Appendix F

Solar Orbiter STM Thermal Testing and Correlation

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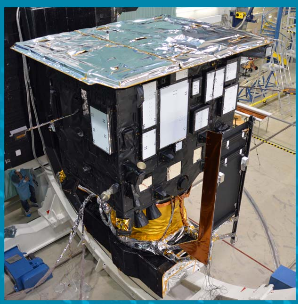
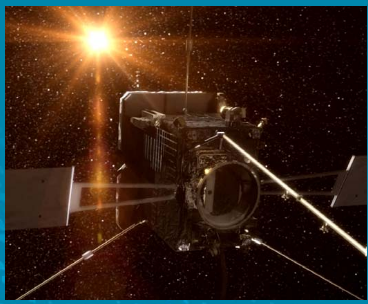
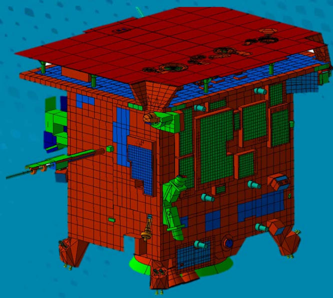
Abstract

Solar Orbiter is an ESA mission which will explore the Sun and the heliosphere closer than ever before. One of the main design drivers for Solar Orbiter is the thermal environment, determined by a total irradiance of 13 solar constants (17500 W/m^2), due to the proximity to the Sun. As part of the thermal design and validation process, the Solar Orbiter STM platform thermal balance test was performed in the IABG test facility in November- December 2015. This presentation will describe the Thermal Balance Test performed on the Solar Orbiter STM and the activities performed to correlate the thermal model and to show the verification of the STM thermal design.

Thermal Test Campaign of the Solar Orbiter STM

Scott Morgan

5th October 2016

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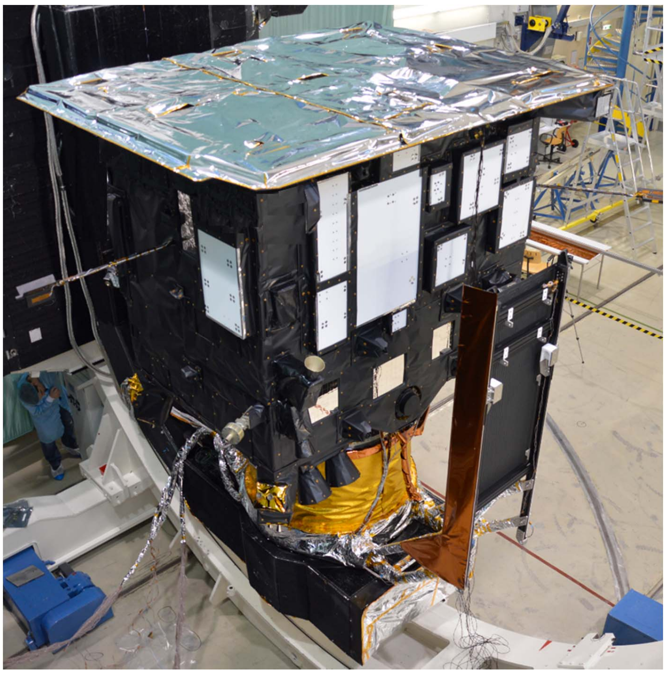
Overview

- Solar Orbiter Spacecraft
- Thermal Test Overview
- Test Article
- Test Set-Up
- Test Description
- Correlation Activities
- Conclusions



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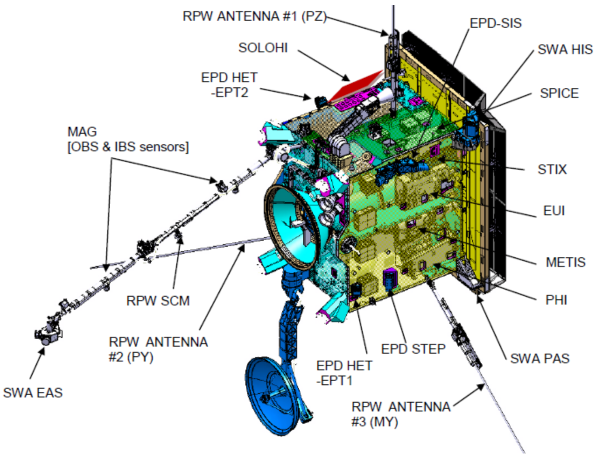
Solar Orbiter Spacecraft



Mission Facts:

- Launch Date : October 2018
- Orbits Sun at distances between 0.28AU (perihelion) and 1.47AU (aphelion)
- Cruise Phase (3 years) – Nominal Mission Phase (3.8 years) – Extended Mission Phase (2.5 years)

Spacecraft Features:

- Heatshield to protect against 17,500 W.m^{-2} solar flux at perihelion, sized to offer complete Sun shielding of the platform within an 8° half-cone.
- High Gain Antenna which is articulated to enable communication with Earth throughout the mission
- Instrument boom to isolate magnetically sensitive instrument from the rest of the spacecraft

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Thermal Test Overview

Test Location: IABG, Munich

Test Objectives:

- Verify and Correlate Platform Thermal Model
- Demonstrate adequacy of spacecraft level thermal control, payload radiator assemblies and MLI
- Verify thermal power requirements in relation to heater consumption needed for TCS

Items Excluded from Test:

- Instrument boom, HGA and solar arrays
- The HGA and solar array effect on the spacecraft is simulated using IR heater plates
- Spacecraft heatshield has undergone its own STM campaign . To meet the objectives of the spacecraft level STM, it was sufficient to use a heated plate to simulate the heat flux from the rear of the heat shield.

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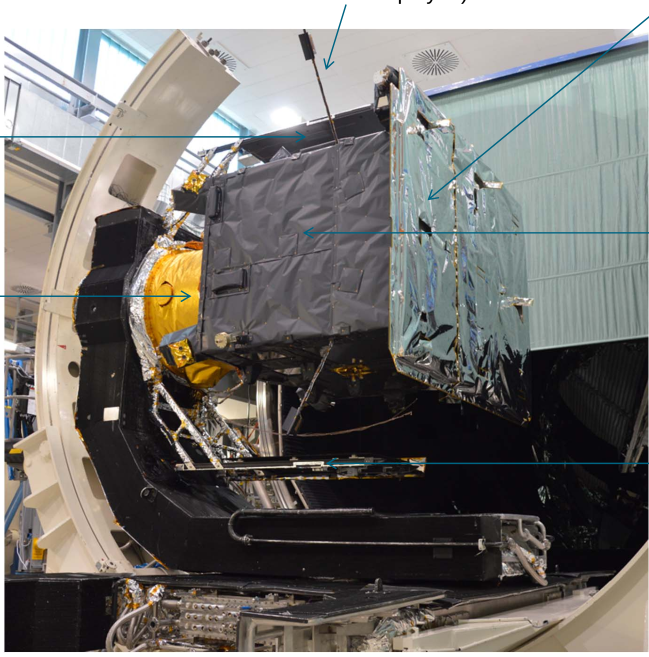
Test Article - I



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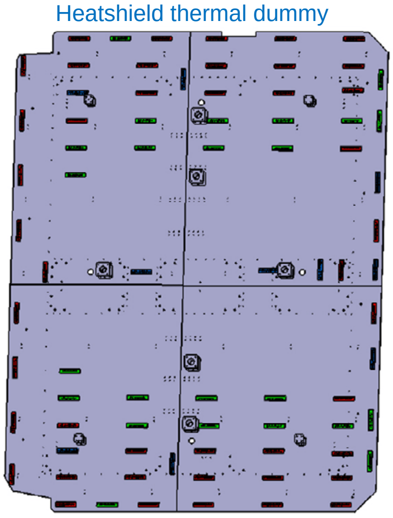
Test Article - II

- Heatshield thermal dummy (see image on right)
  - Consists of four aluminium plates assembled together, painted black with heaters located as shown. Front (non-SC facing side) of heatshield covered with MLI to ensure heat rejection is directed towards spacecraft
  - Purpose of heatshield thermal dummy is to provide radiative and conductive fluxes to the spacecraft which are comparable with those expected in flight at 0.28AU

Heatshield thermal dummy



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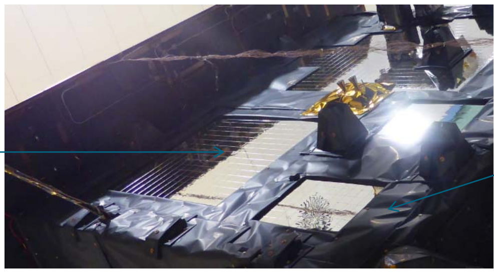
Test Article - III

STM thermal hardware was installed to represent the flight TCS design:

- Flight representative MLI to insulate platform external walls and battery
- Flight representative platform radiators
- 8 flight representative stood off radiators (SORA) located on –Y and +Z panels
- Thermal filler for improved thermal contact between unit baseplates and SC panels
- Heatpipes for SORA and some platform units (PCDU and RIU)
- TCS heaters to represent operation flight heaters that will be used to protect equipment interfaces in flight

Platform radiator



Platform MLI

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Test Article IV – Stood-Off Radiator Assembly (SORA)

- The five internal remote sensing instruments have very stringent temperature requirements.
- Some must be kept below -60°C when in operational mode at 0.28AU.
- To enable efficient radiator design, the radiator panels are decoupled from the spacecraft panel via isostatic feet.
- To achieve efficient heat transfer from the instrument interfaces to the radiator, they are connected via flexible thermal straps and rigid bars using pyrolytic graphite with aluminium end-fittings
- To meet STM schedule, it was decided that two flexible and two rigid bars would be represented. These simulate the full chain from payload instrument interface to radiator. All other strap interfaces are simulated using a heated interface blocks.

+Y SORA integrated

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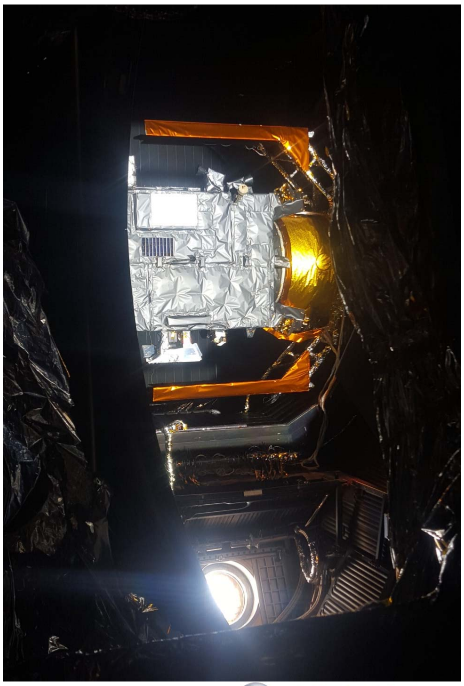
Thermal Test Campaign of the Solar Orbiter STM

Test Set-Up

- Thermocouples (TC)
  - Approx. 400 thermocouples in total
  - For MTDs, one TC was located on the TRP and two or more on the panel around the baseplate to enable temperature gradients between the unit and panel and within the panel itself to be resolved
  - TCs also located along the heatpipes beneath the PCDU and RIU
- Heaters
  - Approx. 173 heater circuits
  - Four categories:
    - Test heaters (approx. 90) to simulate heat dissipated due to operation of the equipment
    - Flight heaters for TCS (approx. 75) to represent those heaters which are used to maintain equipment within temperature limits
    - Heaters located on IR simulators to represent the radiative environment presented to the SC radiators due to external components such as the solar array, HGA etc.
    - Guard heaters to prevent unwanted conductive heat loss through the test facility interfaces (mechanical and electrical).



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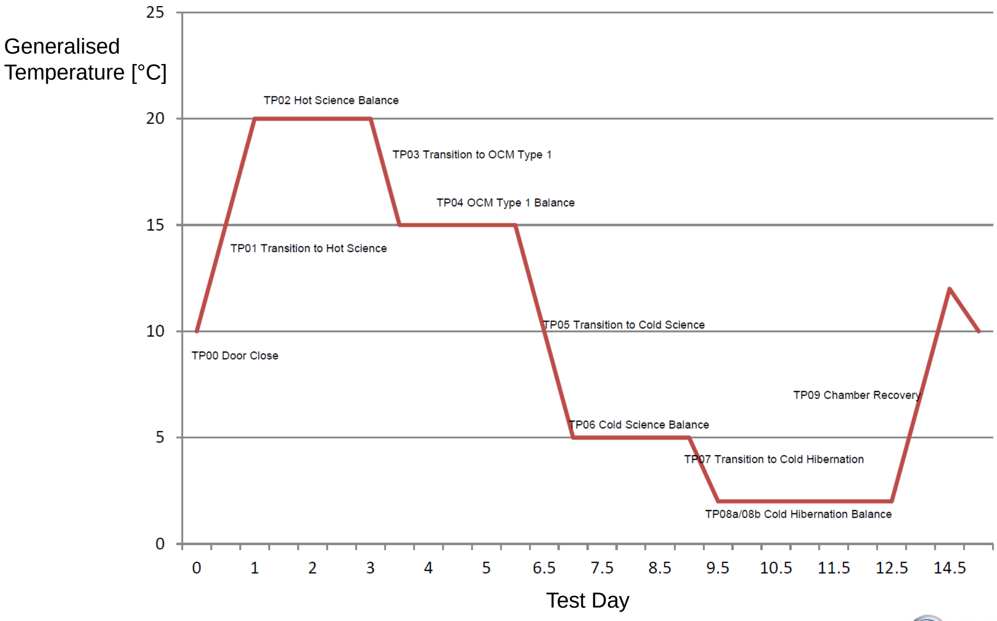
Test Description



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Correlation Activities - I

- A correlation activity was performed after the event, aiming to correlate all four balance phases
- The correlation procedure was performed in ESATAN TMS
- The first step of the correlation involved the parameterisation of key values within the model, such as
  - Interface couplings
  - MLI couplings
  - Optical properties

- The data from the test was then sanitised. This involved:
  - Removal of data for spurious or failed thermocouples
  - Averaging TC data where there was significant noise (non twisted pair cables)
  - Exponential based extrapolation of TC data for high capacity units

- Next, any large deviations between predictions and test were investigated

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Correlation Activities - II

The main model updates coming out of the correlation activity are:

- Geometric Mathematical Model:
  - Position and thermo-optical properties of the Solar Array simulator
  - Orientations and thermo-optical properties of RPW antenna MTDs
  - Correction of SADM MLI
  - Correction of position of EPD HET +Y bracket
  - Modification of the LVA internal MLI
  - OSR emissivity (small reduction)

- Thermal Mathematical Model:
  - Improved modelling of PHI HE1 heatpipe
  - Corrected conductive couplings between SWA electronics box, SPICE electronics box and EPD with radiators
  - Improved modelling of TWT doublers
  - Instrument conductive couplings of star trackers and thrusters
  - Propellant tank MLI couplings

The above changes are all minor – overall the correlation of most elements of the thermal model was good without need for modification.

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Correlation Results

The final status of the correlation is stated below:

	Hot Science	Hot OCM	Cold Science	Cold Hibernation	Requirement
Temp deviation test vs TMM (±5°C)	97.7%	94.6%	95.5%	93.8%	
Temp deviation test vs TMM (±8°C)	100.0%	99.4%	100.0%	99.4%	
Temp mean deviation [°C]	0.61	-0.25	0.05	0.91	2.0
Temp standard deviation [°C]	2.07	2.44	2.33	2.45	3.0

The table above shows that both the mean temperature deviation and the standard deviation of thermocouple measurements are within limits in all four balance phases

The vast majority of internal units show good adherence to the above requirement. Areas which were difficult to correlate were:

- Propulsion tanks
- Optics unit feet
- SORA

The most difficult case to correlate is TP04 (off-pointing, Sun illumination case). For most TCs the TMM predicts hotter than measured in test.

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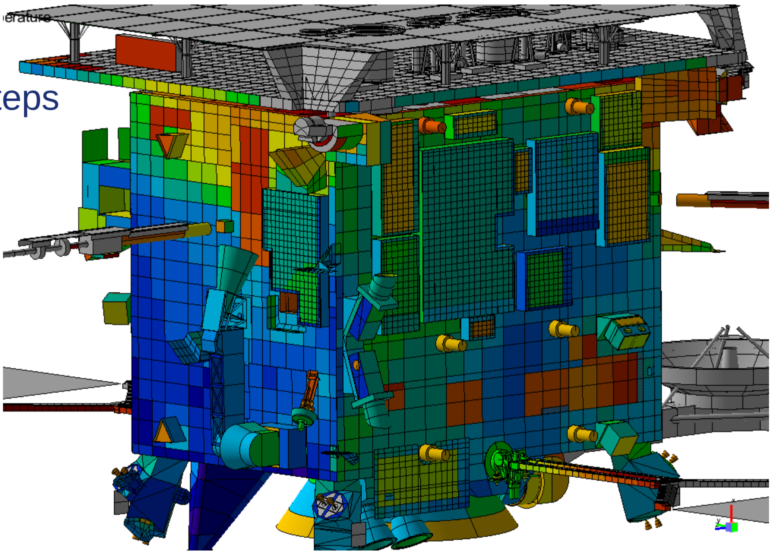
Conclusions and Next Steps



Conclusions:

- STM thermal balance test for Solar Obiter was performed between 23rd November and 2nd December 2015
- 98% thermocouples reached stabilisation in all test phases
- Good level of correlation has been achieved with minor modifications made to thermal model

Next Steps:

- Feedback from the SC STM correlated thermal model will be implemented in the SC flight model. Together with integration of thermal models from the major subsystems (Heat shield, HGA solar arrays), the thermal model will then be in a position to inform the Solar Orbiter PFM Thermal Campaign.

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