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# Assessment and Comparison of Conditions in Vacuum with Experiments in Open Air of Thermal Infrared Cameras for Use in Debris Removal

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1. INTRODUCTION AND OVERVIEW
2. TEST SETUP AND EXECUTION
3. SIMULATIONS AND IMAGE RENDERING
4. RESULTS
5. CONCLUSIONS AND OUTLOOK



**ADMATIS LTD.** is a Hungarian SME founded in 2000, is fully dedicated to space engineering with significant background of material science.

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#### Competencies:

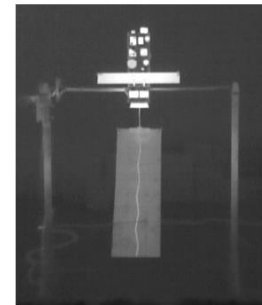
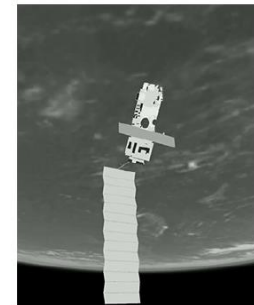
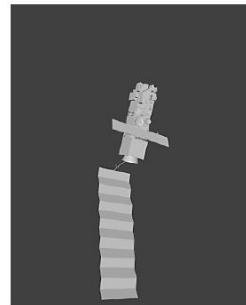
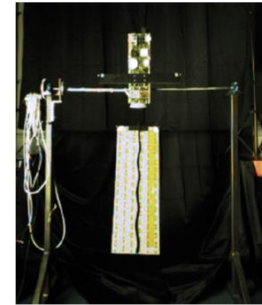
- Structural and thermal engineering [CAD Design / Analysis]
- Manufacturing / assembly [CAD/CAM, 5 axis milling, conversion coating and thermo-optical paints application]
- Verification [mechanical and environmental/aging tests]
- Various applied R&D activities

## BACKGROUND

Multispectral imaging in VBN can help to possess more reliable navigation solutions in various scenarios, like:

- Active debris removal,
- Collaborative rendezvous,
- Minor planet/small body navigation,
- Moon landing, landing on planets.

Thermal infrared imaging can provide additional / complementary information, or may be solely used when no other information is available (e.g. eclipse)



(a)

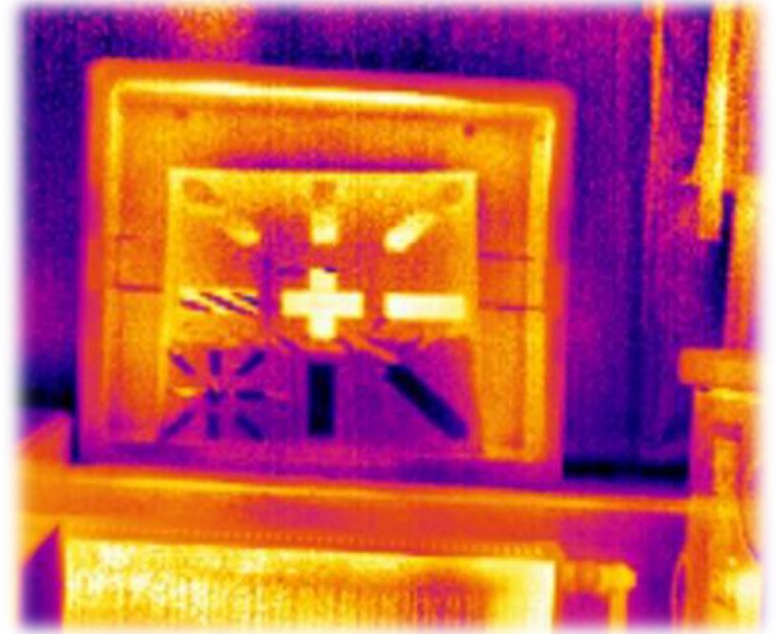
(b)

(c)

## DIFFICULTIES

Taking representative TIR images for testing is problematic due to

- Thermal radiance of background (-> cooling),
- Unwanted reflections,
- Low SNR, low resolution,
- Uncontrolled (natural) convection,
- Heat conduction (depending on experiment timescale),
- Limited amount of ground truth data are available
- ...

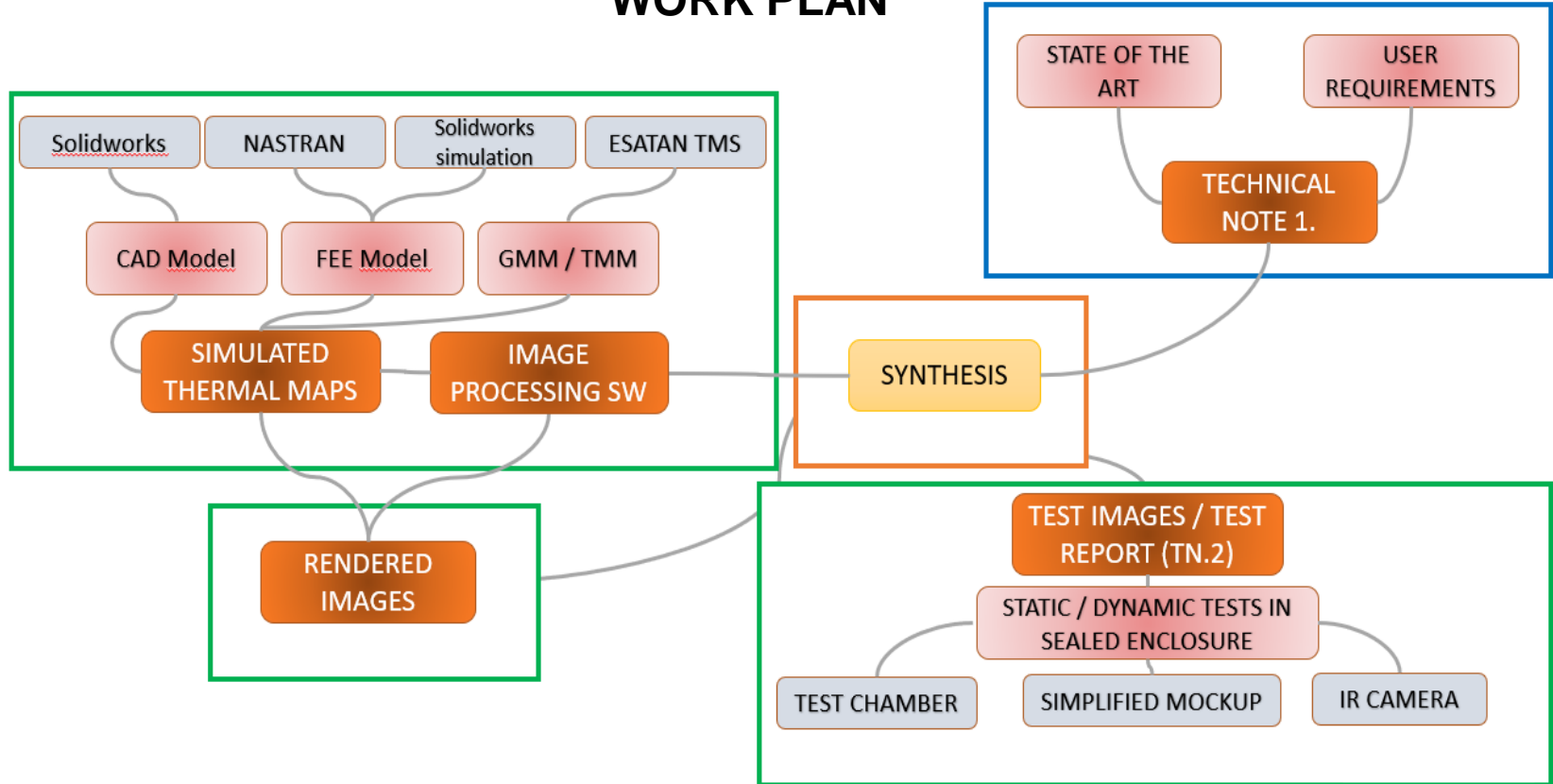


Credit: ADMATIS/ESA PEMSUN Project

See: „Markers Supporting Navigation” by L. Szegedi, on Friday at 10:00 in debris removal and servicing session

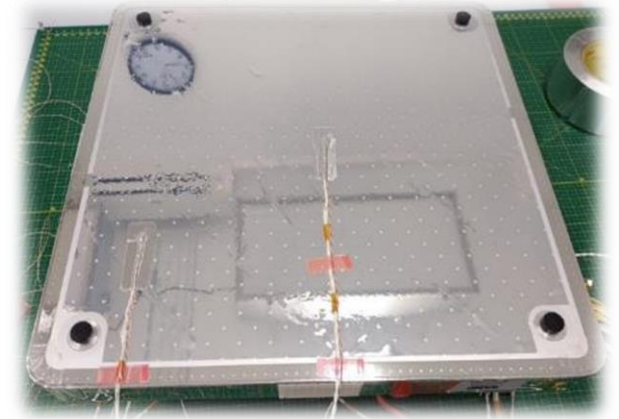
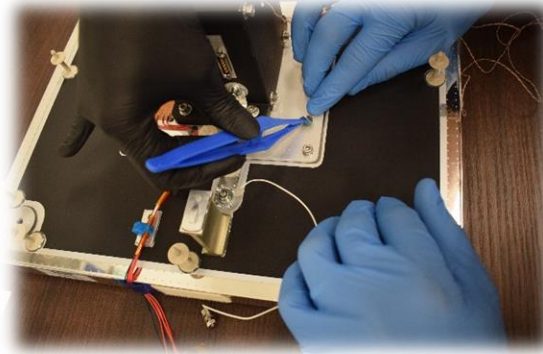
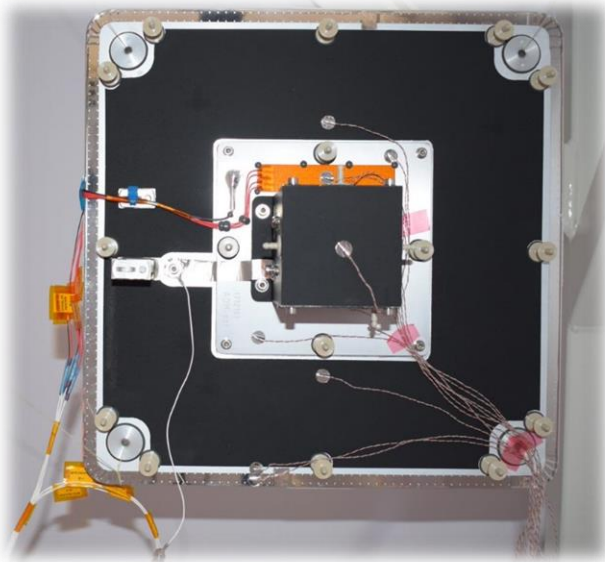
The objective of TIRVOA project is to define and validate models that correlate results from on-ground activities in open-air testing with results that would be experienced in orbit.

## WORK PLAN

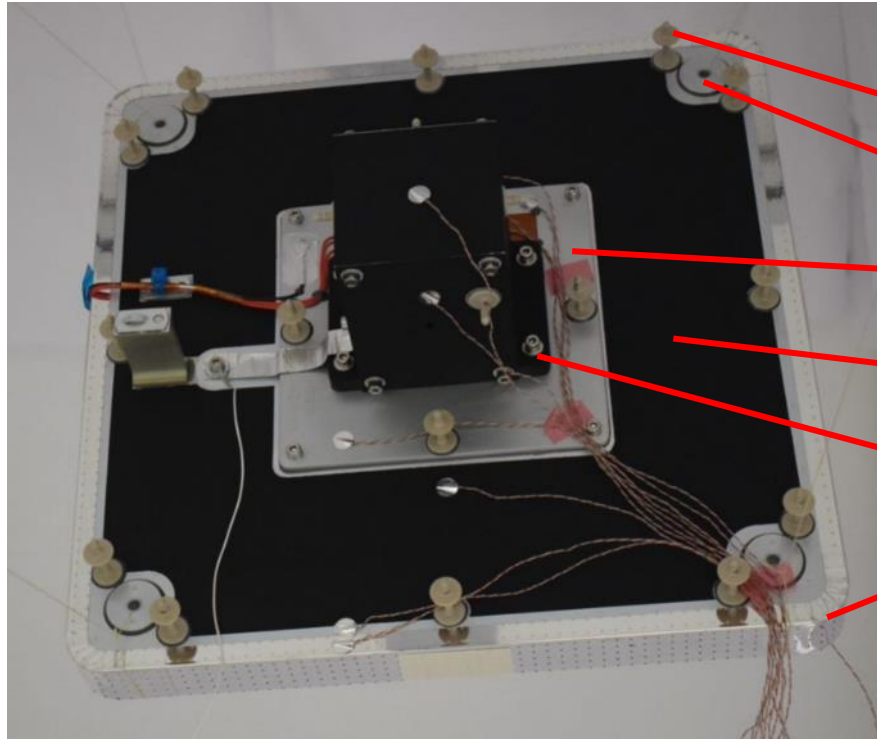


Small scale mock-ups have been built to cover the predefined scenarios:

- ADR mock-up with fully representative materials
- Equipped with a set of thermocouples
- Internal heating is available (for the imitation of operating satellite)



The original mock-up is a complex, flight representative hardware, built for the demonstration of qualified manufacturing processes.



MLI Standoff

Sandwich Panel Insert

Conversion Coated Aluminum (low emissivity)

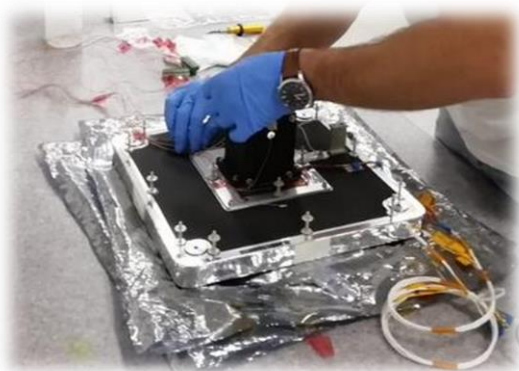
PUK Paint (high emissivity)

Stainless steel screws (low emissivity)

Perforated SSM (very low emissivity)



- Exchangeable MLI cover
- Solar panel appendage
- whole 3D model is available for performing thermal simulations in SolidWorks Simulation Tool



Thermocouples adjustment



MLI mounting



Solar panel application

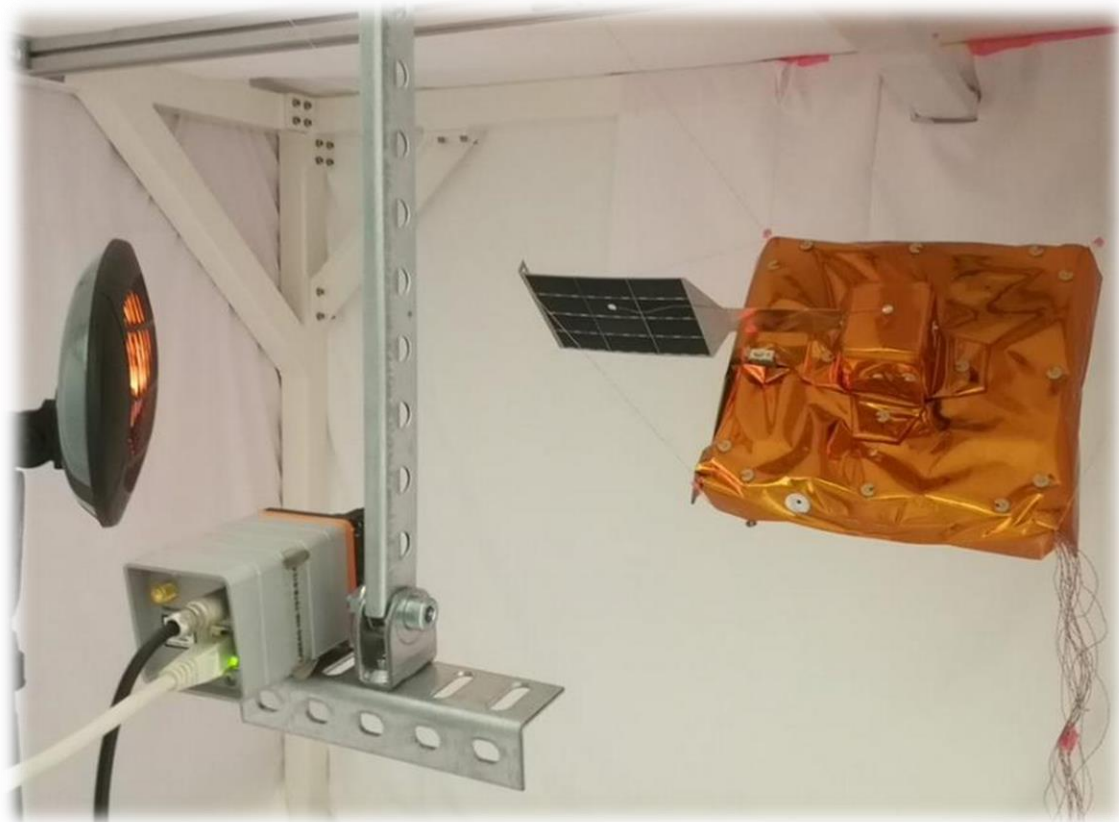
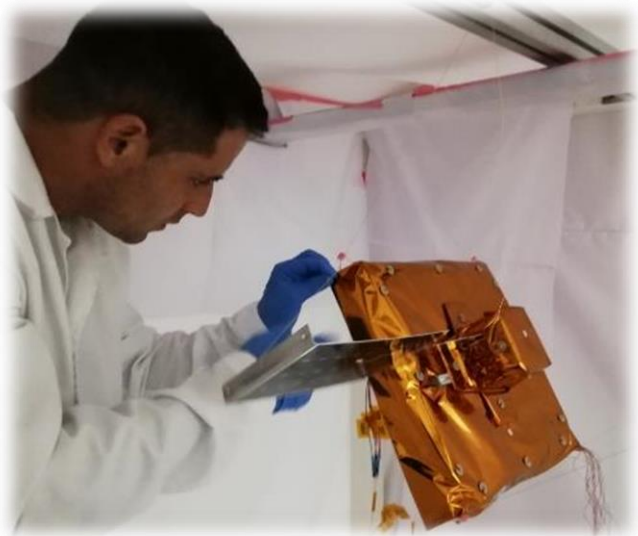
Tests have been carried out inside a sealed experiment container:

- Removeable lid
- Temperature/humidity controlled
- Equipped with camera rail



Test setup consists of

- Mock-up
- Illuminator (quartz lamp)
- TIR camera (XENICS Gobi 640 – ESA)
- Data acquisition system



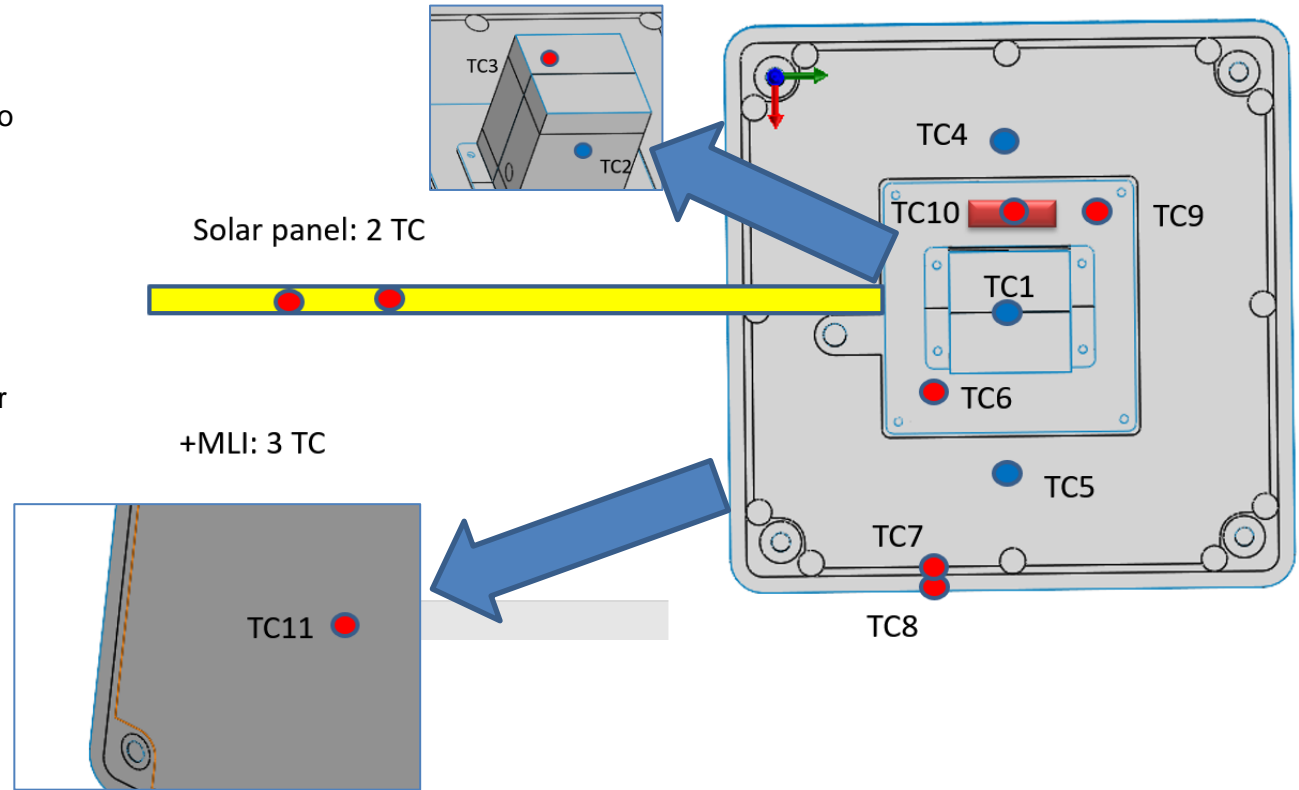
Test cases were defined based upon the TIR camera / mock-up attitude, illumination/eclipse duration and internal heater functioning.

Test outputs are:

- Temperature evolution of the mock-up measured using 16 thermometers at various places
- Sequence of TIR images
- Scene data i. e. geometrical positions of the whole setup.



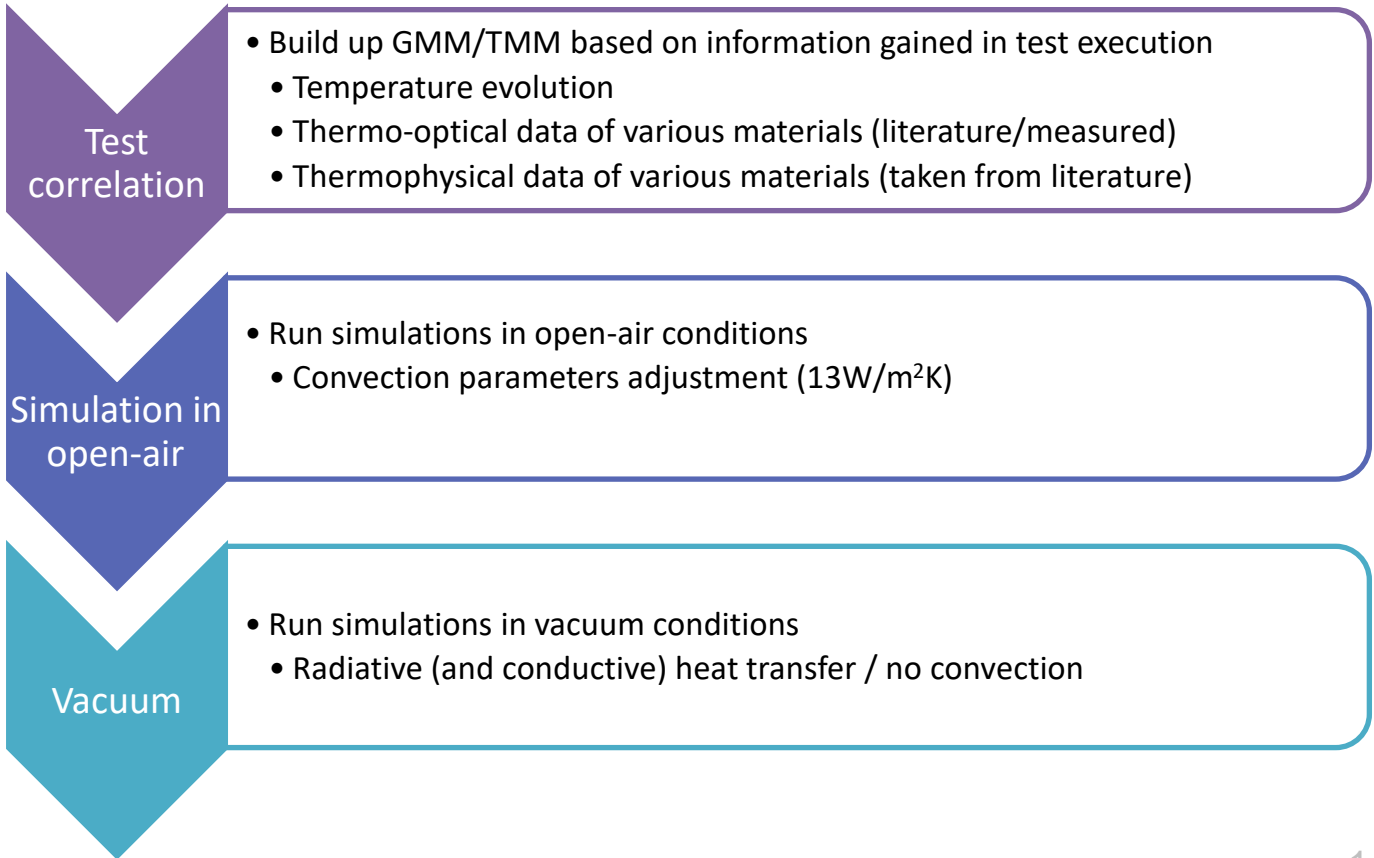
- Mock-up is equipped with 11 thermocouples.
- 5 additional TC-s has been put onto MLI cover and solar panel appendage.
- Mock-up was fixed using Kevlar threads into test container.
- Data acquisition units and all other unwanted heat sources (e.g. power supply unit) are placed outside of test container to reduce „thermal noise” on images



Simulations are currently in progress.

**SolidWorks Simulation** tool have being used to generate thermal data in various test cases in open-air and vacuum conditions.

Some selected test cases are being studied.



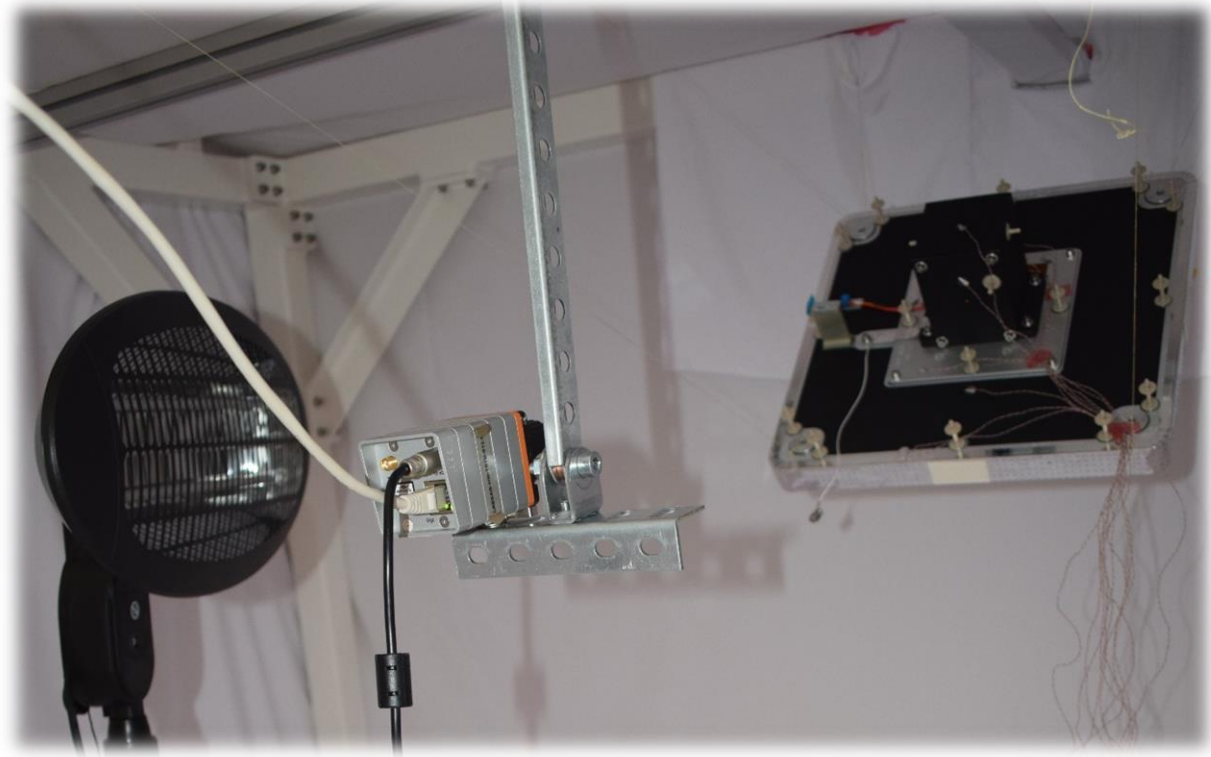
Thermal infrared images of the simulation output are generated by the **PANGU [Planet and Asteroid Natural Scene Generation Utility]** toolset, developed by University of Dundee.

- The new toolset (VRML2PAN) is able to convert external temperature model to PANGU binary format. [additional image rendering mode]
- Temperature and emissivity values are given in one single VRML file.
- *See „Real-time image rendering for simulation of thermal infrared cameras with application in Space Debris Removal” today at 17:20 by Iain Martin, University of Dundee*



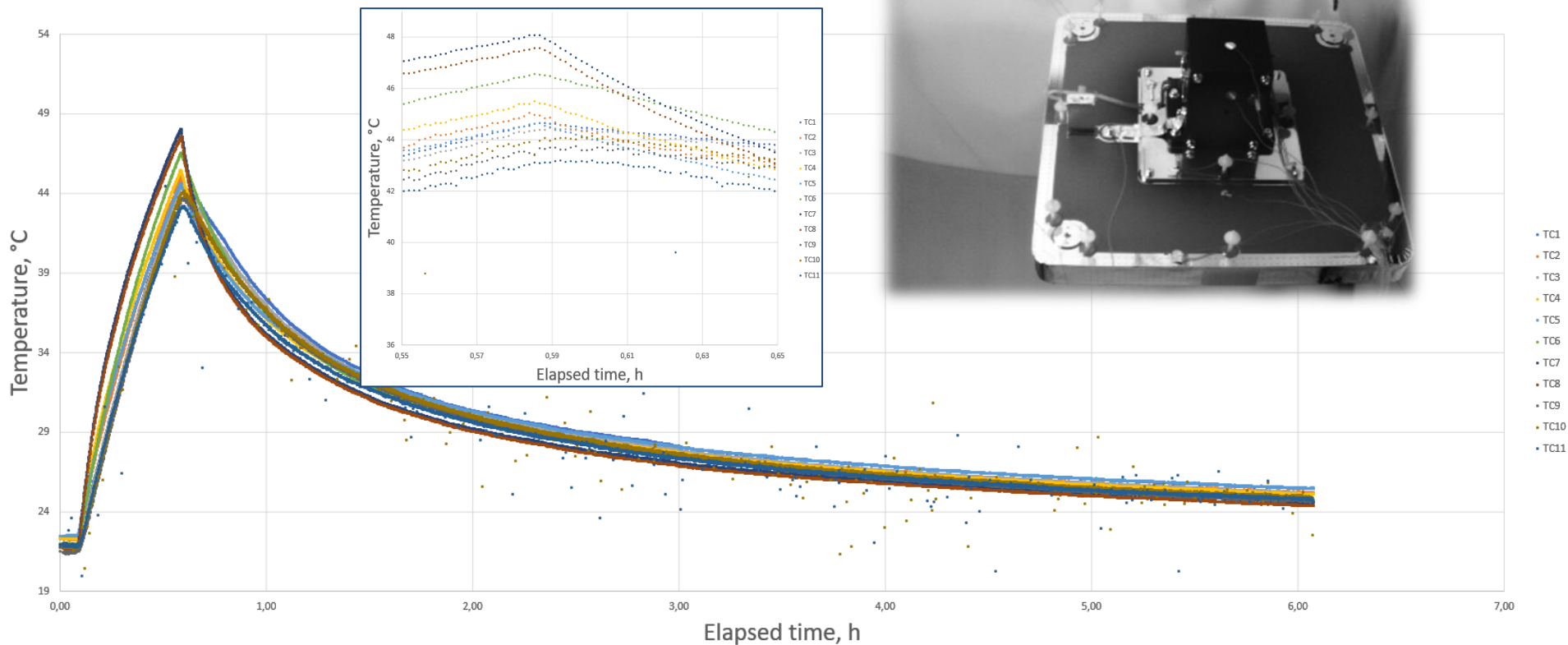
### Man-made object test case 1:

- Natural convection
- Illumination for 0.5 hours, then „switching” to eclipse
- Without VDA/Kapton MLI coverage

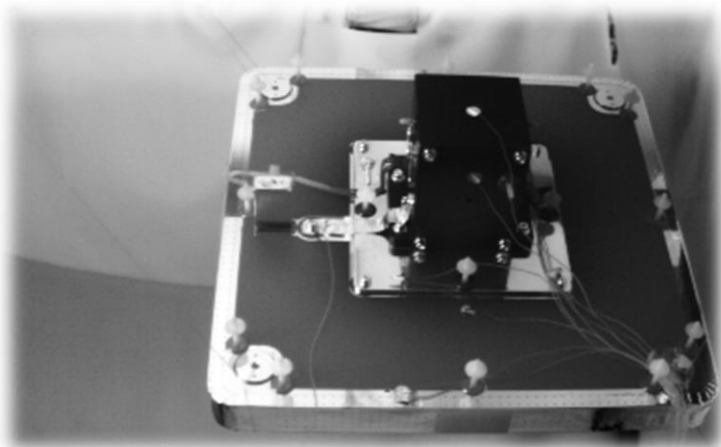




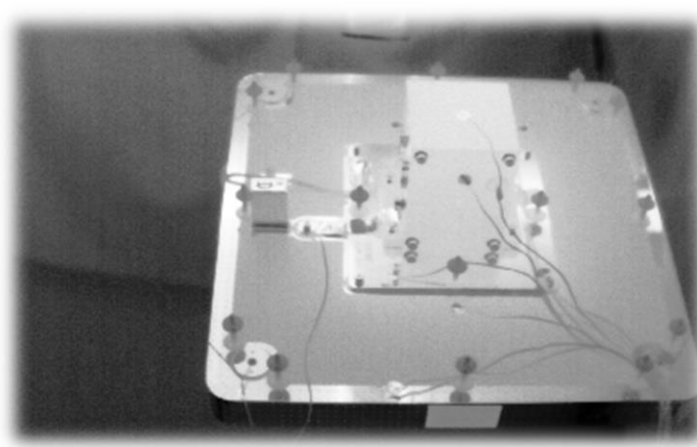
## Temperature evolution



Selected TIR images:

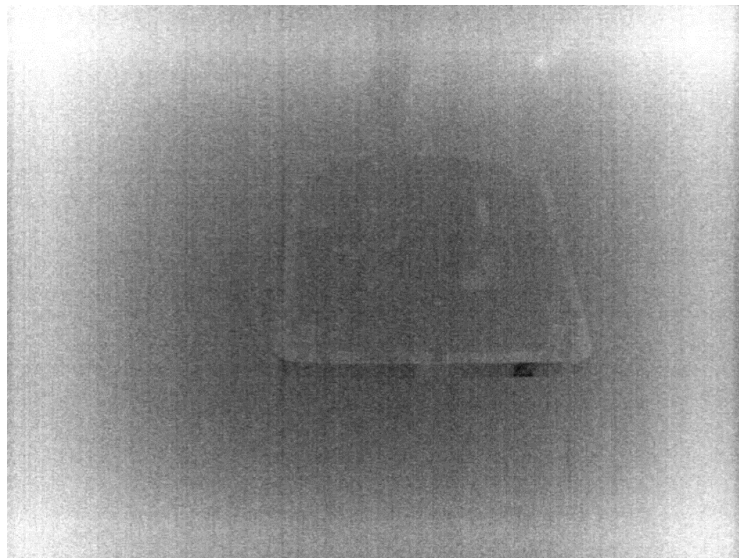


During „daylight”



During „eclipse”

Timelapse movie including basic feature tracking algorithm for demo purposes:



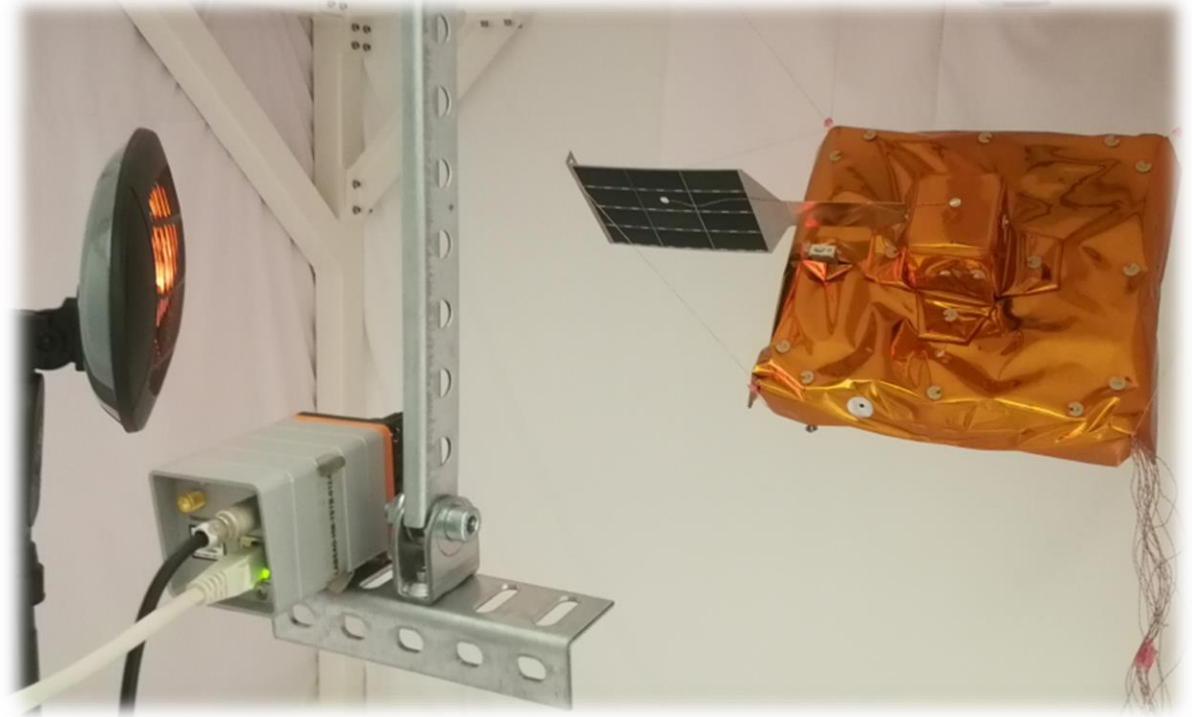
TIR Images



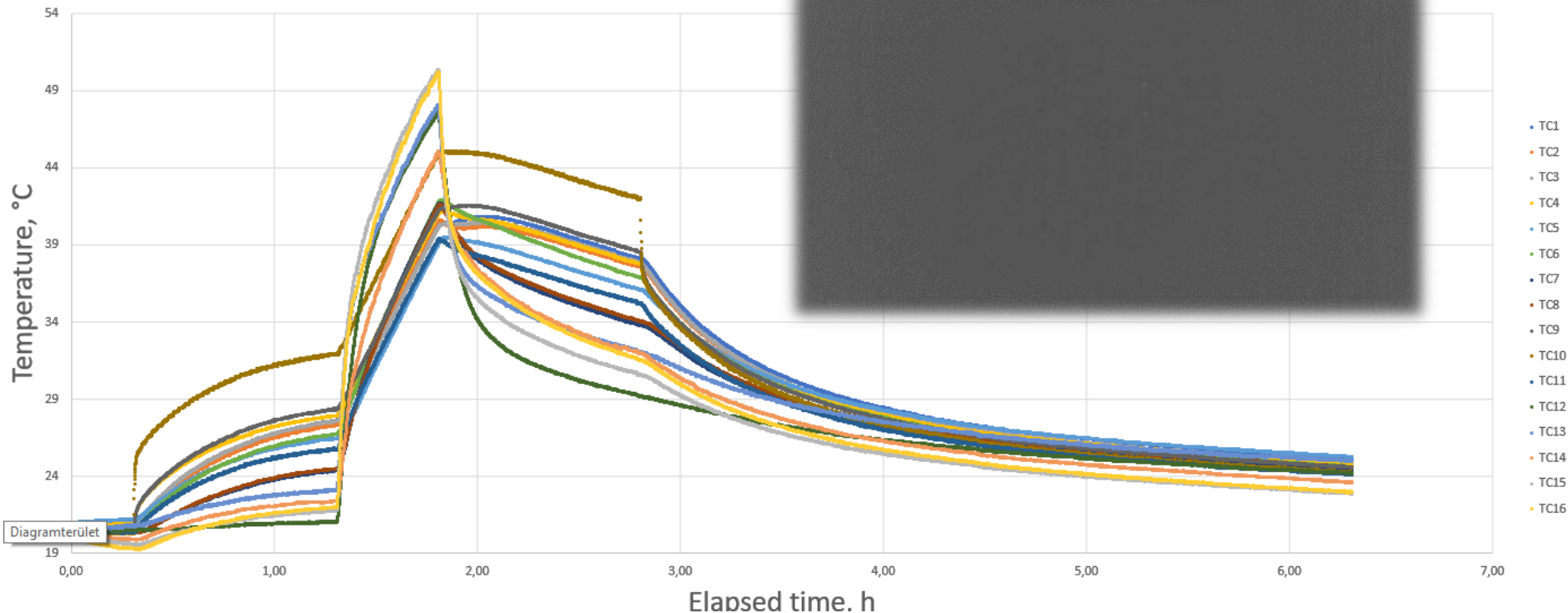
Feature tracking

### Man-made object test case 2:

- Natural convection
- Internal heating together with illumination, then „eclipse” phase
- VDA/Kapton MLI coverage
- [e. g. MLI behaves very differently in vacuum compared to open air]
- Solar panel appendage



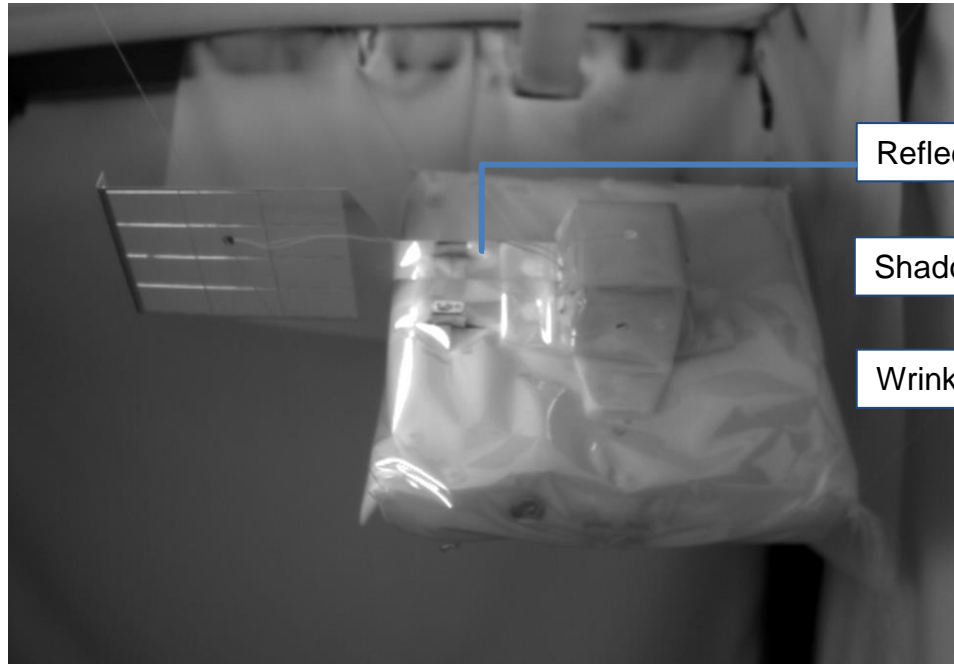
## Temperature evolution



**INTERNAL HEATING ON**

**ILLUMINATION ON**

## Observable features on TIR test image



Reflections (on MLI and on aluminium surface)

Shadow (self-casted)

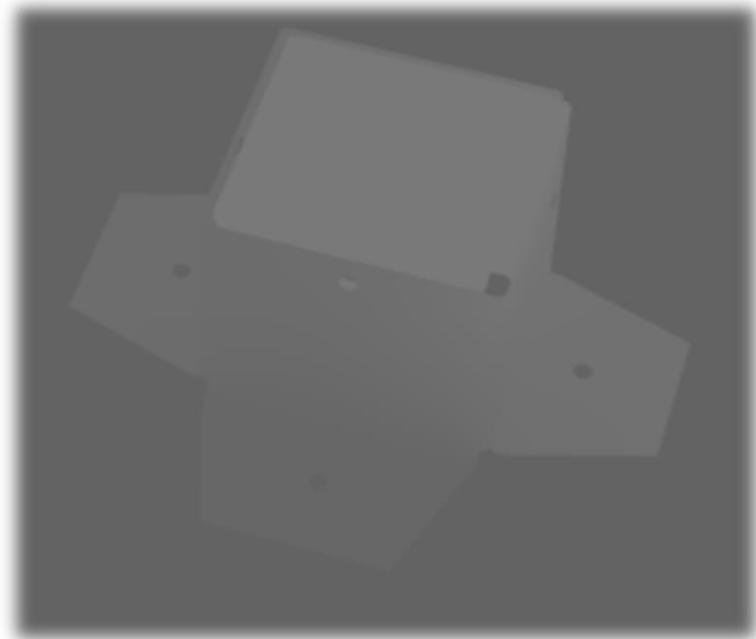
Wrinkles visible on MLI

It is important to have background with:

- uniform temperature,
- emissivity,
- No wrinkles, folds on background material
- Temperature difference between mock-up and environment.

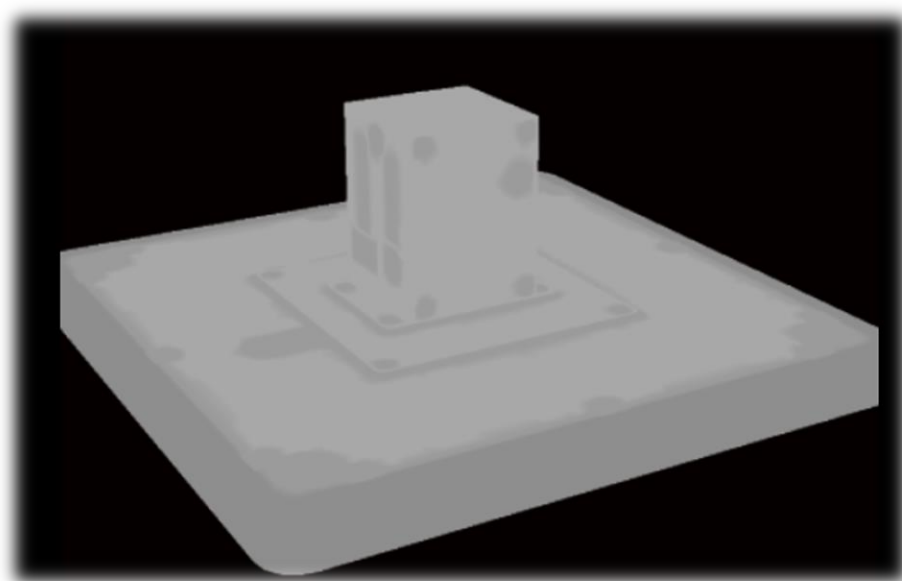
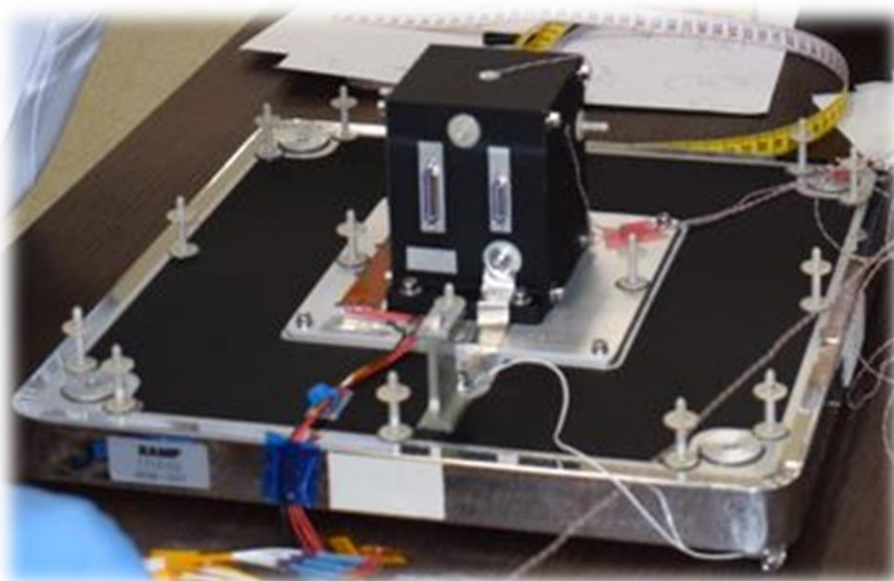
Unwanted background effects can be easily avoided in simulated images.

Rendering TIR image of MTD Box MLI blanket cover separately:




Similar features can be reproduced on rendered images using only two physical parameters (temperature map + emissivity)

## MANMADE OBJECT „EMISSION MODEL” (WITHOUT MLI BLANKET)





- Large amount of data has been collected under controlled environment that can serve as input for simulation of space environment,
- Phenomena known from previous studies have been reproduced and now can be studied under fully controlled environment (through tests and simulations).
- Sensitivity analysis can be performed on all relevant and controllable parameters once we possess reliable simulation results based on test correlations.
- Pixel intensities on rendered images are in line with temperature and emissivity data.
- PANGU Tool is also capable of generating movies using our models
- Test and rendered images can already be used for feature detection algorithms tests/development.
  - With basic feature detection tools it is possible to show that TIR images can be used during eclipse and the duration of usability depends primarily on the temperature evolution of the target.
  - Conversion tools can be further developed for other simulation software outputs [e. g. ESATAN, NASTRAN]
- Temperature maps of selected test cases together with emissivity data, etc. shall be handed over to image rendering tool to generate TIR images in vacuum and to compare them with open-air images.
- More complex mock-up will be available in-house for further collection of test data in 2022.
- Mock-ups and test container detailed 3D models are continuously developed and the reliability of simulation results can be increased.

A thermal image of a person, likely a firefighter, wearing a helmet and jacket. The person is holding a piece of equipment, possibly a fire extinguisher or a tool, which is highlighted in bright red and yellow, indicating high heat. The background is a dimly lit room with some structural elements visible.

**THANK YOU FOR YOUR ATTENTION!**