Date: 30/08/2023
Ref:
Template: 83230347-COM-TAS-EN-012

PROPRIETARY INFORMATION

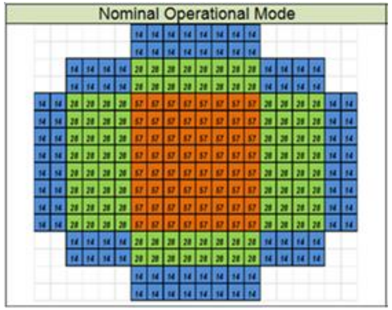

THALES ALENIA SPACE OPEN

ThalesAlenia Space
a Thales / Leonardo company

# THERMAL JUSTIFICATION OF 6 QUADS M&T MODULE DESIGN

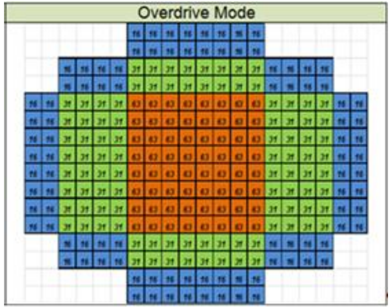
- Antenna dissipated budget (2 scenarii)
  - Nominal operating mode

TOTAL power budget in NOMINAL OPERATING MODE = **7.7 kW**




  - Overdrive operating mode

TOTAL power budget in OVERDRIVE MODE = **8.6kW**

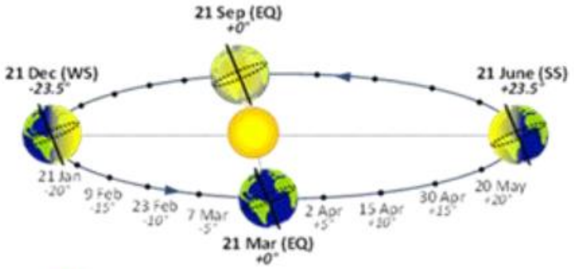


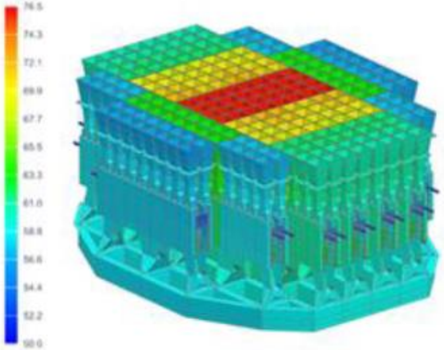

- Geostationary 2 worst cases have been studied :
  - Worst HOT case: SSEOL & Worst COLD case: EQBOL

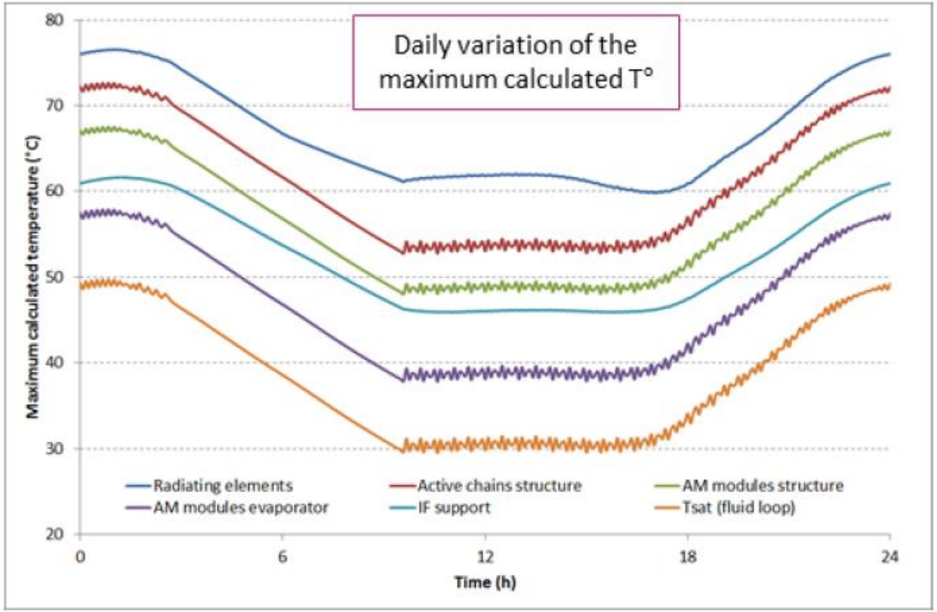

Date: 30/08/2023
Ref:
Template: 83230347-COM-TAS-EN-012

# THERMAL JUSTIFICATION OF 6 QUADS M&T MODULE DESIGN

- Results for the worst HOT case






The DRA antenna qualification temperatures are compliant with M&P temperature limits

# THERMAL JUSTIFICATION OF 6 QUADS M&T MODULE DESIGN

- Conclusion
  - A complete thermal model of a DRA antenna with 256 radiating elements has been done in accordance with the antenna final design
  - Calculation cases in orbit have been performed in a NEO satellite environment for 2 RF scenarios
  - The main results are the following ones:
    - All DRA antenna temperatures are compliant with M&P limit temperatures
    - All RF performances criteria are compliant with the specification
- This thermal analysis at antenna level demonstrates the robustness of the technical solution
- For more details of the thermal analysis results, see slides in the confidential appendix document.


Date: 30/08/2023
Ref: 0005-xxx
Template: 83230347-COM-TAS-EN-012

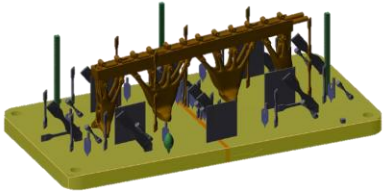
# 8. MANUFACTURING OVERVIEW


Date: 30/08/2023
Ref: Not referenced
Template: 83230347-COM-TAS-EN-012

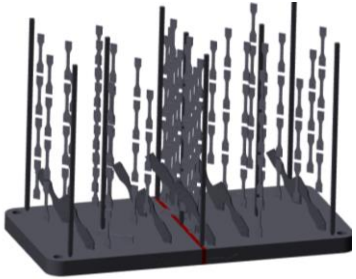
# MANUFACTURING OVERVIEW

## /// 4 jobs were printed in the frame of this GSTP

Job **SN5483**:
Cantilevers for simulation tool calibration



Job **SN5469**:
PoC and samples

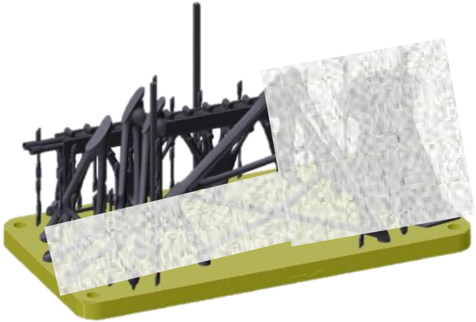


Job **SN5424**:
LAAM Qualification job incl. fatigue samples

TN6 _ Samples test and characterization plan
TN7_Manufacturing plan of PoC
TN8_Samples test report

Job **SN5630**:
Breadboard(s)

TN9_Manufacturing plan of the breadboard
RFP_3-15938_TN11_Manufacturing_report



Job **SN5872**:
Final Breadboard printing

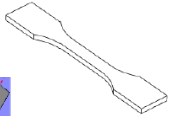
# 9. SAMPLES AND CHARACTERIZATION

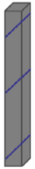
# SAMPLES ET CHARACTERIZATION – TN6

## /// Test plan (TN6):

- Mechanical characterization: static and fatigue properties
- Material health assessment: metallography and CT scan
- Corrosion sensitivity: environmental aggresion and ammonia contact
- Residual stress: cantilevers and XRD analysis

| GSTP Active Antenna - SAMPLES | Objective / Test | JOB n° | | | |
|---|---|---|---|---|---|
| | | SN5424 (X-Line 2000R qualif job) | SN5483 (cantilevers) | SN5469 (samples + PoC) | SN5630 (breadboards) |
| Tensile samples (E / Rp0,2 / UTS / A%) | Tensile test at room temperature | | | x | |
| | Tensile test at room temperature | | | | x |
| | Tensile test at high temperature (+170°C) | | | | x |
| Fatigue samples | Fatigue test at room temperature 4 load cases | x | | | |
| | | x | | | |
| | Fatigue test at low temperature (-55°C) | | | x | |
| Fatigue samples | Reference: Fatigue test at room temperature (no contact with ammonia)<br>Fatigue test at room temperature after ammonia immersion - 4 load cases | | | x | |
| Porosity tower for metallography | Microcuts for the assessment of porosity rate, max size of porosity, microstructure | | | x | |
| Plates (100 x 80 x 2 mm) | Environmental aggression Observation of potential marks of corrosion | | | x | |
| Cantilever (150 x 20 x 20 mm) | Residual stress assessment | | x | | |
| XRD samples Cubes (10x10x10 mm) | Residual stress assessment | | | | x |

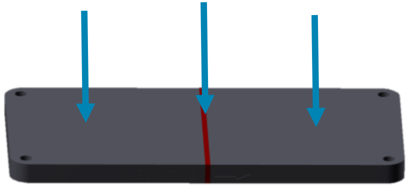


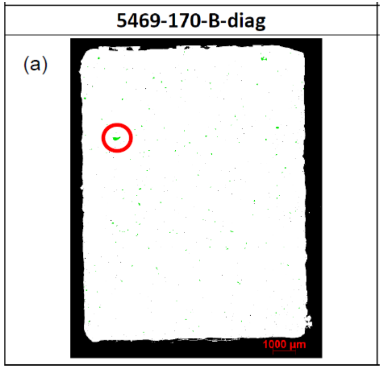

Date: 28/03/2024
Ref: Not referenced
Template: 83230347-COM-TAS-EN-012

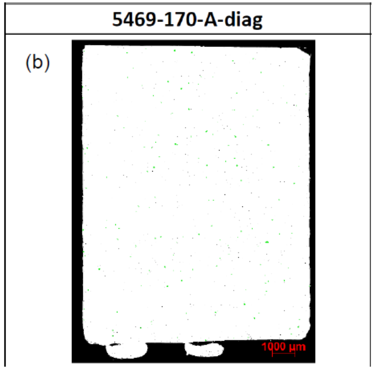
# SAMPLES ET CHARACTERIZATION – TN8

## /// Metallographic analysis by LAAM



- Performed on 3 bars printed on each laser area of the machine
- Post-treatment: HT, sandblasting
- Cut in the diagonal
- Results:
  - Porosity rates all below 0.2 %
  - One porosity (325 µm) slightly above the success criteria




| Page : (Page) | N° échantillon : (N°prod-Hauteur-N°barreau-Orientation) | Taux de porosité (%) : (Porosity rate) | Taille de la plus grosse porosité (µm) : (Size of biggest porosity) | Zone (pour SLM280 et Xline 2000R) : (Zone) | Statut de conformité par échantillon: (Compliance status per sample) |
|---|---|---|---|---|---|
| 2 | 5469-100-A-diag | 0,15 | 170,07 | Zone 1 | CONFORME |
| 2 | 5469-100-B-diag | 0,16 | 171,23 | Recouvrement | CONFORME |
| 2 | 5469-100-C-diag | 0,13 | 128,85 | Zone 2 | CONFORME |
| 2 | 5469-170-A-diag | 0,17 | 136,01 | Zone 1 | CONFORME |
| 2 | 5469-170-B-diag | 0,18 | 325,46 | Recouvrement | NON CONFORME |
| 2 | 5469-170-C-diag | 0,15 | 106,34 | Zone 2 | CONFORME |

samples manufactured in overlap area

# SAMPLES ET CHARACTERIZATION – TN8

## /// Residual stress assessment

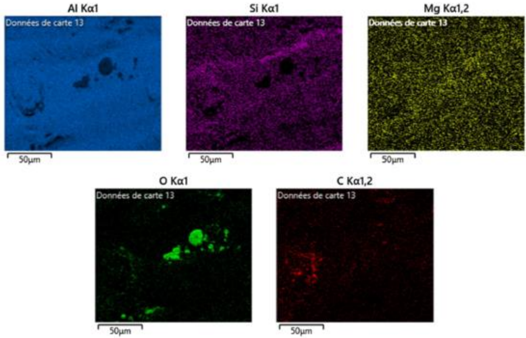
- Cantilevers printed to assess residual stress
- The results from the characterization were used by LAAM for the calibration of the simulation tools (Simufact)

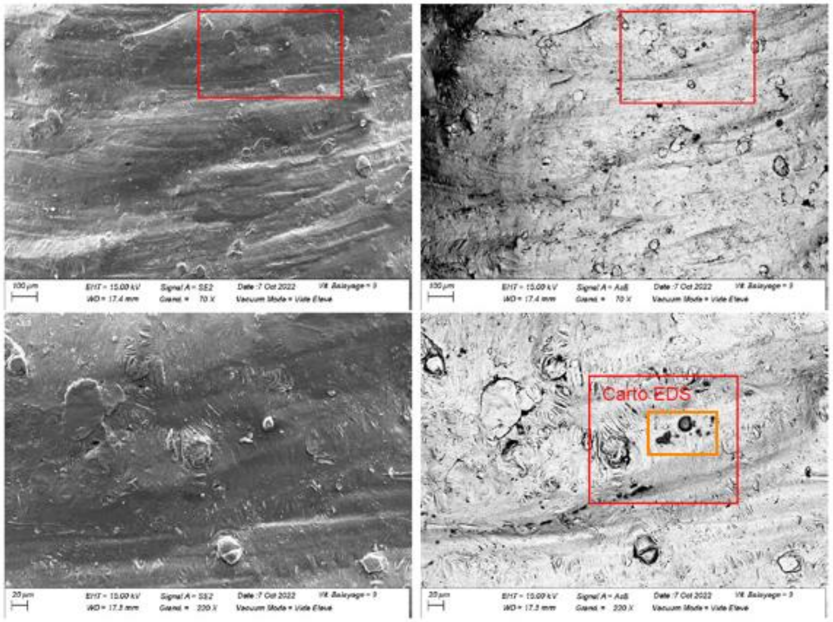
- XRD analysis performed by ESA on cubes submitted to different conditions:
  - With and without heat treatment
  - With and without sandblasting
- Test report in progress

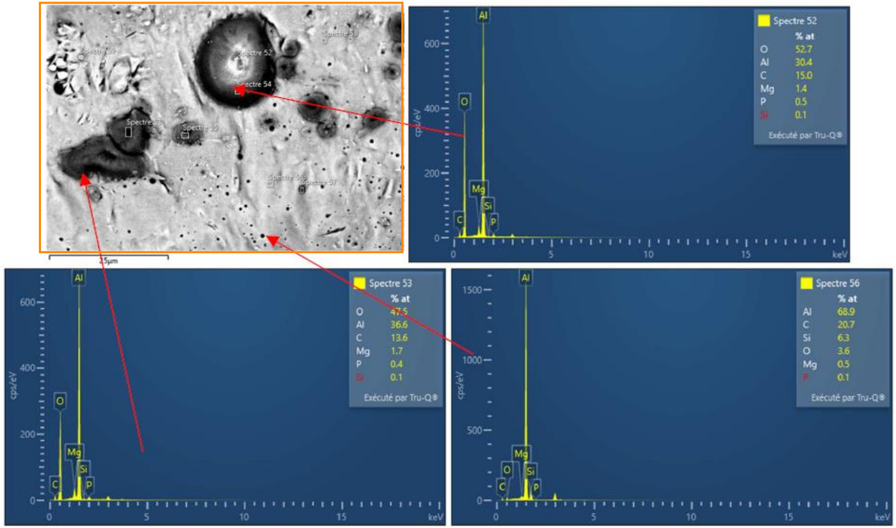
# SAMPLES ET CHARACTERIZATION – TN8

## /// Sensitivity to corrosion

- Example of MEB analysis on a sample with prolonged ammonia immersion
- A few area were recorded as potential marks of corrosion





Date: 28/03/2024
Ref: Not referenced
Template: 83230347-COM-TAS-EN-012

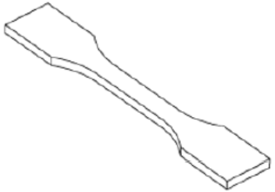
# SAMPLES ET CHARACTERIZATION – TN8

## /// Static properties

- Samples were printed on each laser area of the machine

- The average results of the 24 tensile flat samples are provided in the table here after :

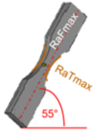
| AlSi7Mg0,6 | E (GPa) | $R_{p0.2}$ (MPa) | UTS (MPa) | $A_t$ (%) |
|---|---|---|---|---|
| **Average** | **65.9** | **243.8** | **370** | **4.1** |
| **Std dev** | **1** | **2.7** | **8.7** | **0.6** |
| **Discrepancy (%)** | **1.5** | **1.1** | **2.3** | **NA** |



# SAMPLES ET CHARACTERIZATION – TN8

## /// Fatigue properties

- Samples were printed on each laser area of the machine
- Post-treatment: HT, with and without sandblasting




- Several fatigue batches of fatigue samples to establish Wöhler curves
  - **Flat** samples 55° – -55°C – As-built
  - **Flat** samples 55° – RT – As-built
  - **Flat** samples 55° – RT – Sandblasting

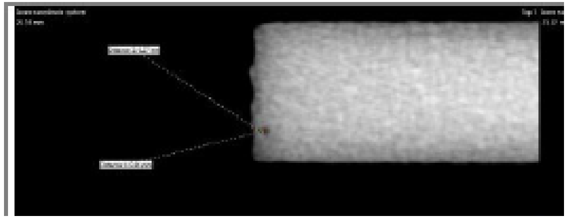
- Assessment of the **impact of finishing on fatigue properties** at RT
- Assessment of the **impact of low temperatures (-55°C) on the fatigue properties** without finishing

# SAMPLES ET CHARACTERIZATION – TN8

## /// Fatigue properties – Roughness measurements and CT scan inspection (resolution = 75 µm)

### **Flat** samples 55° – RT – As-built

| | Samples | A | B | C | D | | |
|---|---|---|---|---|---|---|---|
| | | Ra (µm) | Ra (µm) | Ra (µm) | Ra (µm) | | |
| As built | SN5424-118 | 10.449 | 6.590 | 7.638 | 13.850 | | |
| | SN5424-119 | 8.760 | 9.187 | 6.757 | 19.580 | | |
| | SN5424-121 | 8.696 | 6.987 | 7.348 | 13.506 | | |
| | SN5424-124 | 8.736 | 8.373 | 8.269 | 14.051 | | |
| | *SN5424-126 | 7.395 | 12.953 | 9.598 | 29.845 | | 3 pores – max 140 µm |
| | *SN5424-129 | 8.723 | 24.525 | 6.892 | 16.341 | | 2 pores – max 410 µm |
| | *SN5424-131 | 7.660 | 25.872 | 12.149 | 15.610 | | 2 pores – max 270 µm |
| | SN5424-133 | 11.670 | 7.507 | 12.186 | 18.788 | | |
| | SN5424-134 | 12.864 | 12.455 | 17.318 | 21.352 | | |
| | SN5424-136 | 14.639 | 8.074 | 9.384 | 14.644 | | |
| | SN5424-139 | 10.019 | 10.736 | 9.013 | 15.154 | | |
| | *SN5424-140 | 6.856 | 19.109 | 7.739 | 16.564 | | 1 pore – 200 µm |
| | **Average** | **9.71** | **12.70** | **9.52** | **17.44** | **12.34 µm** | |
| | **Std dev** | **2.34** | **6.79** | **3.05** | **4.61** | | |



### **Flat** samples 55° – RT – Sandblasting

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Sandbalsted | SN5424-117 | 6.593 | 5.371 | 7.922 | 11.751 | | |
| | SN5424-120 | 7.391 | 6.086 | 7.085 | 10.387 | | |
| | SN5424-122 | 6.100 | 6,440 | 6.654 | 8.409 | | |
| | SN5424-123 | 5.863 | 6.950 | 5.271 | 7.452 | | |
| | *SN5424-125 | 8.061 | 9.963 | 6.983 | 17.958 | | 1 pore – 160 µm |
| | *SN5424-127 | 6.044 | 14.365 | 5.248 | 12.813 | | 2 pores – max 160 µm |
| | *SN5424-128 | 5.240 | 14.390 | 7.242 | 7.362 | | 1 pore – 150 µm |
| | *SN5424-130 | 6.013 | 13.474 | 5.996 | 9.189 | | 3 pores – max 200 µm |
| | SN5424-132 | 7.197 | 6.407 | 8.315 | 12.250 | | 1 pore – 160 µm |
| | SN5424-135 | 7.871 | 8.168 | 6.400 | 15.229 | | |
| | SN5424-137 | 7.384 | 8.155 | 6.793 | 7.808 | | 1 pore – **810 µm** |
| | SN5424-138 | 7.687 | 6.255 | 6.567 | 9.941 | | |
| | **Average** | **6.79** | **8.84** | **6.71** | **10.88** | **8.31 µm** | |
| | **Std dev** | **0.92** | **3.39** | **0.92** | **3.29** | | |

### **Flat** samples 55° – -55°C – As-built

| Samples | Face 1 | Face 2 | Face 3 | Face 4 | | |
|---|---|---|---|---|---|---|
| | Ra (µm) | Ra (µm) | Ra (µm) | Ra (µm) | | |
| SN5469-30 | 7.682 | 10.132 | 7.231 | 12.026 | | |
| SN5469-31 | 7.221 | 7.225 | 9.417 | 11.870 | | |
| SN5469-32 | 8.283 | 9.809 | 5.211 | 13.116 | | |
| *SN5469-33 | 16.567 | 12.470 | 13.071 | 16.506 | | 9 pores – max 161 µm |
| *SN5469-34 | 15.751 | 24.271 | 14,573 | 35.329 | | 3 pores |
| *SN5469-35 | 15.976 | 12.808 | 13.099 | 32.105 | | 1 pore – 167 µm |
| *SN5469-36 | 9.030 | 16.266 | 17.136 | 38.825 | | 6 pores – max 184 µm |
| SN5469-37 | 8.990 | 20.879 | 14.469 | 23.333 | | 2 pores – 373 µm |
| SN5469-38 | 11.681 | 21.783 | 14.741 | 23.030 | | |
| SN5469-39 | 10.764 | 19.684 | 10.359 | 19.308 | | |
| **Average** | **11.19** | **15.53** | **11.93** | **22.54** | **15.30** | |
| **Std dev** | **3.64** | **5.86** | **3.76** | **9.89** | | |

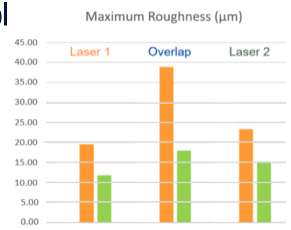


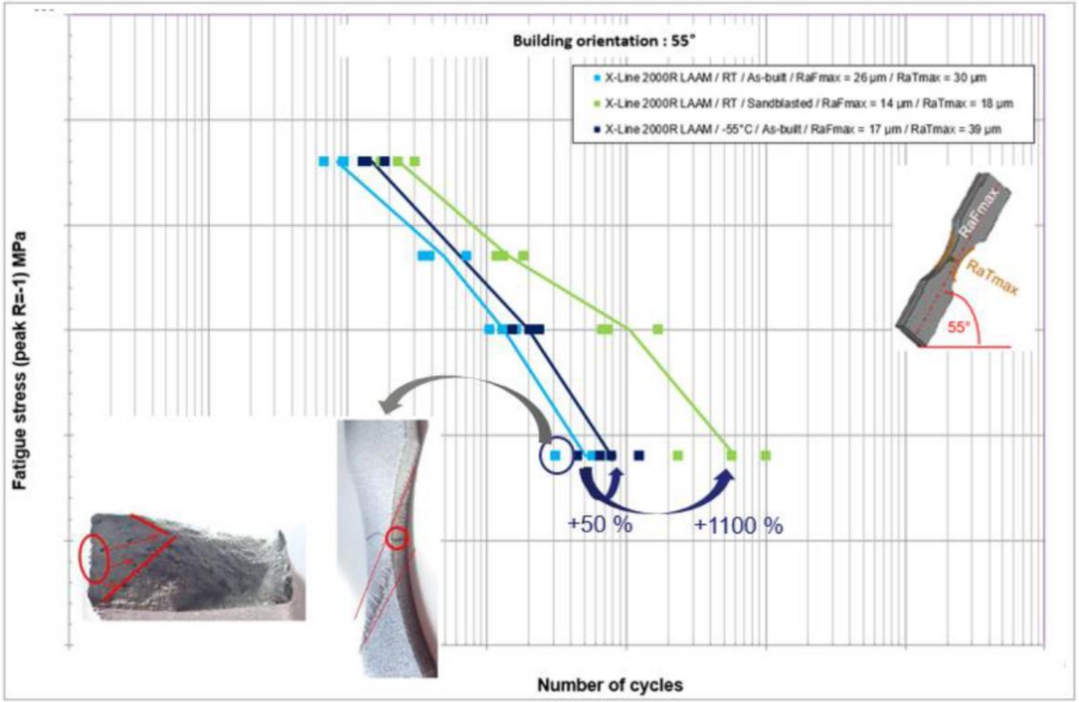
Date: 28/03/2024
Ref: Not referenced
Template: 83230347-COM-TAS-EN-012

# SAMPLES ET CHARACTERIZATION – TN8

## /// Fatigue properties – flat samples

- Both surface conditions were characterized
  - **As-built** → representative of the internal channel not accessible for finishing = **WORST CASE**
  - Sandblasted → representative of the external surfaces of the part
- As expected, at RT, the samples reach a higher number of cycles when sandblasted
- For as-built conditions, the results are higher when tested at -55°C
- Influence of the printing localization: lower

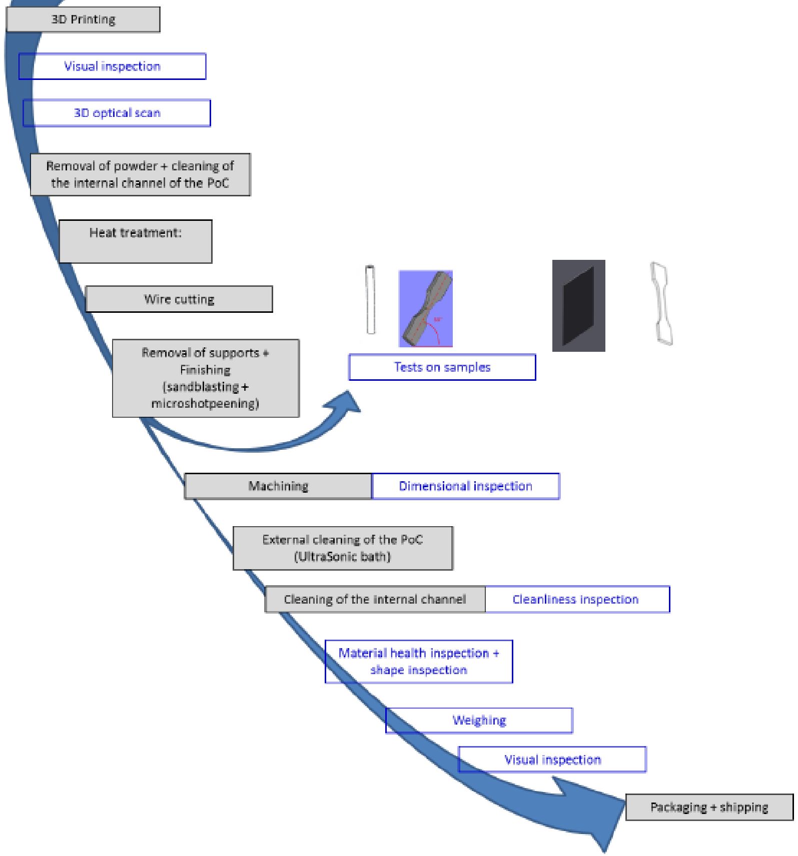


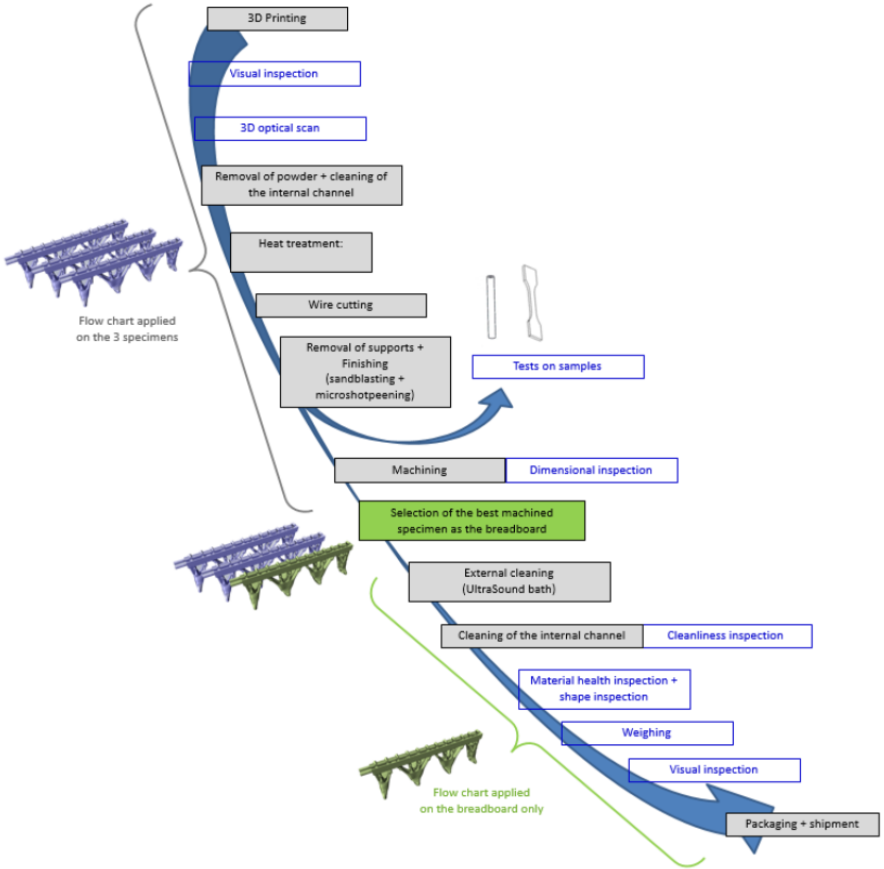
Date: 28/03/2024
Ref: Not referenced
Template: 83230347-COM-TAS-EN-012

# 10. POC AND BREADBOARD MANUFACTURING AND VALIDATION


Date: 30/08/2023
Ref: Not referenced
Template: 83230347-COM-TAS-EN-012

# POC AND BREADBOARD - MANUFACTURING OVERVIEW



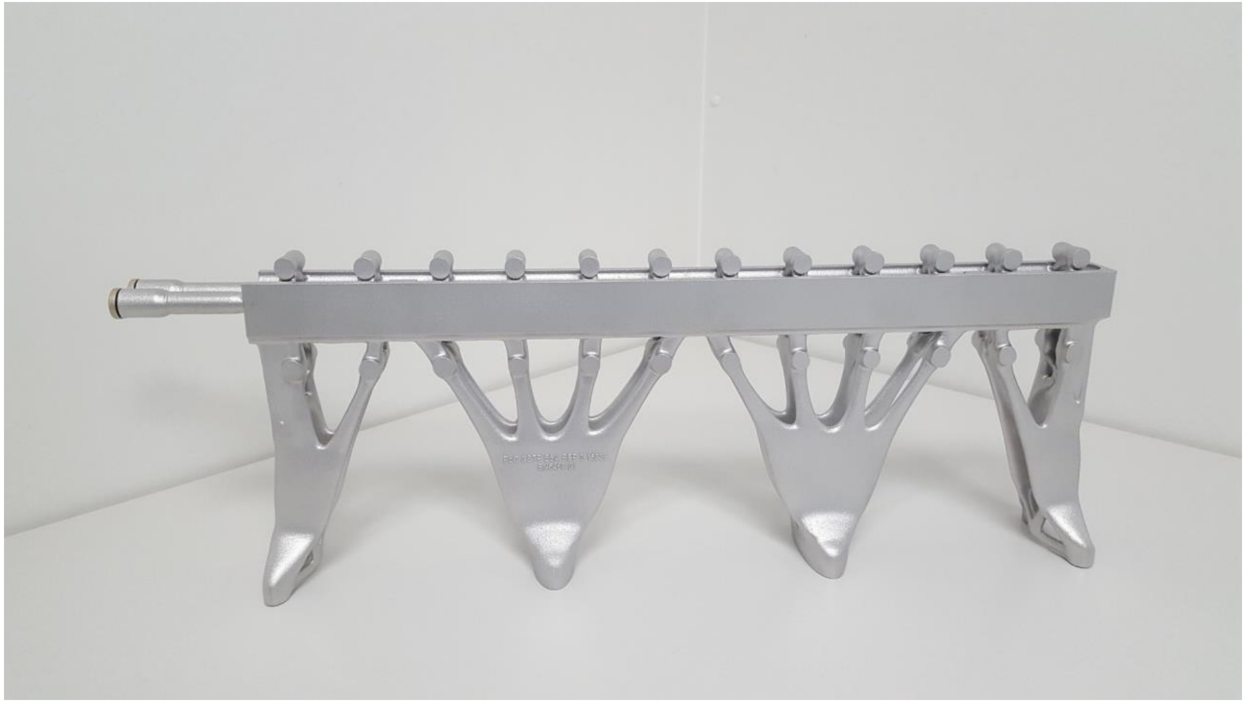






Date: 28/03/2024
Ref: Not referenced
Template: 83230347-COM-TAS-EN-012

# 10A. POC MANUFACTURING AND VALIDATION

# VISUAL INSPECTION AFTER FINISHING : COMPLIANT



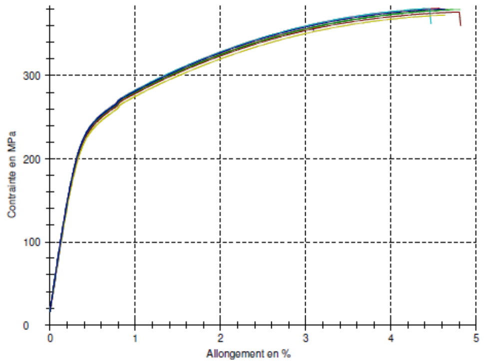

**Date:** 28/03/2024
**Ref:**
**Template:** 83230347-COM-TAS-EN-012

# TESTS

- Z Tensile test: compliant
- Porosity analysis: 1 cutting view non-compliant: 325 µm max and average rate: 0,16 %
- Powder analysis: compliant

| lisi AEROSPACE | Rapport de traction (Tensile test report) | Révision : 02 | Création : 22/08/2016 |
|---|---|---|---|
| | | Référence : | Mise à jour : 20/03/2019 |
| | | ENR - 1813 - 5469 - F13 | Page2/2 |

*GRAPHIQUE (CHART)*




*Statistiques (Statistics)*

| Série n = 10 | E GPa | $R_{p0.2}$ MPa | $R_m$ MPa | $A_t$ % | $S_0$ mm² |
|---|---|---|---|---|---|
| max | 68 | 247,4 | 381,0 | 4,8 | 22,57 |
| min | 63 | 241,1 | 358,3 | 3,1 | 21,50 |
| x | 66 | 245,7 | 374,4 | 4,3 | 21,88 |
| s | 1 | 1,9 | 8,8 | 0,7 | 0,39 |
| Disp% | 2 | 0,8 | 2,3 | NA | NA |

*Paramètres d'essais (Testing parameters)*

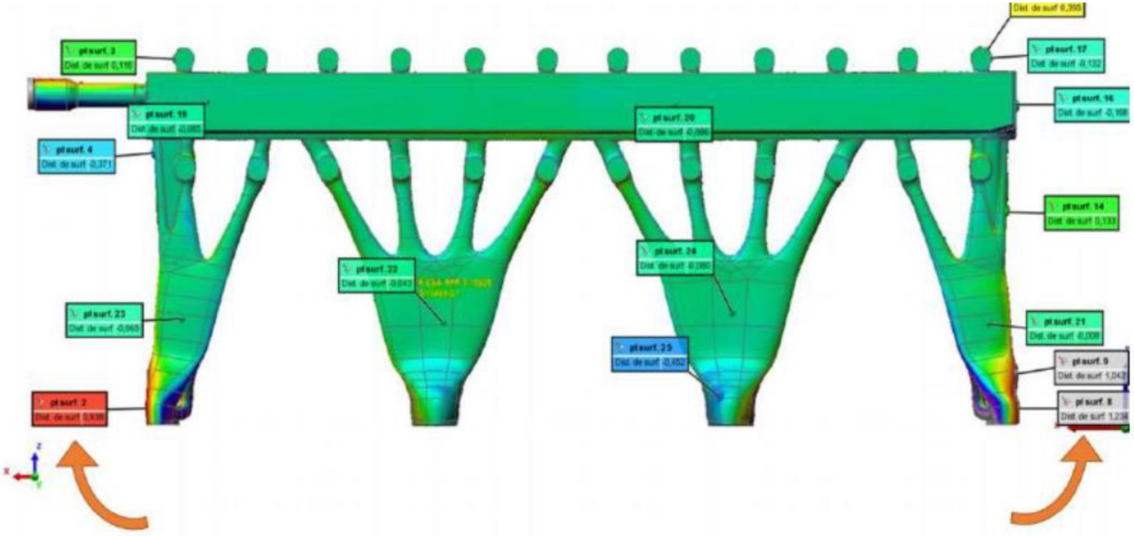
| | | | |
|---|---|---|---|
| Machine d'essai (Test machine) | : | 726796/2016 | |
| Norme d'essai (Testing standard) | : | ISO 6892-1 A224 | |
| Précharge | : | 15 | MPa |
| Vitesse du module | : | 0,45 | mm/min |
| Vitesse de la limite d'élasticité | : | 0,45 | mm/min |
| Vitesse d'essai | : | 12,06 | mm/min |

Opérateur (Operator): A. IDARO

Visa responsable (Manager visa): A. DU GRANRUT

# 3D SCAN - DEFORMATIONS

- Part is outwardly deformed
- No possibility to improve support structure for next parts without important work (not planned in this project)
  - Deformation to be integrated in design





Date: 28/03/2024

Ref:

Template: 83230347-COM-TAS-EN-012

# DIMENSIONAL INSPECTION

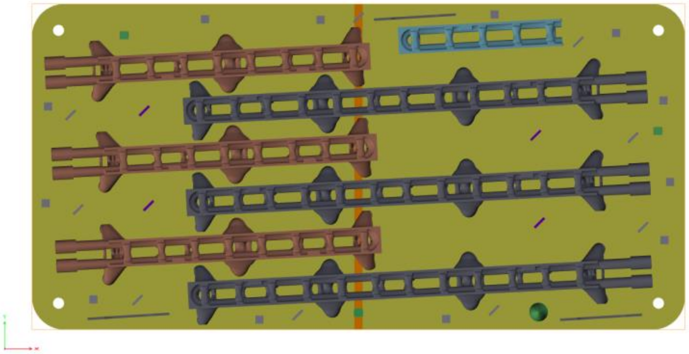
- Major feedback
  - Deformations after manufacturing
  - Delocalisation several tenth of millimeter : non-acceptable by THALES ALENIA SPACE
  - Clamping system to be improved
  - Double-Check results with internal inspection
  - Add 3D scan during steps of machining
- Strategy for next parts
  - 1st part : same machining strategy to check non-conformance
  - 2nd and 3rd part : depending of 1st part

# 10B. 1ST BREADBOARD MANUFACTURING AND VALIDATION

# MANUFACTURING ROUTE

- Manufacturing – XLINE 2000R
- Internal tensile test
- Visual inspection after manufacturing
- 3D Scan on manufacturing part
- First cleaning operation on plate
- Heat Treatment
- EDM
- Finishing operation
- Sandblasting / Microblasting
- 3D Scan after finishing
- Machining
- 3D Scan after machining
- Ultrasonic bath
- CMM inspection
- Roughness inspection
- Selection of part
- Second cleaning operation
- CT Scan
- Weighing
- Final visual inspection

- Porosity analysis
- Powder analysis
- Tensile test on TAS samples
- Microstructure
- Partial part sample

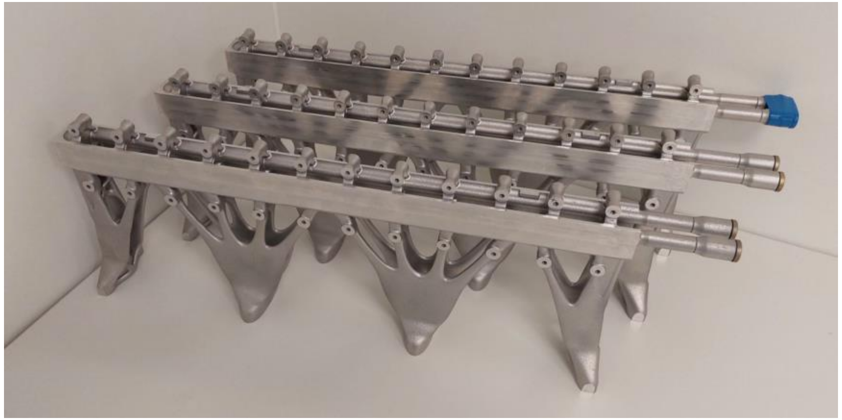




Date: 28/03/2024
Ref:
Template: 83230347-COM-TAS-EN-012

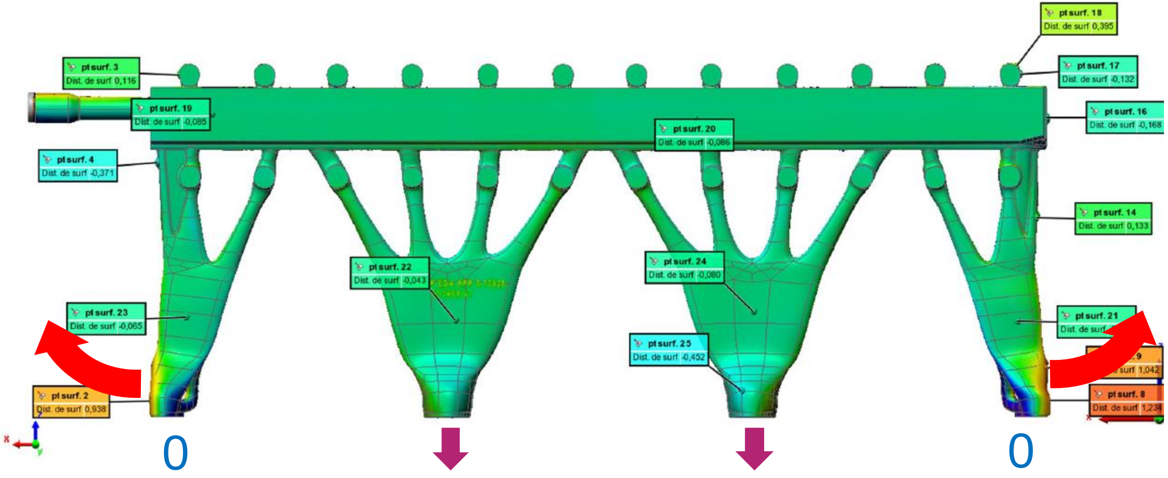
# INSPECTIONS

- Visual inspection after manufacturing: compliant
- First cleaning operation on plate: compliant
- 3D Scan before machining: same deformation than POC
- Visual inspection after machining: compliant



# MACHINING EXPERIENCE FEEDBACK ON THE FIRST PART (POC)

- **Deformation of the blank before machining:**
  - Raw deformed after plate separation: The 2 outer legs open symmetrically outwards (RED arrows)
  - Piece longer overall by some millimeters at the level of the feet
  - Gross flatness of the feet: The 2 central feet are lower than the 2 end feet (PURPLE ARROWS)
  - Impact of machining adjustment OP1 (reference milling)





Date: 28/03/2024
Ref:
Template: 83230347-COM-TAS-EN-012

# STRATEGY FOR MACHINING OPERATIONS OF 3 FINAL PARTS

- 3 parts machined:
  - 5630-01
    - Identical conditions to the POC → Goal: Check the repeatability of the faults obtained: CONFIRMED
  - 5630-02
    - Origins adjustment according to 3D scan result → See if we can improve the precision of the machine adjustment: NOT OPTIMAL
  - 5630-03
    - Origin adjustment by measuring position R1 in relation to REF1, 2 and 3 → Same as test 2: CONFIRMED
    - Optimization of the first grip positioning for reference milling. Objective = Improve the flatness of the 4 surfaces of the feet: CONFIRMED


Date: 28/03/2024
Ref:
Template: 83230347-COM-TAS-EN-012

# MACHINING NON-CONFORMITIES

- 2 families of non-compliance
  - Localization
  - Threading
- Actions
  - **Localization**: we think that tolerances are too tight to be achieved with deformation of blank part
    - Proposition: tolerance increase
  - **Threading**: They are all picked up manually, and mostly dry. That may explain the defect. The best would be to be able to take them out finished directly from the 5 axis machine.
    - Proposition for these parts: threaded insert (to be confirmed)
    - Proposition for a future part: make threading directly with the milling cutter. More complex to program, but the diameter is managed via the dynamic tool radius correction. We do the direct depth, no tool tip constraint.


Date: 28/03/2024
Ref:
Template: 83230347-COM-TAS-EN-012

# 10C. 2ND BREADBOARD MANUFACTURING AND VALIDATION

# GOAL OF $2^{ND}$ BREADBOARD MANUFACTURING

/// Use the lessons learnt from the previous production to :

- improve machining strategy
- improve tapping operations
- use an optimized cleaning procedure

Passenger production to limit additional project costs


Date: 28/03/2024
Ref: Not referenced
Template: 83230347-COM-TAS-EN-012

# MANUFACTURING ROUTE

- Manufacturing – XLINE 2000R
- Internal tensile test
- Visual inspection after manufacturing
- 3D Scan on manufacturing part
- First cleaning operation on plate
- Heat Treatment
- EDM
- Finishing operation
- Sandblasting / Microblasting
- 3D Scan after finishing
- Machining
- 3D Scan after machining
- Ultrasonic bath
- CMM inspection
- Roughness inspection
- Second cleaning operation
- Weighting
- CT Scan
- Final visual inspection

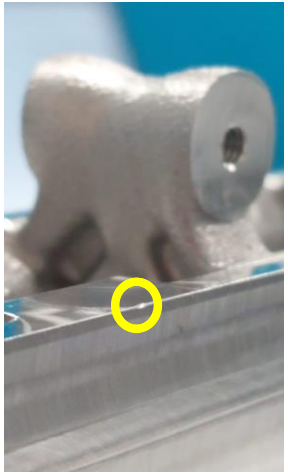
- Porosity analysis
- Powder analysis
- Tensile test on TAS samples
- Microstructure
- Partial part sample

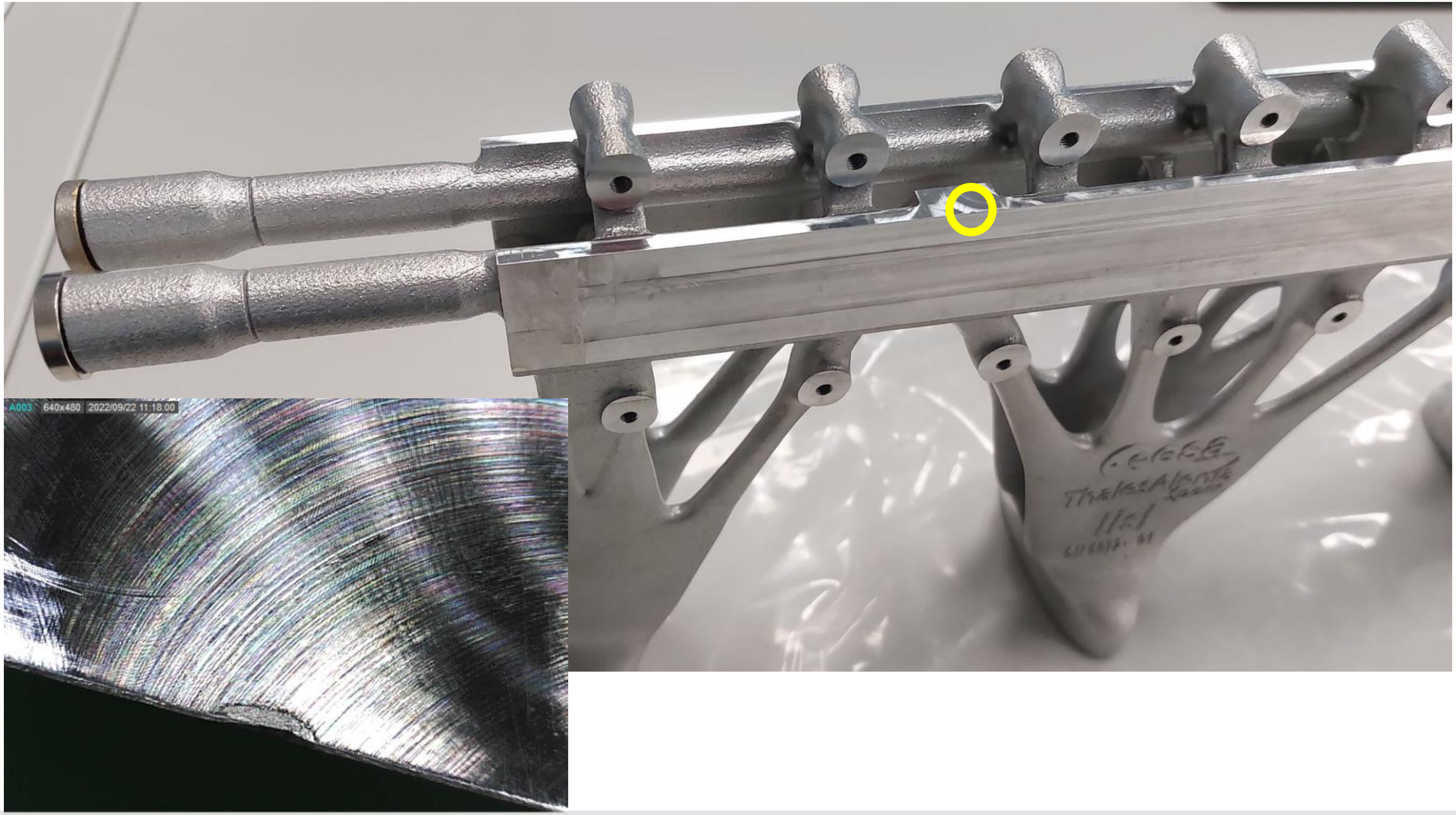
# INSPECTIONS

- Visual inspection after manufacturing: compliant
- Porosity analysis: compliant
- Tensile test: compliant
- Weight: compliant
- Cleaning operation: compliant
- Material health (CT Scan): compliant
- 3D scan analysis : Same deformations as the previous job

# FINAL VISUAL INSPECTION

- Shock 1

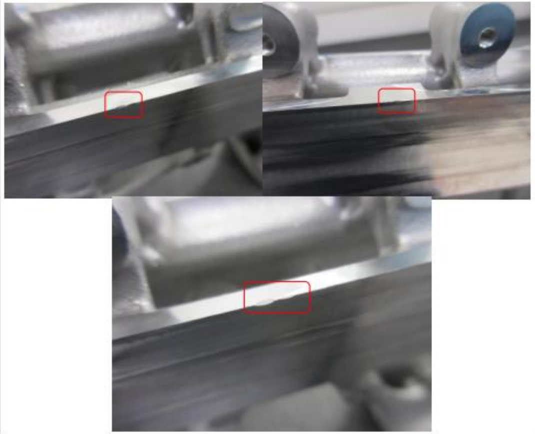
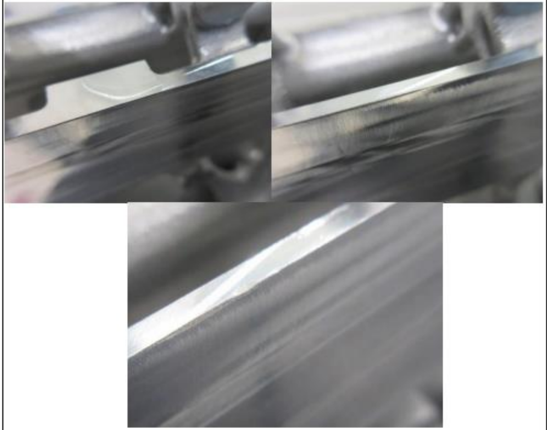







**Date:** 28/03/2024
**Ref:**
**Template:** 83230347-COM-TAS-EN-012

# REWORK OF DEFECTS

| | | | |
|---|---|---|---|
| Chocs |  | SN5872-01 | |
| Chos après retouche à la lime : retrait des "bosses" |  | SN5872-01 | |

# SUMMARIZE

| Operation | Compliant / non-compliant |
|---|---|
| Manufacturing – XLINE 2000R | Compliant |
| Internal tensile test | Compliant |
| Visual inspection after manufacturing | Compliant |
| 3D Scan on manufacturing part | For information |
| First cleaning operation on plate | Compliant |
| Heat Treatment | Compliant |
| EDM | Compliant |
| Finishing operation | Compliant |
| Sandblasting / Microblasting | Compliant |
| 3D Scan after finishing | For information |
| Machining | / |
| 3D Scan after machining | Non-compliant, due to shape of part |
| Ultrasonic bath | Compliant |
| CMM inspection | Non-compliant, some tolerances are too restrictives |
| Roughness inspection | Compliant |
| Second cleaning operation | Compliant |
| Weighting | Compliant |
| CT Scan | Non-compliant, idem 3D Scan |
| Final visual inspection | Non-compliant, three shocks due to transportation |

| | |
|---|---|
| Porosity analysis | Compliant |
| Powder analysis | Granulometry inspection non-compliant |
| Tensile test on TAS samples | Compliant |
| Microstructure | Compliant |
| Partial part sample | NA |

# VALIDATION OF THE BREADBOARD / NC JUSTIFICATION

/// Some non-confirmities resulting from controls on the breadboard : 4 types

- Grain size analysis : Minor non compliance (0,8µm out of criteria) → Acceptable
  - Compliant tensile test results
  - No material health defect identified

- CT-Scan / Shape defects : A few NC → Acceptable
  - Dimension deviation : smaller sections but sufficient remaining thickness
  - Deformations : defects anticipated in the design but in-depth simulation analysis necessary for future productions

- Machining : Some NC identified→ Acceptable
  - Partly because of deformation of the raw part
  - No impact for the assembly

- Visual inspections / Shocks : Impacts on surfaces during handling / transport steps → Acceptable after reworking

# LESSONS LEARNT

## /// Overall deformation of the part

- We have improved the supports as much as possible with the current geometry to keep deformation to a minimum. Nevertheless, some deformations remain.
- There are several possibilities to improve this point:
  - Adapt dimensional tolerances to actual geometry
  - Work on a pre-deformed part to anticipate these deformations during manufacturing
- For this last point, the required work is very extensive and time-consuming, given the current state of our know-how. We're already doing this for mass-produced parts, with very long (1 year) and costly industrialization.
- What's more, simulation gives us the deformation zones, but not yet the exact deformation values. One of our current priorities is to reduce the time it takes to industrialize a new part, and in particular the time spent on pre-deformed parts.

## /// Machining non-conformance

- The point is directly linked to the previous one. If the raw material is less deformed, we will no longer have dimensional control non-conformities after machining.

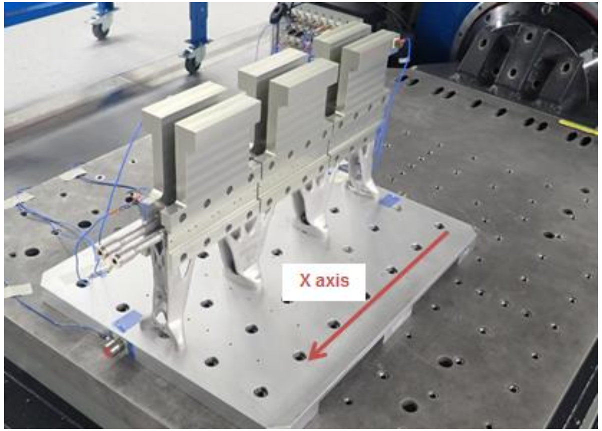
.→ For the future, several cost-reduction measures are identified (see slides in the confidential appendix document)

# 11. 6 QUADS M&T MODULE BREADBOARD TEST CAMPAIGN

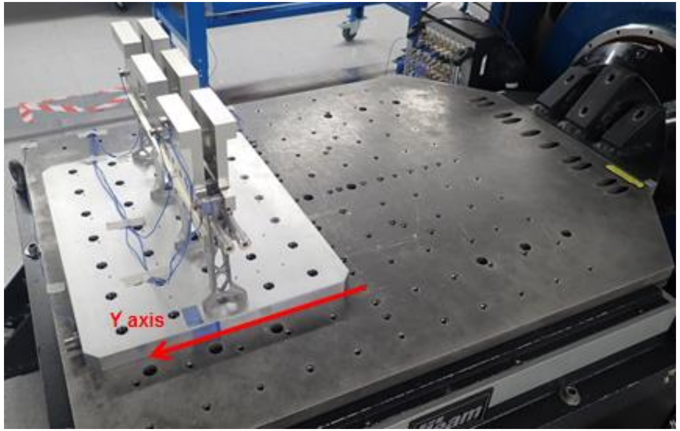

**Date:** 30/08/2023
**Ref:** Not referenced
**Template:** 83230347-COM-TAS-EN-012

# 6 QUADS M&T MODULE BREADBOARD MECHANICAL TEST - SINE TEST

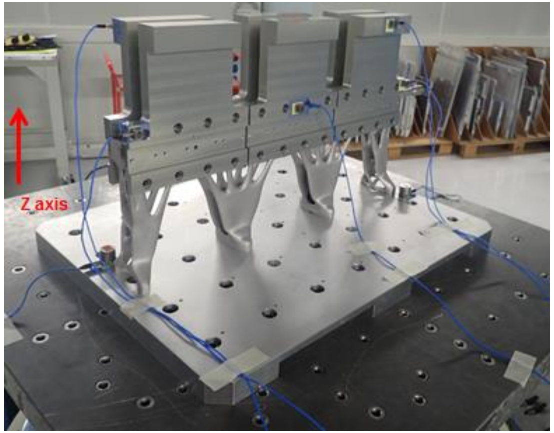
- MECHANICAL TEST OBJECTIVE
  - SINE TEST on THE ADDITIVE MANUFACTURING SUPPORT for MODAL IDENTIFICATION
    - Low level : 0.25g from 5 to 2000 Hz – The input level of 0.25g allows to keep positive safety margins in the structure without notching
    - 3 axes tested




X axis




Y axis




Z axis

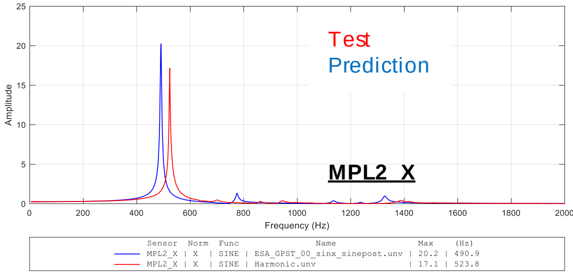

Date:
Ref: 0005-0016627502
Template: 83230347-COM-TAS-EN-012

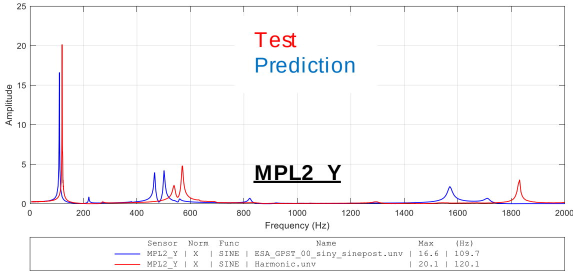
# 6 QUADS M&T MODULE BREADBOARD MECHANICAL TEST - SINE TEST

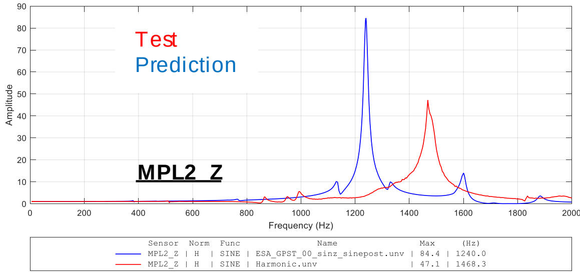
## SINE TEST RESULTS

### STIFFNESS RESULTS

| Test results Freq [Hz] | Test predictions Freq [Hz] | Discrepancy % | Description | Q factor Measured | Sensor / axis |
|---|---|---|---|---|---|
| **523.8** | 490.9 | +6.7% | 1st X main mode | 100 | MPL2_X |
| **120.1** | 109.7 | +9.5% | 1st Y main mode | 140 | MPL2_Y |
| **1468.3** | 1240.0 | +18.4% | 1st Z main mode | 50 | MPL2_Z |




**Sine results show that the FEM used for the test predictions is not well correlated.**

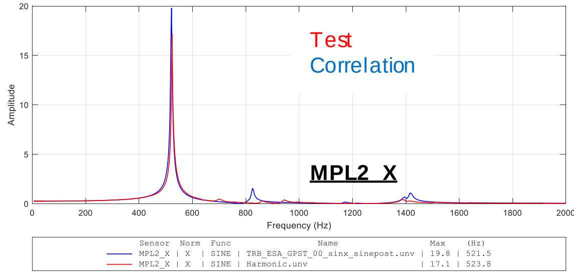

Date: 30/08/2023
Ref: 0005-0016627502
Template: 83230347-COM-TAS-EN-012

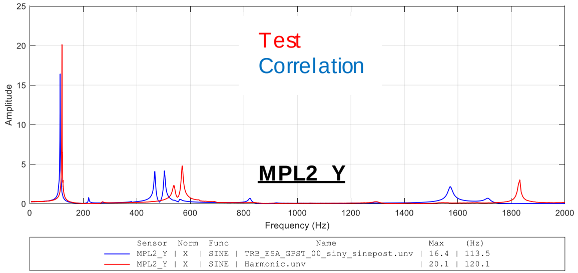
# 6 QUADS M&T MODULE BREADBOARD MECHANICAL TEST - SINE TEST

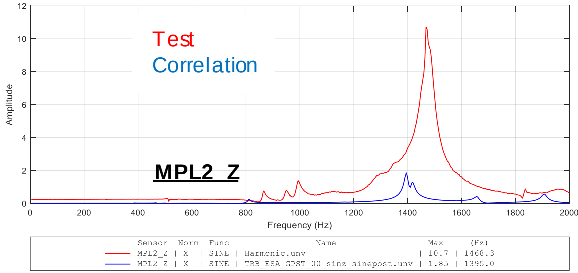
## SINE TEST RESULTS

- STIFFNESS RESULTS compared with the correlated model : the boundary conditions have been modified to be representative of the test conditions

| Test results Freq [Hz] | FEM correlation Freq [Hz] | Discrepancy % | Description | Q factor Measured | Sensor / axis |
|---|---|---|---|---|---|
| **523.8** | 521.5 | +0.4% | 1st X main mode | 100 | MPL2_X |
| **120.1** | 113.5 | +5.8% | 1st Y main mode | 140 | MPL2_Y |
| **1468.3** | 1395.8 | +5.2% | 1st Z main mode | 50 | MPL2_Z |




**The FEM is well correlated :**
**Measured mode are around 5% of the FEM**
**Predicted modes are always lower than the measured ones, predictions are conservative**

# 6 QUADS M&T MODULE BREADBOARD THERMAL TEST

- THERMAL TEST OBJECTIVE
  - The initial two main objectives deal with thermal performance:
    - The thermal gradient between all antenna FERM shall be less than 15°C
    - Demonstrate the capability to predict the thermal cartography
  - An additional objective (raised during the project) is to address the issue of particles release in the $NH_3$ flow

- TEST SPECIMEN
  - The same as for mechanical tests / Use of heaters to simulate the thermal dissipation of active antenna components


Date: 28/03/2024
Ref: Not referenced
Template: 83230347-COM-TAS-EN-012

# 6 QUADS M&T MODULE BREADBOARD THERMAL TEST

- TEST PLAN
  - It covers several realistic fluidic layouts: evaporators in series or in parallel
  - First parameter : The global mass flow rate which depends on the hydraulic architecture
  - Second parameter : The inlet subcooling
    - The higher the inlet subcooling is, the worst the temperature homogeneity within the antenna is.
    - Two different inlet subcoolings were tested : a high and a low value.
  - Last parameter : The power dissipation
    - Different power levels have been tested corresponding to power distribution patterns in nominal operational mode and overdrive mode.

→ Total number of test cases = number of flow rates x number of subcoolings x number of powers x number of studied modules

For more details, see slides of the confidential appendix document.



Date: 28/03/2024
Ref: Not referenced
Template: 83230347-COM-TAS-EN-012

# 6 QUADS M&T MODULE BREADBOARD THERMAL TEST

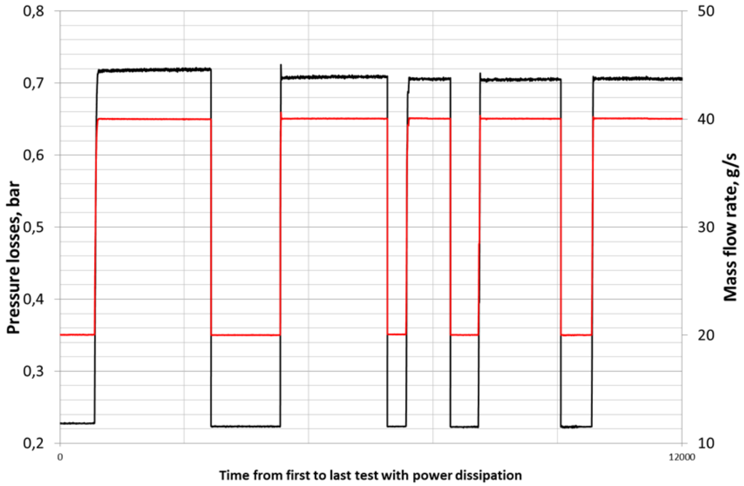
- TEST BENCH
  - The test specimen is installed on TAS test facilities, in Cannes
  - Aim to characterize the performances of different MPL components
  - Equipped with temperature sensors and flowmeters
  - Each dummy equipped with heaters and thermal grease.
  - Thermal sensors on dummies for the validation of the thermal model.

- For more details, see slides in the confidential appendix document


Date: 28/03/2024
Ref: Not referenced
Template: 83230347-COM-TAS-EN-012

# 6 QUADS M&T MODULE BREADBOARD THERMAL TEST

- PARTICLES RELEASE TEST
  - The objective is to use two filters to trap the particles in different flow conditions
  - The pressure drop variation gives an indication on particle release
  - With no power, the two-phase flow is characterized by an increasing pressure drop.
  - When power dissipation is transferred to tube inner surface with local boiling conditions, the pressure drop does not vary through the test.



# 6 QUADS M&T MODULE BREADBOARD THERMAL TEST

- THERMAL PERFORMANCE TESTS
  - Focus is made on thermal homogeneity of FERMS: maximum gradient within the dissipating FERMS shall be lower than 15°C
  - The worst case regarding thermal homogeneity is the combination of highest mass flow rate, highest subcooling and large dissipation
  - At the opposite, the smallest thermal gradient within the antenna is obtained with the lowest mass flow rate, the lowest subcooling and the lowest heat dissipation
  - The maximum measured temperature gradient in the worst case never exceeds the maximum specified value.

  - For more details, see slides of the confidential appendix document

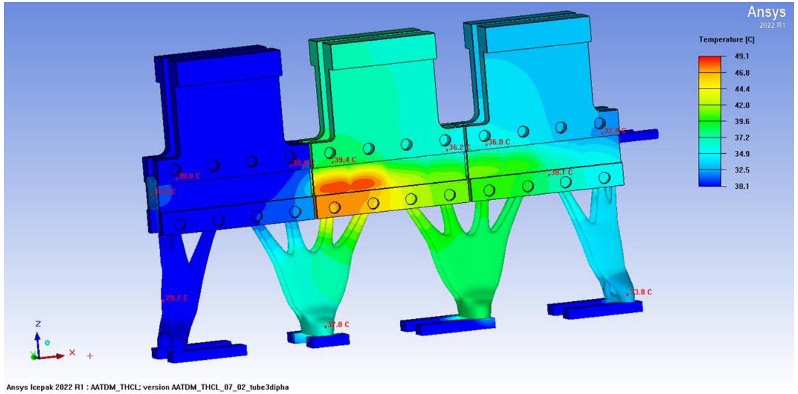
# 6 QUADS M&T MODULE BREADBOARD THERMAL TEST

- NUMERICAL SIMULATION
  - The objective is to demonstrate the capability to predict the temperature field of the active antenna under different flow conditions
  - Thermal model assumptions
    - Evaporators and dummies geometry based on CAD model
    - Thermal conductivities of AM Aluminium for breadboard and 167 W/m/K for dummies
    - The breadboard is mounted on Teflon cuboids submitted to convection with ambient air (10 $W/m^2/K$).
    - Specific heat transfer correlations used for single phase and two-phase flow : the intensity of heat transfer depends mainly on mass flow rate for single phase flow, and on vapor mass fraction and wall heat flux density for two-phase flow.


Date: 28/03/2024
Ref: Not referenced
Template: 83230347-COM-TAS-EN-012

# 6 QUADS M&T MODULE BREADBOARD THERMAL TEST

- NUMERICAL SIMULATION: RESULTS
  - Correlation is performed on 4 cases, covering a wide range of flow condition and power dissipation
  - Degrees of freedom of the model for correlation are non-flight parameters : thermal conductivity of the foam and natural convection heat transfer intensity.
  - The agreement between the numerical prediction and the measured temperatures is very good, within [0.5; 1°C] with local discrepancy lower than 2°C
  - Even if the location of fluid phase transition cannot be predicted with good accuracy, the impact on temperature field is moderate.



# 6 QUADS M&T MODULE BREADBOARD THERMAL TEST

- CONCLUSIONS
  - The lessons learnt from the 6 quads breadboard thermal test campaign are:
    - The largest gradient between antenna FERMS is less than 15°C for all cases
    - Smallest gradient is for lowest mass FR, lowest SC and lowest thermal dissipation → the design shall favor fluidic layout with as many branches as possible in parallel
    - The numerical simulation demonstrates the ability to predict the temperature field with a characteristic discrepancy of about 1°C
    - The local boiling seems to be a very efficient method for surface cleaning

# 12. DELIVERABLES ITEMS


**Date:** 30/08/2023
**Ref:** Not referenced
**Template:** 83230347-COM-TAS-EN-012

# DELIVERABLES ITEMS SUMMARY

| ESA Deliverable | Implied WP n° | WP title | Status |
|---|---|---|---|
| TN1 : Selection of the antenna and preliminary specification | 1101 | Active antenna selection | Delivered 2020 |
| TN2 = TN1 | 1102 | Active antenna specification | Chapter included in TN1 (+ TAS internal document) as agreed during PDR |
| TN3 : Parametric study | - | - | Chapter included in TN4 as agreed in nego meeting |
| MOD1 : CAD model of structure + drawing | 1103<br>1105 | Preliminary design<br>Breadboard detailed design & Justification | Delivered for PDR<br>Delivered for CDR |
| TN4 : Design justification document (TN4-1 Mechanical and TN4-2 / Design impacts and Thermal ) | 1201<br>1104<br>1105 | Co-eng / Manufacturing feasability<br>Impacts on antenna<br>Breadboard detailed design & Justification | TN4-1 and TN4-2 delivered for CDR |
| TN5 : Description of the final end-to-end AM materials and process verification route | 1202 | Definition of end to end manufacturing scenario | Covered by TN6, TN7 and TN9 |


Date: 28/03/2024
Ref:
Template: 83230347-COM-TAS-EN-012

# DELIVERABLES ITEMS SUMMARY

| ESA Deliverable | Implied WP n° | WP title | Status |
|---|---|---|---|
| TN6 : Material samples test plan + Test sheet | 1202<br>2101 | Definition of end to end manufacturing scenario<br>Samples test plan | Delivered 04/21 |
| MOD2 : CAD models of materials samples + drawings | 2101 | Samples test plan | Delivered for CDR |
| TN7 : Material samples manufacturing plan | 1202<br>2201 | Definition of end to end manufacturing scenario<br>Samples manufacturing and controls | Delivered 04/21 |
| TN8 : Samples Test report | 2102 | Samples tests and reports | Delivered for FR |
| HW1 : Materials samples and remainders | 2102 | Samples tests and reports | To be defined with ESA |
| TN9 : Breadboard manufacturing plan (FDP) + Breadboard test sheet (FE) | 1202<br>3201 | Definition of end to end manufacturing scenario<br>Breadboard Manufacturing & Controls | Delivered 09/21 and 02/22 |


Date: 28/03/2024
Ref:
Template: 83230347-COM-TAS-EN-012

# DELIVERABLES ITEMS SUMMARY

| ESA Deliverable | Implied WP n° | WP title | Status |
|---|---|---|---|
| TN10 : Breadboard test plan | 1106 | Breadboard test plan | Delivered for CDR |
| TN11 : Breadboard manufacturing and testing report (Manufacturing report + NC justification / Mechanical test report / Thermal test report) | 3201<br>3101<br>4101 | Breadboard Manufacturing & Controls<br>Breadboard Validation<br>Breadboard integration and Tests | Delivered for PTR-2 |
| TN12 : Breadboard evaluation | 4102 | Breadboard Test evaluation | Delivered for FR |
| HW2 : Manufactured Breadboard | 3201 | Breadboard Manufacturing & Controls | One delivered for FR |


Date: 30/08/2023
Ref:
Template: 83230347-COM-TAS-EN-012

# 13. CONCLUSIONS


Date: 30/08/2023
Ref: Not referenced
Template: 83230347-COM-TAS-EN-012

# CONCLUSIONS AND LESSONS LEARNT

/// Compliance matrix

| | Ref | Specification | | Status | |
|---|---|---|---|---|---|
| Design requirements | (1) | Compatible dimensions and architecture of the antenna | | C | |
| | (2) | AM feasibility and integration | | C | |
| | (3) | Embedded thermal control (connected to MPL) | | C | |
| | (4) | Alignment requirement | | C | |
| | (5) | Structure mass budget | < 35% | C | 33 % → Slight mass saving |
| | (6) | No Quad FERM design modifications | | C | |
| Mechanical requirements | (7) | First frequency | > 60 Hz | C | F1 > 100 Hz |
| | (8) | Positive safety margins for applied loads | | C | |
| Thermal / RF requirements | (9) | Power dissipation budget | | C | |
| | (10) | M&P temperature limits | | C | |
| | (11) | Maximum qualification temperature range | | C | |
| | (12) | Thermal gradient | < 15°C pp | C | |
| Cost / Planning requirements | (13) | Competitive cost | | PC | To be defined at the satellite level |
| | (14) | Shorter manufacturing and AIT lead time | | C | |


Date: 30/08/2023
Ref: Not referenced
Template: 83230347-COM-TAS-EN-012

# CONCLUSIONS AND LESSONS LEARNT

/// <u>Mechanical conclusions :</u>

- Well-sized structure with the best stiffness / mass ratio : High first frequency and comfortable positive safety margins for each quad module

→ Robust and secure solution of design for the whole antenna : only an acoustic analysis necessary

- Correlation between FEM calculations and results of sine test : reliability of mechanical simulations + smooth running of manufacturing

# CONCLUSIONS AND LESSONS LEARNT

## /// Thermal and RF conclusions:

- Fulfilling of all requirements : capability to manage huge power budget, high level of integration, extended temperature range, quasi-isothermal behavior

- Thermal gradient < 15°C whatever a well-adapted fluidic arrangement of the antenna + inlet sub-cooling of the fluid → high level of confidence in the case of a defined antenna

- Areas for improvement for further work in order to increase the TRL level :
  - Development, manufacturing and testing in a representative environment of a prototype of global DRA antenna with more representative Quad-FERM dummies and a well dedicated fluidic arrangement
  - Consolidation / development of a more efficient cleaning process


Date: 30/08/2023
Ref: Not referenced
Template: 83230347-COM-TAS-EN-012

# CONCLUSIONS AND LESSONS LEARNT

## /// Manufacturing and M&P conclusions :

- Feasible design in AM with smooth running of most of manufacturing steps

- 2 mains difficulties identified :
  - Global deformations despite preventive actions
  - Cleaning of the internal surface of the thermal control : the study has demonstrated the current process is not enough reliable for removing particles inside. The cleaning procedure shall be consolidated.

- Areas for improvement for further work :
  - For flight model development, an in-depth deformation study is required

  → Several solutions could emerge as pre-deformed geometry / improvement of supporting strategy…
  - Consolidation / development of a more efficient cleaning process
  - In-depth characterizations to demonstrate the material compatibility with ammonia


Date: 30/08/2023
Ref: Not referenced
Template: 83230347-COM-TAS-EN-012

# CONCLUSIONS AND LESSONS LEARNT

/// General conclusions :

- Positive conclusion : objectives of the study fulfilled

→ Feasibility of an advanced active antenna structure with embedded thermal control made by AM that meets the requirements and can be applied to any antenna : flexible and robust design with low complex and risky assembly / integration

→ Reliability of the numerical predictions : validation of a method for both design and model construction

→ Smart solution for future high capacity transmit phased array antennas using a satellite MPL system

- Manufacturing cost savings solutions conceivable (other material, improvement of the integrated concept, more efficient printing parameters set…)

- Level TRL5 reached but areas for improving the TRL are identified.

→ For more details, see slides of the confidential appendix document


Date: 30/08/2023
Ref: Not referenced
Template: 83230347-COM-TAS-EN-012

# LOG OF CHANGES AND APPROVAL

| Issue | Log of change - Description | Date |
| --- | --- | --- |
| 001 | Creation of the document | 25 August 2023 |
| 002 | Addition of slides in appendix | 7 September 2023 |
| 003 | Modification of the mention « OPEN » at the bottom of each slides / Slides with confidential content in an appendix document | 12 March 2024 |
| | | |

| Actors | Approval - Name and role | Date |
| --- | --- | --- |
| Written by | Marine NUVOLI | 25 August 2023 |
| Verified by | | |
| Approved by | | |