Appendix L

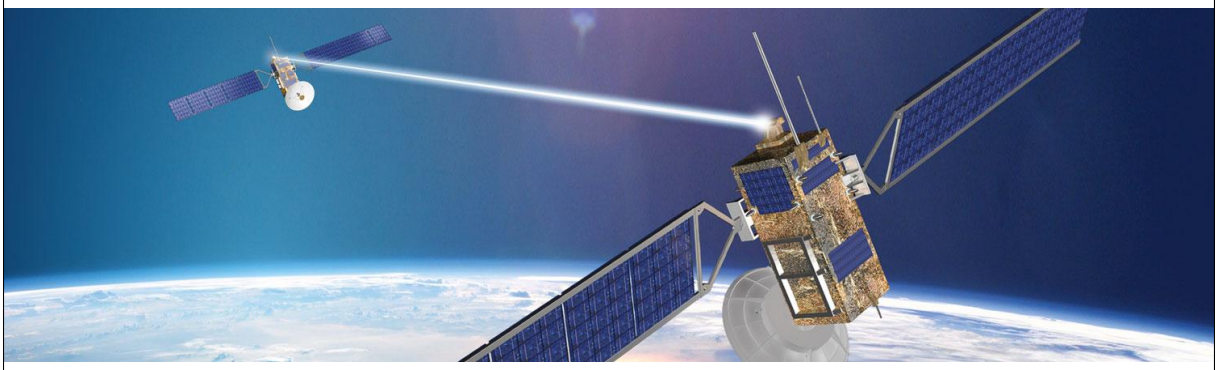
A MLI model based on transient model correlation

Jan Klement Lena Bötsch Jonas Klose Christian Walker
(Tesat-Spacecom GmbH, Germany)

Abstract

Measuring and predicting the thermal heat flux trough a MLI is a challenging task. A modelling approach is presented based on sectioning the MLI into different areas (Flat surface, corners and edges with and without seam). The parameters for this model are obtained using an inverse problem approach. Transient testing and model correlation is used instead of the typical steady state approach.

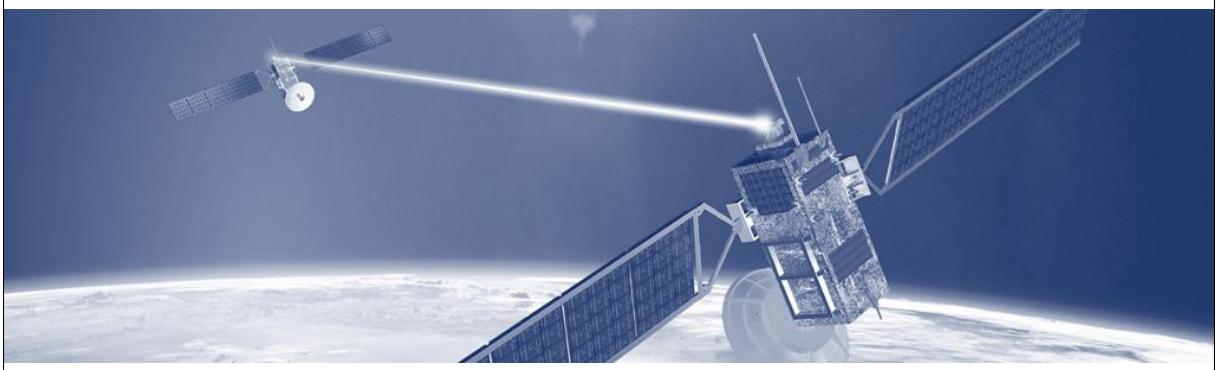
TESAT SPACECOM
PIONEERING WITH PASSION



A MLI MODEL BASED ON TRANSIENT CORRELATION

Jan Klement, Lena Bötsch,
Jonas Klose, Christian Walker

TESAT SPACECOM
PIONEERING WITH PASSION



INTRODUCTION: THE CURRENT STATUS OF MLI MODELS

26.10.2017 2

TESAT SPACECOM
PIONEERING WITH PASSION

THE THEORETICAL EFFECTIVE EMISSIVITY OF AN IDEAL MLI

A theoretical ideal MLI has the thermal heat flux described by an effective emissivity between the inner an the outer layers

$$\varepsilon_{theory} = \frac{1}{\frac{2}{\varepsilon_{Al}} - 1} * \frac{1}{N+1}$$

26.10.2017 3

TESAT SPACECOM
PIONEERING WITH PASSION

THEORETICAL EFFECTIVE EMISSIVITY OF MLI

In reality this value is never reached.
There is also a huge scatter

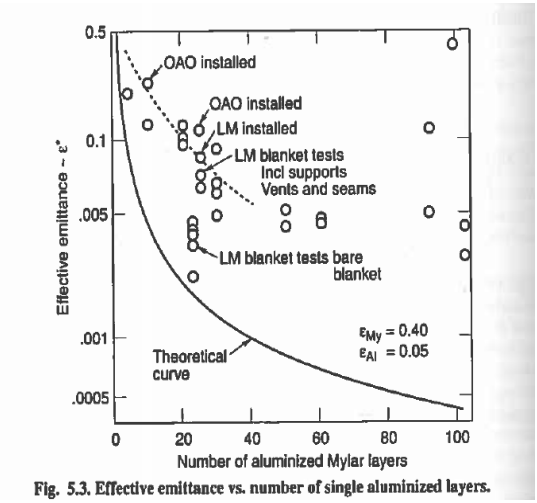


Fig. 5.3. Effective emittance vs. number of single aluminized layers.

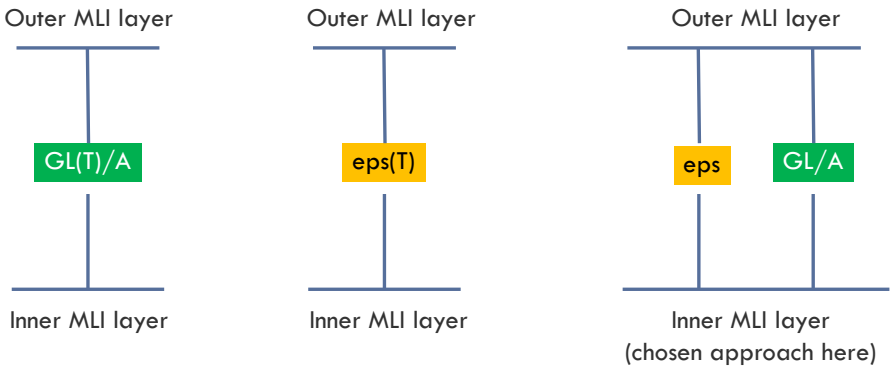
Source: David G. Gilmore, „Spacecraft Thermal Control Handbook Volume I 2nd ed“, The Aerospace Press, 2002

26.10.2017 4

TESAT SPACECOM
PIONEERING WITH PASSION

TYPICAL THERMAL MLI MODEL DEFINITIONS

Temperature dependant linear conductivity	Temperature dependant Emissivity	Constant linear conductivity and emissivity in parallel



26.10.2017 5

TESAT SPACECOM
PIONEERING WITH PASSION

TYPICAL MLI HEAT FLUX MEASUREMENT

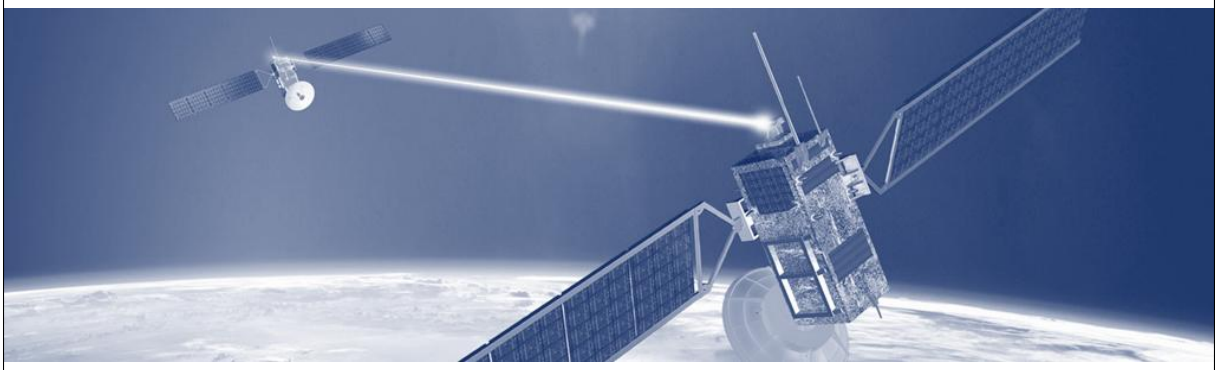
The heat flux through an MLI is quite small. Therefore to measure these heat fluxes following is normally needed:

» a very precise calorimeter for a large range of temperatures

» a very stable steady state for each temperature level

26.10.2017 6

TESAT SPACECOM
PIONEERING WITH PASSION



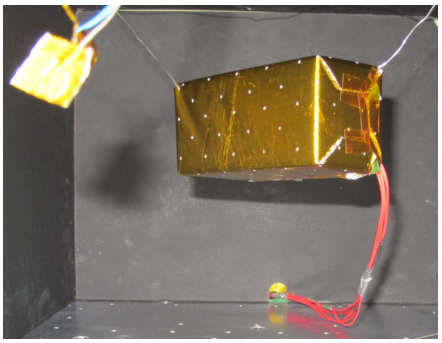
THE NEW MODEL APPROACH

26.10.2017 7

TESAT SPACECOM
PIONEERING WITH PASSION

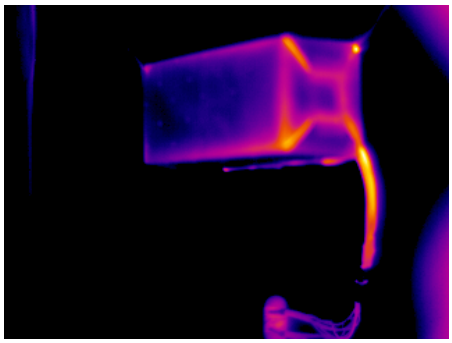
VISUALIZING THE HEATLOSS

Test body packed in MLI inside TV chamber



(This MLI design is not representative)

IR picture



- Body inside the MLI is heated
- shroud is cold

yellow = warm; black = cold

Conclusion: corners, edges and wires have a significant contribution to the heat loss
Heat loss trough the wires have to be minimized

26.10.2017 8

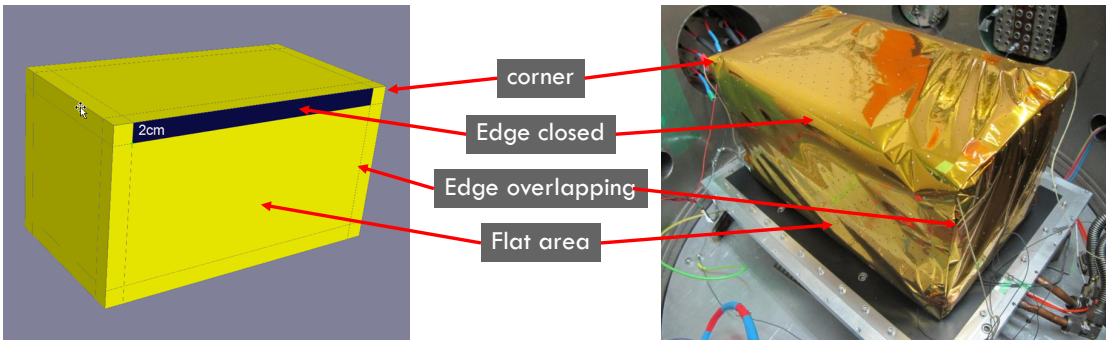
TESAT SPACECOM
PIONEERING WITH PASSION

THE MODEL

The is MLI divided into 4 areas
The edge area is defined as 2cm wide

Thermica GMM

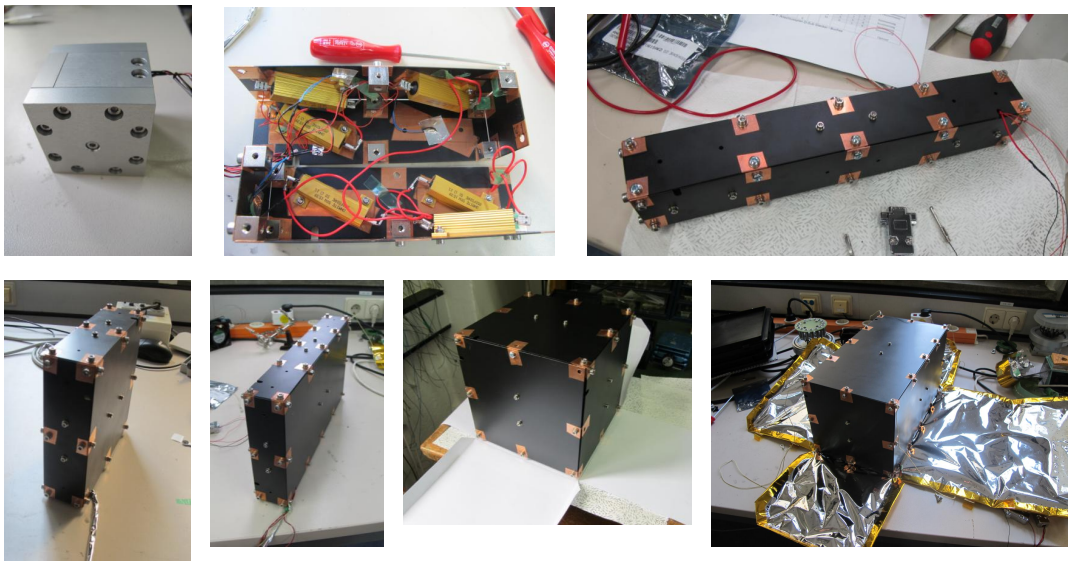
hardware



26.10.2017 9

TESAT SPACECOM
PIONEERING WITH PASSION

The 7 test bodies with very different dimensions are used. One is tested with different 2 MLI configurations (7 and 12 overlapping edges). 8 tests in total

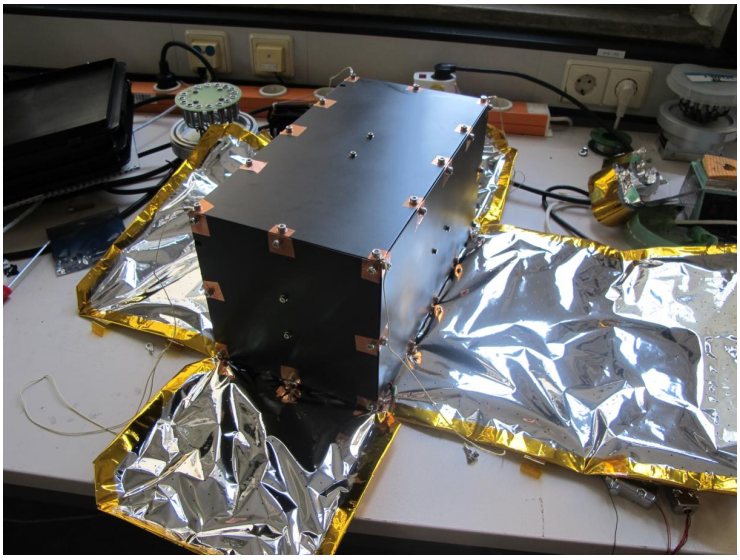


26.10.2017 10

TESAT SPACECOM
PIONEERING WITH PASSION

THE APPROACH

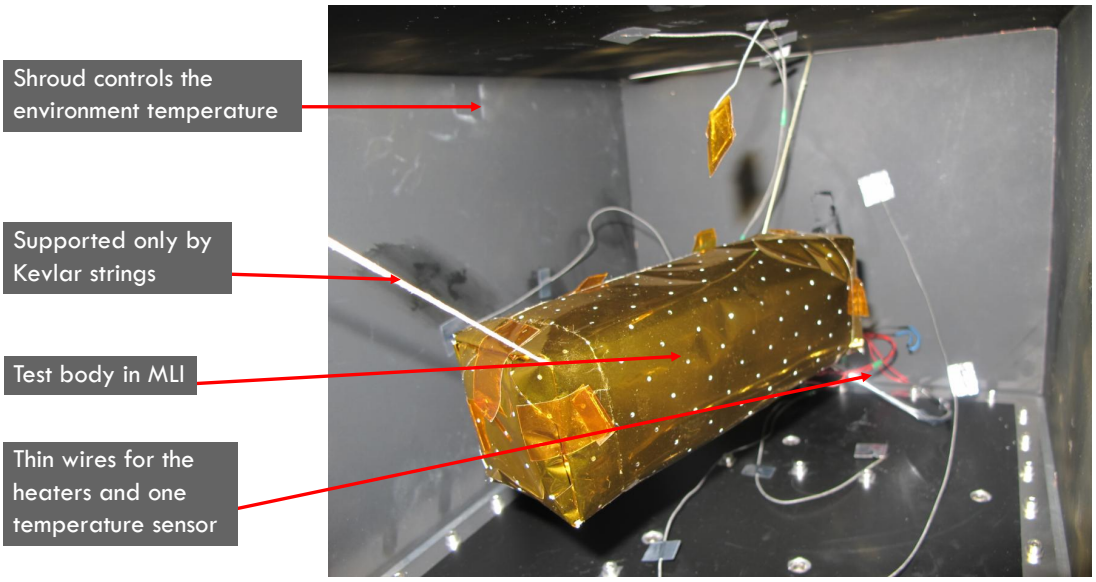
- 7 bodies made out of copper are packed in
  - 15 (Mylar VDA on both sides)
  - 2 (Kapton) layer MLI



26.10.2017 11

TESAT SPACECOM
PIONEERING WITH PASSION

TEST BODY IS PLACED IN THERMO VACUUM CHAMBER

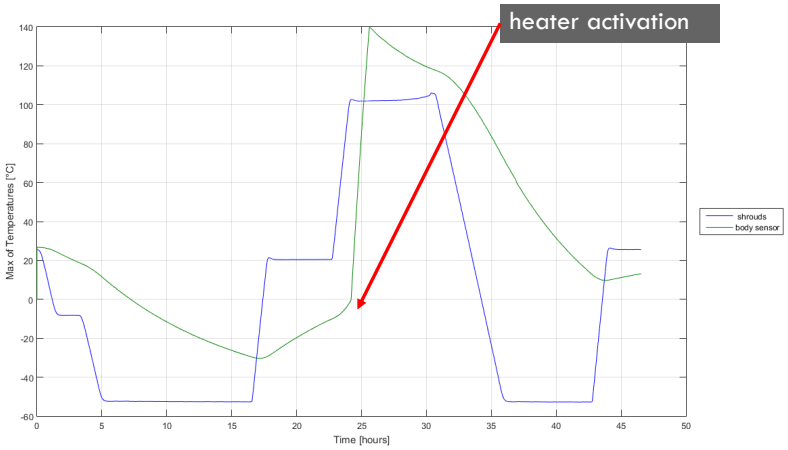


26.10.2017 12

TESAT SPACECOM
PIONEERING WITH PASSION

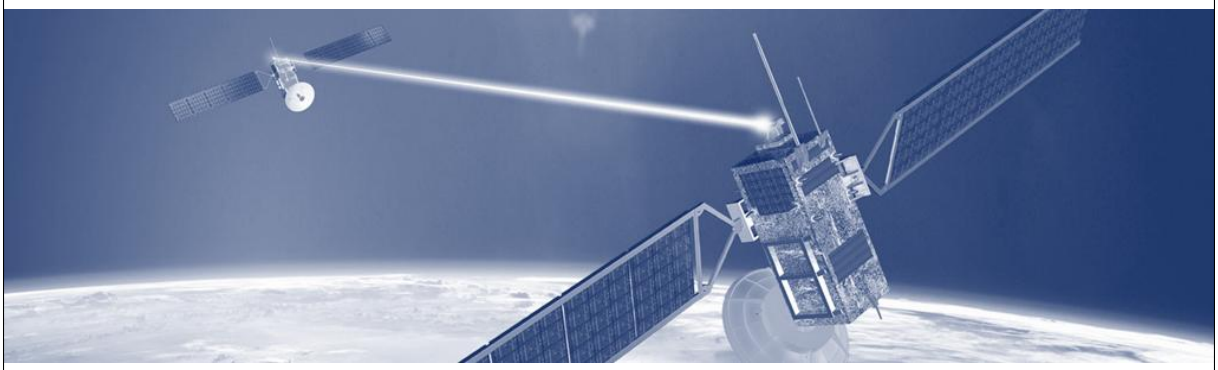
TEST PROCEDURE

All bodies where tested with a similar procedure in a thermo vacuum chamber.
Different body and environment temperatures where used.



26.10.2017 13

TESAT SPACECOM
PIONEERING WITH PASSION



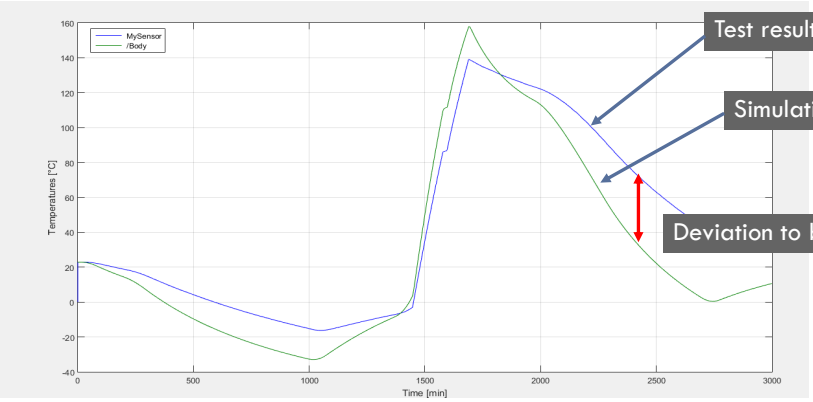
MODELLING AND CORRELATION

26.10.2017 14

TESAT SPACECOM
PIONEERING WITH PASSION

Comparison to simulation (before correlation)

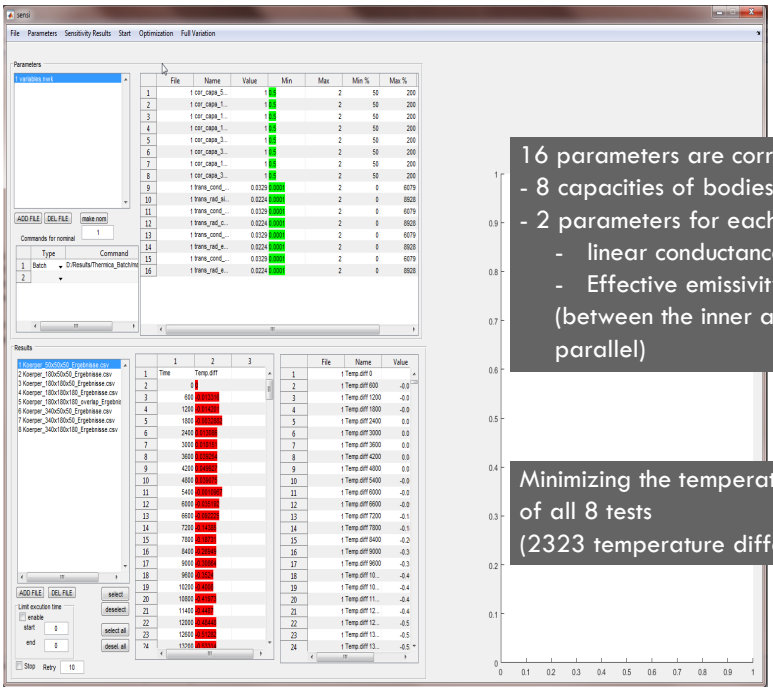
All tests where simulated in Thermica using typical values.
The shroud temperature from the has been mapped onto the shroud nodes.



26.10.2017 15

TESAT SPACECOM
PIONEERING WITH PASSION

Correlation Software (developed at TESAT)



16 parameters are correlated
- 8 capacities of bodies
- 2 parameters for each MLI area
  - linear conductance W/Km²
  - Effective emissivity

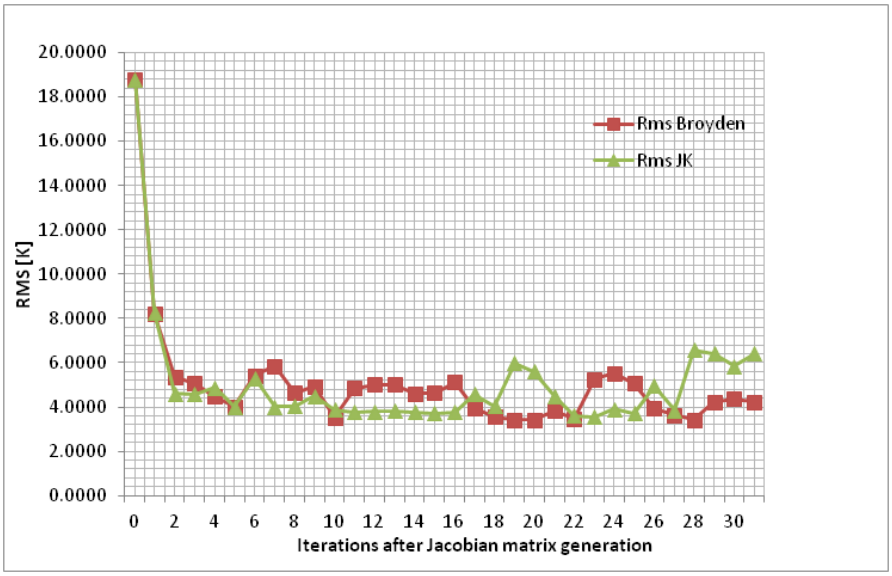
(between the inner and outer MLI layer in parallel)

Minimizing the temperature differences of all 8 tests
(2323 temperature differences in total)

26.10.2017 16

TESAT SPACECOM
PIONEERING WITH PASSION

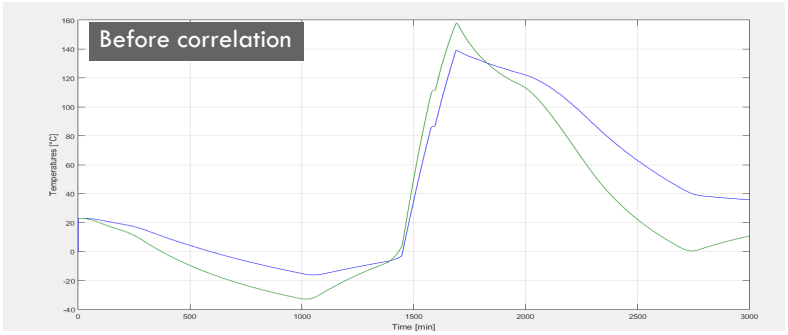
A BROYDEN CLASS ALGORITHM MINIMIZES THE RMS OVER ALL TEMPERATURE DIFFERENCES



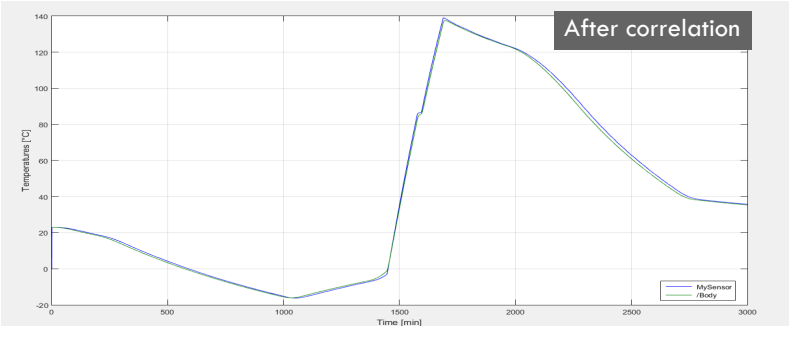
After only 3 iterations a optimum is nearly reached. (16 iterations needed for the Jacobian)
It is not expected that it is possible to minimize the RMS to 0K because the problem is highly over constrained

TESAT SPACECOM
PIONEERING WITH PASSION

CORRELATION RESULTS



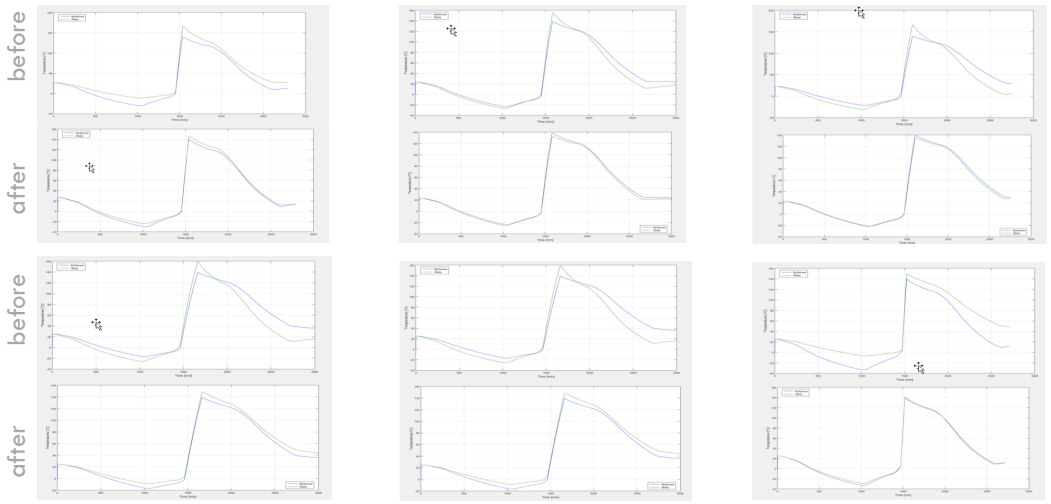
Green: Simulation
Blue: Test



26.10.2017 18

TESAT SPACECOM
PIONEERING WITH PASSION

ALSO THE OTHER SIMULATION GOOD FIT BETWEEN TEST RESULTS AND SIMULATION



19

TESAT SPACECOM
PIONEERING WITH PASSION

RESULTING MLI PARAMETERS FROM THE CORRELATION

Parameter	Effective conductivity*	Effective emissivity*
Flat area	0.004445 W/m²K	0.003365
Corners	1.013198 W/m²K	0.000179
Closed Edges (only bent)	0.000101 W/m²K	0.014994
Edges with overlapping MLI	0.264138 W/m²K	0.007348

*) The conductivity and the and the emissivity must be used in parallel between the inner and outer layer.

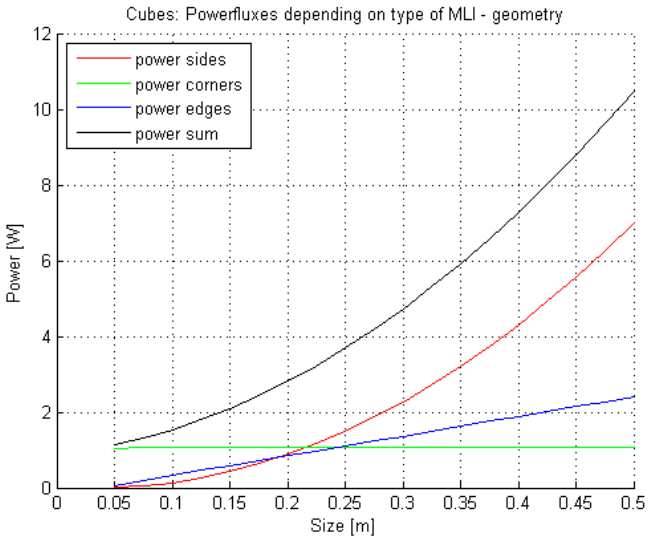
These are effective nominal parameters. They fit to the results but their temperature dependency may not be accurate. The corresponding assessment of their accuracy is to discussed tomorrow.

26.10.2017 20

TESAT SPACECOM
PIONEERING WITH PASSION

HEATLOSS OF A CUBE PACKET IN MLI

cube temperature: 100°C
Environment temperature: -40°C



26.10.2017 21

TESAT SPACECOM
PIONEERING WITH PASSION

CONCLUSION

- The advantages of transient testing are:
  - No complicated and precise calorimeter is necessary
  - Temperatures changes are used which can be measured quite accurate
  - It is not necessary to wait until steady state is reached
  - Each test gives a information for whole range of temperatures instead of one single point
  - Only one temperature sensor is necessary inside the body

  In other words: More data with an easier, faster and cheaper test.

- Correlation
  - Broyden class algorithms needed only a few(<20) iterations to reach an optimum (transient model, 16 parameters, 8 configurations & tests, 2323 temperatures differences)

26.10.2017 22

TESAT SPACECOM
PIONEERING WITH PASSION

Outlook

- The method can be used to extend the MLI model for:
  - Different corner angles
  - Stand-offs
  - Flaps
  - Slits
  - Different layer setup
  - Larger bodies
- With more extreme temperatures the temperature dependency can be analyzed with higher accuracy.
- The correlation software(Sensitool) can be obtained by other companies of the Airbus Group

26.10.2017 23

TESAT SPACECOM
PIONEERING WITH PASSION

Thank you

Gefördert durch:

Bundesministerium
für Wirtschaft
und Energie

aufgrund eines Beschlusses
des Deutschen Bundestages

26.10.2017 24

TESAT SPACECOM
PIONEERING WITH PASSION

REFERENCES

- Alifanov, O.M. , „5th Paolo Santini memorial lecture: Inverse methods in identification and modeling of thermal process in aerospace materials and structures: Theory and practice"
- David G. Gilmore, „Spacecraft Thermal Control Handbook Volume I 2nd ed", The Aerospace Press, 2002
- Klement, J, 2014, "On Using Quasi-Newton Algorithms of the Broyden Class for Model-to-Test Correlation", Journal of Aerospace Technology and Management, Vol.6, No 4, pp.407-414, doi: 10.5028/jatm.v6i4.373
- Klement, J, 2014, "On Using Quasi-Newton Algorithms of the Broyden Class for Model-to-Test Correlation", Proceedings of the 28th European Space Thermal Analysis Workshop, Appendix Q pp. 314-228
- Klement, J, 2014, "Satelliten heiß-kalt Thermische Modelle an die realen Testergebnisse angleichen", Elektronik Industrie, 2014/11, pp 134-139, http://www.all-electronics.de/texte/anzeigen/56104/Modelle-von-Satelliten-Komponenten-an-reale-Testergebnisse-angleichen
- Klement, J, Anglada, E, Garmendia, I, 2016,"Advances in automatic thermal model to test correlation in space industry", 46th International Conference on Environmental Systems - ICES-2016-54

26.10.2017 25