MLI Efficient Mounting

beyond gravity

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Executive Summary Report

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1. Introduction

1.1 Scope

This document summarises the evaluation, selection and qualification of new, efficient MLI mounting solutions. Moreover, the document includes a description of a full-scale conceptual demonstration mock-up, which was manufactured to demonstrate the integration feasibility of the novel attachment concepts.

1.2 Acronyms

AD .... Applicable Documents
BGA .... Beyond Gravity Austria GmbH
DMS .... Document Management System
N/A .... Not Applicable
RD .... Reference Document
TBC .... To Be Confirmed
TBD .... To Be Defined

2. Documents

2.1 Applicable Documents

AD1	ESA-TECMTT-SOW-024016, Issue 1.0	Statement of Work MLI Efficient Mounting

2.2 Reference Documents

RD1	-

3. Project Objectives and Requirements

3.1 Project Objectives

Passive thermal control of a satellite is typically performed using multilayer insulation (MLI) blankets.

The current state-of-the-art method for MLI fixation makes use of stand-offs, which are glued to the spacecraft structure, and clip-washers, which fix the blankets on these stand-offs.

This method is highly reliable and has a wide heritage, however it is time-consuming for several reasons:

- For a typical satellite more than 1000 stand-offs with variable geometries are involved.
- There is a considerable design effort, as the exact stand-off positions need to be included in the 3D CAD model and transferred to 2D template drawings.
- It is common that positioning clashes with adjacent hardware such as harness occur during installation, which requires lengthy clarification between AIT teams.
- Since the state-of-the-art stand-offs are rigid items, the stand-off holes can only be punched in the blankets after an on-site integration fit-check of the blankets is performed.

All these circumstances lead to a long throughput time of blanket installation.

The goal of the study is to overcome these drawbacks by developing alternative MLI mounting systems, which considerably reduce the time effort and overall cost for MLI integration.

Apart from the commercial aspects, the characteristic technical requirements were verified, such as electrical grounding, thermal performance, cleanliness, outgassing, removability, overlapping and interfaces, environmental conditions (thermal conditions, vibrations).

3.2 Key Requirements

Functional & performance Requirements

Thermal insulation efficiency (same or better as for state-of-the-art fixation method)

Electrical grounding (<10 Ω between MLI bonding point and structure, <100 Ω between MLI bonding point and aluminized MLI layer)

Mass (less than 10% increase)

Thermal Requirements

Temperature range for MLI (-130°C to +200°C)

Temperature range for attachment points on the S/C structure (-100°C to +70°C for different substrates)

Environmental Requirements

Vibrations random and sine (typical launcher vibration levels enveloping all common launchers)

General Requirements

Outgassing (RML < 1%, CVCM < 0.1%)

Cleanliness (particulate contamination < 300 ppm)

Design constraints: geometry envelops, overlapping, interfaces, removability (comparable to state-of-the-art fixation method)

Commercial Goals

Cost (20% reduction compared to state-of-the-art method)

MLI integration time (20% reduction compared to state-of-the-art method)

4. Evaluation and Selection of Efficient MLI Mounting Solutions

4.1 Evaluation and selection of efficient MLI mounting solutions

Several different MLI mounting systems have been evaluated:

- Flexible blanket fixation
  - Ty-wrap
  - Lacing cord
- Structural attachment techniques from other markets
  - bonded with adhesive
  - anchored into panel holes
  - screwed to predefined inserts
- Structural attachment by fixation cleats
  - Cleat bonded
  - Cleat screwed
- Anchor stand-offs
- Self-adhering MLI blankets using reclosable fasteners (Velcros)
- Standardized secondary structure elements
- Modular stand-off

Out of these possible mounting systems, four solutions were selected by conducting a trade-off using a set of defined criteria.

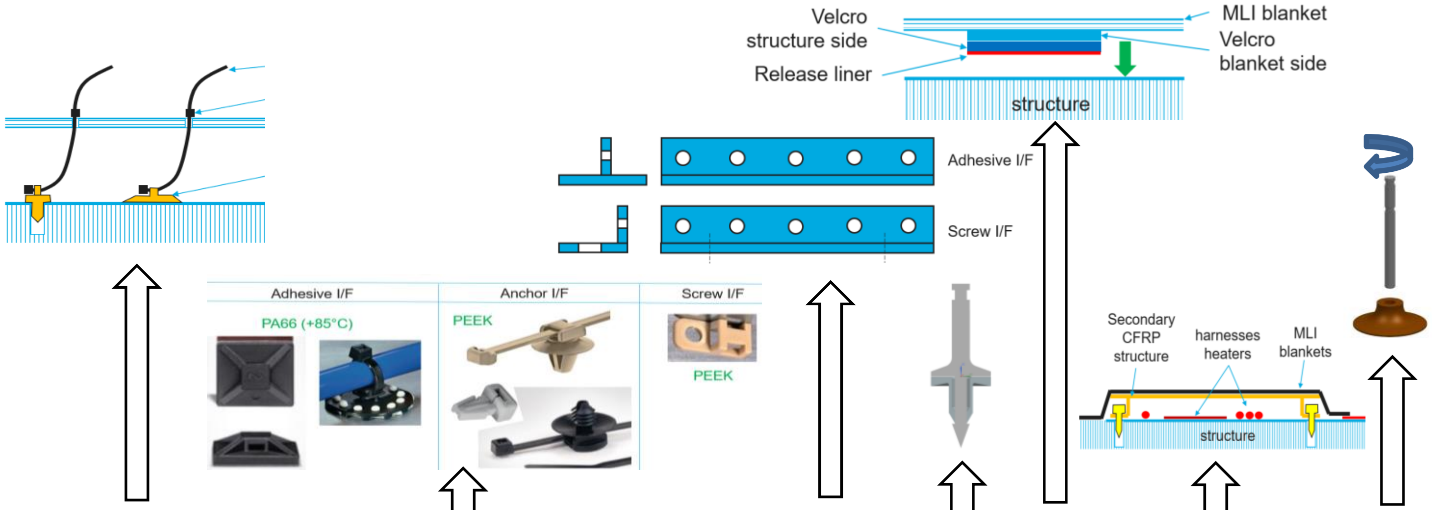
The below table shows the trade-off performed by BGA leading to the following selection with the highest ranking:

Local solutions:

1. Anchor S/O
2. Flexible Blanket Fixation (Ty-wrap/Lace)
3. Self-Adhering MLI Blankets (Velcro)

Global solution:

4. Secondary Structure Elements



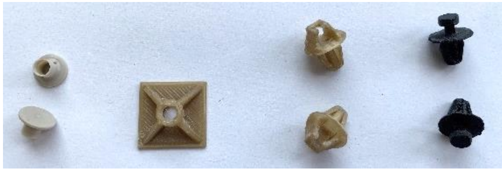
Criteria	Weighting	Flexible Blanket Fixation				Attachment to Structure fixation techniques from other markets						Attachment to Structure fixation cleat				Ancor S/O		Self-Adhering MLI Blankets		Secondary Structure Elements		Modular Standoff	
		para.3.1.1 Ty wrap		para.3.1.2 Fixation - Lace		para.3.2.1 Adhesive I/F		para.3.2.1 Anchor I/F		para.3.2.1 Screw I/F		para.3.2.2 Cleat bonded		para.3.2.2 Cleat screwed		para.3.2.3 Ancor I/F		para.3.3 Velcro Fixation		para.3.4 CFRP structure		para.3.5 Bonded and screwed I/F	
		rating	weighted	rating	weighted	rating	weighted	rating	weighted	rating	weighted	rating	weighted	rating	weighted	rating	weighted	rating	weighted	rating	weighted	rating	weighted
4.3.1 Technical																							
Adaptation for variable structure design	4	4	17	4	16	4	17	3	13	3	10	3	12	2	9	4	16	4	15	4	16	5	20
Area coverage	3	4	13	4	13	4	12	3	10	3	10	3	10	3	9	4	13	4	14	4	13	4	13
Compatibility with S/C I/F	4	4	17	4	17	4	16	3	10	2	8	3	12	2	8	4	15	4	15	4	15	5	19
Thermal perfofrmance	4	4	15	4	15	4	14	4	15	4	14	4	13	4	14	4	14	4	14	4	16	4	14
Mass	3	4	12	4	12	4	12	4	12	3	10	3	8	2	7	4	13	4	11	3	10	4	13
Cleanliness	3	4	13	3	10	4	12	4	12	4	13	4	13	4	13	4	12	2	6	5	14	4	12
average	3,7	4,1	14,2	3,9	13,6	4,0	13,8	3,5	11,9	3,2	10,8	3,3	11,3	2,9	9,9	4,0	13,8	3,6	12,4	4,0	13,9	4,3	15,2
4.3.2 Development costs / risks																							
Complexity	4	4	14	4	15	4	15	4	14	3	12	3	12	3	12	4	15	5	17	4	15	4	15
Reliability	4	4	17	4	15	4	16	4	15	5	19	4	15	4	16	4	16	3	12	4	17	5	20
Development costs	3	4	11	3	9	4	11	4	11	4	12	3	8	3	8	5	14	4	10	3	8	3	8
Qualification need	3	4	9	3	7	2	5	3	8	4	11	3	9	3	8	5	13	4	9	2	5	4	10
average	3,3	3,9	12,7	3,4	11,4	3,5	11,9	3,6	11,8	4,2	13,7	3,4	11,0	3,3	11,1	4,5	14,4	3,7	12,0	3,3	11,2	4,0	13,4
4.3.3 Commercial potential																							
Installation effort	5	4	19	4	19	3	15	5	22	3	16	3	15	4	17	4	19	4	21	5	24	3	15
Recurring costs	4	4	18	4	16	4	15	4	16	3	11	4	14	3	11	4	16	4	17	3	12	3	12
average	4,4	4,2	18,5	4,0	17,7	3,5	15,3	4,3	18,9	3,1	13,7	3,4	14,9	3,2	14,1	4,0	17,7	4,3	18,9	4,0	18,1	3,0	13,3
Sum			45,3		42,6		41,0		42,5		38,1		37,2		35,1		45,9		43,3		43,2		41,8
Rank Total			**2**		**5**		**8**		**6**		**9**		**10**		**11**		**1**		**3**		**4**		**7**

4.2 Layout of local mounting techniques

The following local mounting technique has been derived from the solutions mentioned above. It comprises a flexible, modular stand-off concept consisting of:

- Different shafts:
  - ➢ Ball rod (Aluminium, PEEK, Vespel, Vespel alternative)
  - ➢ Commercial ball ty-wrap (Polyethylene)

- Different bases:
  - ➢ Base type RD (PEEK, PET) – for ball rod
  - ➢ Base type SQ (PEEK) – for ball rod
  - ➢ Clip-in type F (PEEK, PET) – for ball rod
  - ➢ Clip-in type M (PET) – for commercial ball ty-wrap



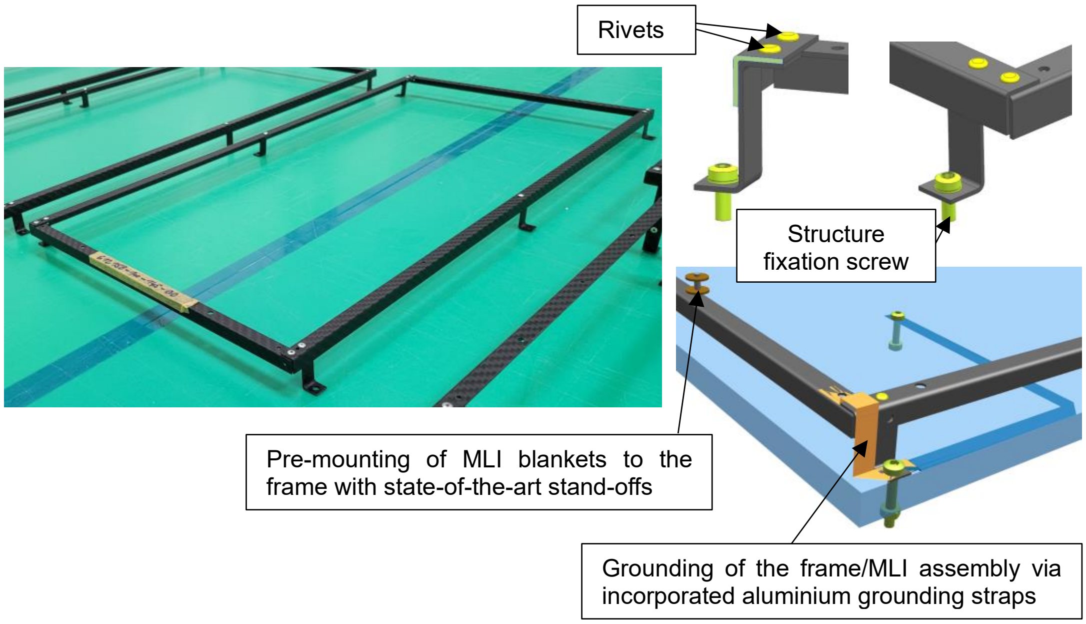
- Different washers:
  - ➢ Clip hat (Vespel, Vespel alternative) – for ball rod
  - ➢ Cover cap clip (PEEK, PET) – for ball rod
  - ➢ Cover cap washer (PEEK) – for commercial ball ty-wrap
  - ➢ Cover cap (Vespel, Vespel alternative) – for cover cap clip and cover cap washer
  - ➢ State-of-the-art clip washers – for ball rod

- Novel type of self-adhering, reclosable fastener

4.3 Layout of global mounting technique

The global mounting technique consists of a

- Standardized, lightweight secondary structure frame
  - with pre-mounted and pre-grounded MLI blanket



5. Qualification of Efficient MLI Mounting Solutions

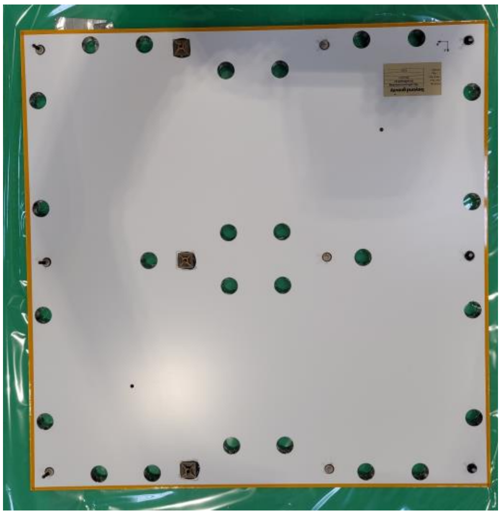
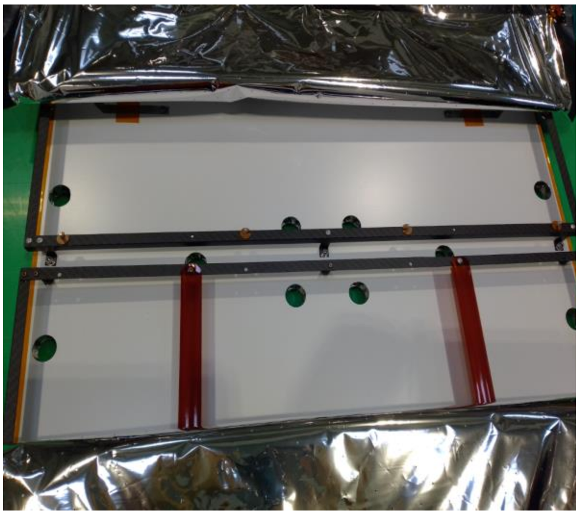
The qualification campaign comprised the following tests:

- Breadboard test
- Attachment test
- 3D thermal performance test
- Outgassing test

5.1 Test samples

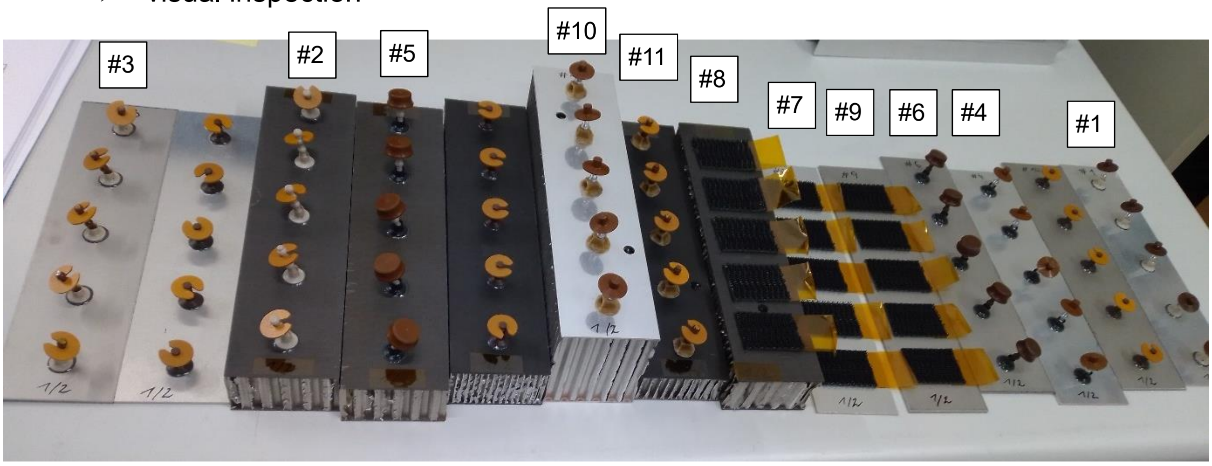
The following breadboards were manufactured:

- 4 breadboards including the new local and global mounting techniques
- 1 reference breadboard including state-of-the-art stand-offs
- Dimension for each breadboard 600 x 600 mm
- The following tests were performed:
  - ➢ thermal cycling, mechanical vibration
  - ➢ visual inspection
  - ➢ electrical resistance measurements
  - ➢ mass measurements
  - ➢ particulate contamination test

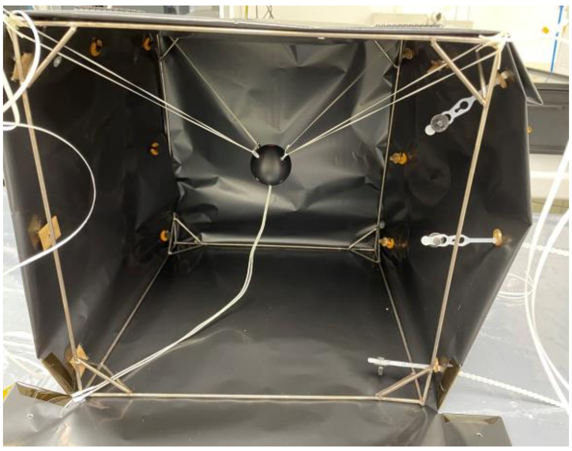
The following attachment test samples were manufactured:

- 11 different material combinations on 3 different substrate materials were tested (base parts made of PEEK and PET respectively reclosable fasteners were attached to aluminium, CFRP and titanium substrates)
- Both bonded attachments and clipped-in attachments were tested
- Dimension for each sample 200 x 50 mm
- The following tests were performed:
  - ➢ thermal cycling, mechanical pull-off test
  - ➢ visual inspection



The following 3D cube test sample was manufactured:

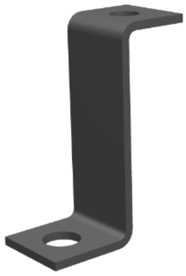
- Dimension of sample 300 x 300 x 300 mm
- Five different, novel attachment elements were incorporated
- The following test was performed:
  - ➢ thermal performance test



The following outgassing test samples were used:

- Four novel materials were tested: PET, PEEK, Vespel alternative, CFRP profile

- The following test was performed:
  - Standard outgassing test at 125°C



5.2 Breadboard test

The breadboard thermal cycling test has been performed as follows:

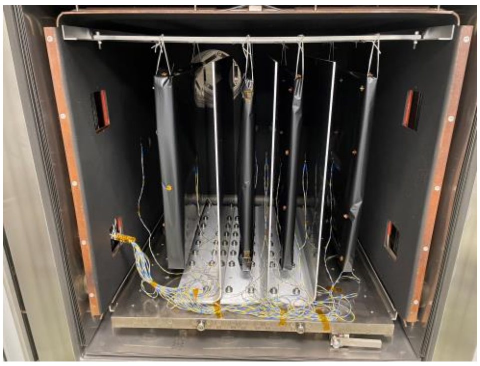
- For the pilot thermocouples a thermal cycling range of -130°C to +200°C was specified on the outermost black Kapton layers

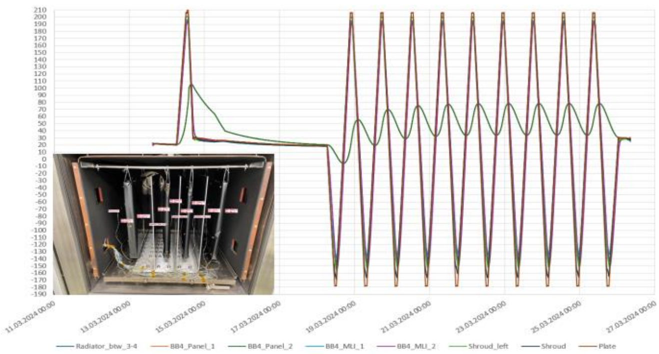
- The actually measured temperatures on the outermost black Kapton layers were down to ≈ [-140°C ÷ -150°C] and up to ≈ +196°C

- On the breadboard panels underneath the MLI blankets temperatures between ≈ [+35°C ÷ +45°C] and ≈ [+80°C ÷ +85°C] for BB1, BB2 and BB4 respectively up to ≈ +110°C for BB3 were measured

- Pressure < 1 x 10^{-5} mbar

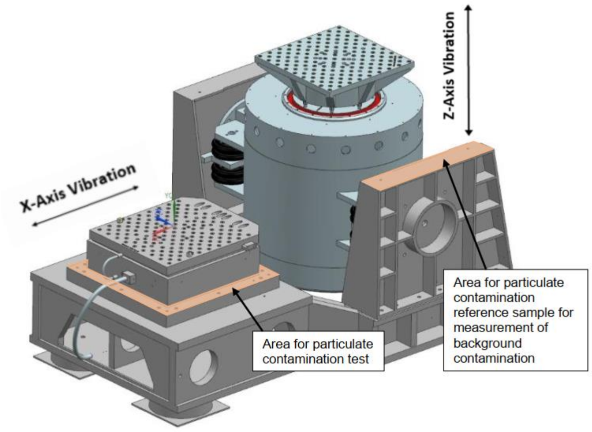
- 10 cycles

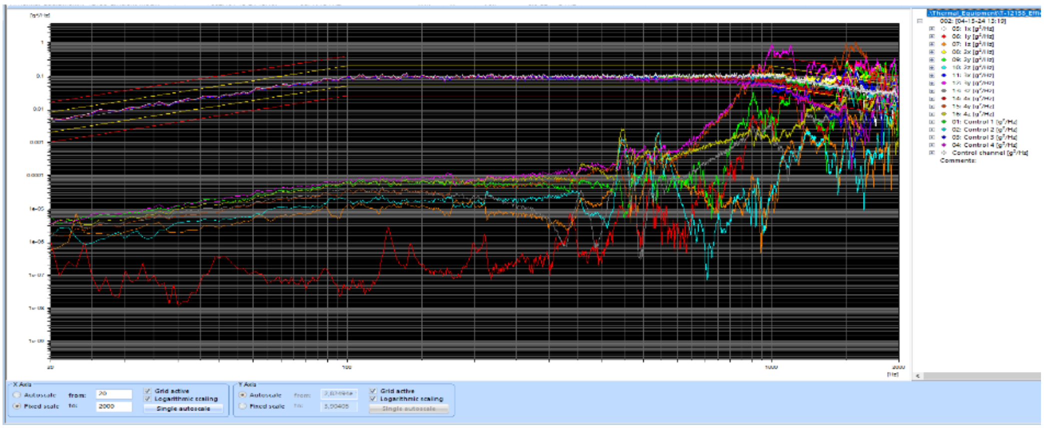


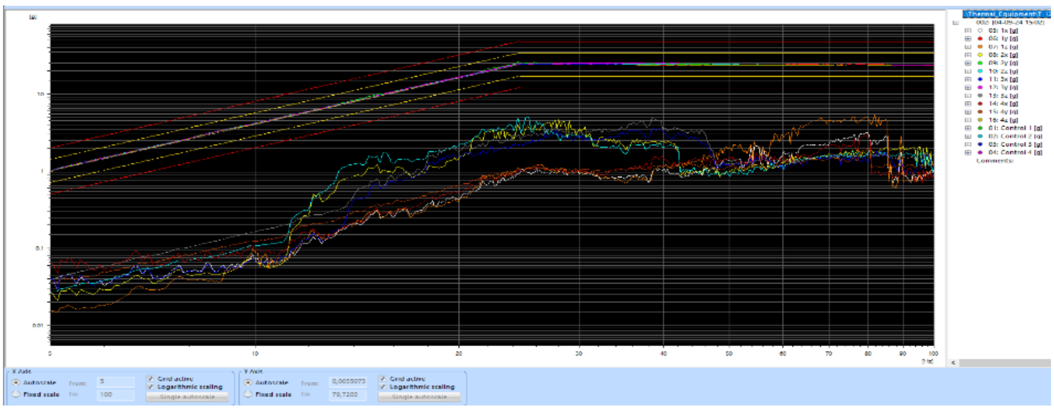


The breadboard mechanical vibration test has been performed as follows:

- Typical launcher vibration levels were used enveloping all common launchers
- Random and sine mechanical environments were applied
- In plane and out of plane directions were tested





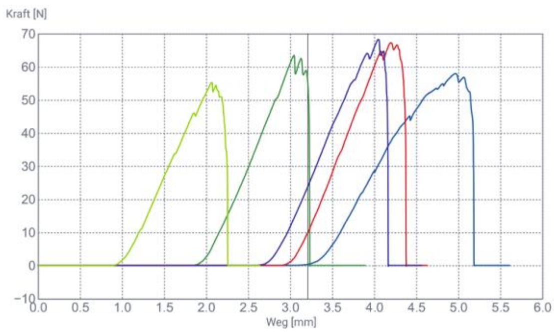


5.3 Attachment test

The attachment test was performed as follows:

- Attachment thermal cycling test
  - Thermal cycling -100°C to +70°C
  - Pressure < 1 x 10^{-5} mbar
  - 100 cycles

- Mechanical pull-off test
  - The mechanical pull-off test was performed at room temperature
  - The cycled and uncycled reference samples were tested and the results were compared



5.4 3D thermal performance test

The 3D cube test has been performed as follows:

- 7 test cases
- Pressure < 1.3 x 10-5 mbar

Test Case	Avg. Temp. Outermost Layer [°C]	Avg. Temp. Innermost Layer [°C]	Avg. Specimen Temp. [°C]
1	-141	-79	-108
2	-141	-37	-84
3	-139	48	-34
4	-81	56	-7
5	0	73	38
6	39	84	62
7	39	112	77

5.5 Outgassing test

The outgassing test has been performed as follows:

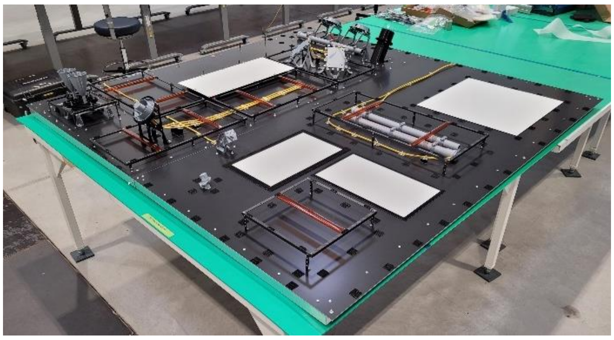
- Acc. ECSS-Q-ST-70-02C
- At nominal temperature of 125°C

6. Conceptual Demonstration Mock-Up (CDM)

The conceptual demonstration mock-up (CDM) was manufactured to demonstrate the integration feasibility of the novel attachment concepts. The CDM without and with MLI blankets is shown in the figures below.

The layout of the CDM was as follows:

- 2m x 2m mock-up representing a full-scale satellite panel, made of aluminium sandwich panel (Alucobond)
- Including typical items:
  - 3D printed polyester brackets from FLEX THW and JUICE SSTS
  - Harness made of commercially available harness
  - Radiators made of simple aluminium plates
  - Pipes made of simple plastic tubes
- 20 pcs. of MLI blankets to cover the structure as on a spacecraft, made of polyester layup with 10 layers
- Attachments consisting of:
  - State-of-the-art stand-offs
  - Different types of new, local attachment elements (bases, ball rods, clips), implemented as bonded and floating stand-offs
  - New type of self-adhering, reclosable fastener
  - Secondary structure CFRP frames



7. Conclusion

Within this project BGA has successfully developed new, efficient MLI mounting systems to TRL 6.

A summary of the results of the thermal and mechanical tests for the single attachment elements is shown in the table below. All new items passed the tests, except for some small parts made of PET, the commercial ball ty-wrap and the self-adhering reclosable fastener.

The 3D thermal performance test was conducted successfully, however the specified thermal performance was not fully reached. While at lower temperatures a similar performance compared to the requirement was reached, at higher temperatures an up to 25% worse performance was observed. As different attachment methods were used in the test sample, it is impossible to differentiate if one or more mounting solutions are the main contributors to the reduced thermal performance. No conclusive correlation was possible from the raw data. Therefore, in case the achieved performance is not sufficient for specific use cases, a follow up calorimeter test is needed for the subset selected for flight hardware.

The outgassing test showed that all tested materials fulfilled the specified values, except for the tested Vespel alternative, which slightly exceeded the specified RML value of <1%. This is however not in agreement with the test data from the material supplier, which show an RML value below 1%.

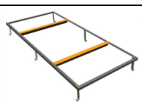
With the conceptual demonstration mock-up the integration feasibility of the novel attachment concepts could be successfully verified.

The targeted improvement concerning time effort and overall cost for MLI integration was to enable both:

- 20% reduction on the MLI cost:
  - ➢ Reached for local concepts using cheap materials (aluminium, reclosable fastener)
  - ➢ Not reached for local concepts using expensive materials (Polyimide) and global concept. These concepts lead to a cost increase.
- 20% reduction on the MLI integration time:
  - ➢ Not reached for local concepts, even though the time reduction is in the order of 16%.
  - ➢ Not reached for global concept used on complex, scientific programs (time reduction in the order of 9%)
  - ➢ Reached for global concept used on constellation programs (time reduction in the order of 50% due to use of a high number of standardized frames)

Overall, for all local concepts a reduction of the total cost (LC and NLC) can be achieved.

Overall, for the global concept a small reduction of the total cost (LC and NLC) can only be achieved for constellation programs.

Picture	Name	Material	Note	Conclusion
	Ballrod	Peek, Vespel, Vespel alternative		Passed
	Ballrod	Aluminium		Passed
	Clip-in Anchor S/O type F	Peek (used together with ballrod)		Passed
		PET (used together with ballrod)	Deformed during thermal test	Failed
	Clip-in Anchor S/O type M + Commercial ty-wrap	PET (used together with ty-wrap)	S/Os partly melted and deformed during thermal tests. All commercial ty-wraps melted above MLI level and head-covers fell off.	Failed
	Square base type SQ	Peek		Passed
	Round base part type RD	Peek, PET		Passed
	Round base part type double	PET		Passed
	Reclosable fastener (Velcro)	PE	Melted during thermal tests at overlap area. Some mushroom heads fell of during tests leading to uncontrolled contamination.	Failed
	CFRP secondary structure elements	CFRP		Passed
	Clip hat	Vespel, Vespel alternative		Passed
	Cover cap	Vespel, Vespel alternative		Passed
	Cover cap clip	Peek		Passed
		PET	PET clips degraded during thermal cycling and mechanical vibration test. (during the vibration test the cover caps fell off the PET clips)	Failed
	Cover cap washer	Peek (used together with commercial ty-wrap)	Washer is used in combination with commercial ball ty-wrap. As the ty-wrap failed, this washer has no use.	Passed
	State-of-the-art clip washer	Vespel		Passed