European Space Thermal Engineering Workshop 2021

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ESA Missions and Thermal Technology Development Update

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Update of ESA Missions and Thermal Technology Developments

Thermal Analysis / 11

Systema-Thermica

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In the past year, two versions of Systema have been issued.

First the V4.9.1 version of Systema-Thermica was released and is available to users in fall 2021. This new version provides some enhanced performances affecting the model creation process, such as for example selection in the meshing, and how node condensation is handled. Moreover some features of the STEP-TAS protocol have been implemented in this latest version: following up the improvements that were done in 2020, Systema now embeds enclosure listing and full support of bulk material definition. Finally some improvements on the Python API and bug fixes were performed.

Also Systema V4.8.3P3 has been released last April 2021 to address some specific issues signalled by users.

Finally a segment will be dedicated to best practices used by our most experienced users at Airbus that can improve your daily use of Systema-Thermica. This part will address optimisation on creation and customization of the modeller and meshing parts.

Thermal Analysis / 29

ESATAN Thermal Modelling Suite - Product Developments

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ESATAN-TMS provides an advanced thermal modelling environment for the thermal analysis of spacecraft and launch vehicles. The suite is continually being enhanced to meet current and future

requirements of space projects, and to support the specific needs of thermal engineers.
A major focus of ESATAN-TMS development this year has been on providing facilities within Workbench to further streamline the thermal process as well as supporting our user needs. This presentation will outline all the developments going into ESATAN-TMS 2022

Thermal Analysis / **19**

Characterization test of thermal heat leaks in electrical harnesses

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The thermal heat leaks in electrical harnesses become one of the major source of uncertainty in space thermal engineering especially for miniaturized systems as nanosatellites, microsatellites or where harness lengths are reduced. In parallel, the space systems become more and more power consuming including more and more electrical needs leading to a high dissipated power and high electrical currents. Furthermore, the accommodation of these harnesses becomes difficult to thermally control in reduced volumes leading to several unknown heat leaks. In this kind of systems, and especially for thermal systems with a few of heating power available, these thermal heat leaks become one of the main heat exchange.

As the heat transfer inside the harness is quite complex (radiation and conduction involved) and as it exists a lot of harness types (various gauge, lengths, shielding, accommodation, MLI, etc…) then the thermal control design can be difficult leading to a large uncertainty philosophy and a system oversizing. In the frame of this difficulty, CNES has performed a thermal characterization test to catch the thermal behavior of harnesses in various configurations in order to understand the heat transfers involved and define a methodology to apply in system analysis. A finite element model is correlated based on test results and a nodal breakdown methodology is defined based on this correlation.

This paper gives the overview of this activity through the test and its results and presents the lessons learned.

Thermal Analysis / **17**

Application of stochastic approach for satellite data processing unit (DPU) thermal analysis

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In the early years of CubeSat technology the reliability of the missions was about 30-50%. However, over time the mission's success rate increased up to about 74% in 2018 (based on Thyrso Villela et al., "Towards the Thousandth CubeSat: A Statistical Overview"). Nevertheless, there's still a place for improvement due to high investment cost. Thermal control of a spacecraft is one of the systems that can be a source of a critical failure. In this technical field, success of the mission relies on numerical analysis, performed tests and finally, in-space thermal behavior. Uncertainty of the simulation and inaccuracy of the laboratory tests enforce engineers to use safety margins on temperature results and make design process more conservative. In the planned presentation we want to propose usage of DAKOTA Sandia software (allowing for a statistical analysis of the numerical model), which we combined with ESATAN-TMS for having wide field of view on achieved results with benefit to our nanosatellite mission Intuition-1.

Despite the small size of nanosatellite, there are many variables which have big overall impact on mission thermal behavior, like emissivities, thermal conductivities etc. which engineers should consider during development. All of this data has its own statistics which have direct impact on final results confidence level. Unfortunately, using this extended statistical data manually is time consuming and ineffective operation. To automate this process the IT tool for stochastic approach was employed. The thermal mathematical model (TMM) of the computational subsystem (DPU) of Intuition-1 nanosatellite was created and the input physical parameters with their uncertainty margins were assessed. The experimental data, which was used for a validation purpose, was obtained during thermal balance tests in thermal vacuum chamber (TVAC) related to relevant ECSS standard. After getting preliminary results, TMM model was correlated with the data from the experiment. Such a model was used for further stochastic analysis.

Firstly, the automated Sensitivity Analysis (SA) was employed to show which parameters have the greatest impact on the chosen model outputs. Knowing this significant parameters, next step was to prepare more precise statistical input data for Uncertainty Quantification (UQ) study, which gave the probability information for output function. This data was used for estimation of new thermal margins. Moreover, input parameters with known upper and lower bounds but unknown statistics (epistemic uncertainty) were also analyzed. This was achieved by employing mixed UQ approach where aleatory and epistemic inputs were considered.

The stochastic approach allowed to make validation process more insightful. Moreover, it gave more information and data about the most relevant heat paths. Additionally, the approach allowed to get more strict error margins for temperature measurement points. These advantages and data help engineers for being confident for virtual prototyping and afterwards decrease probability of mission failure.

Thermal Control / 10

Thin cold plate development for next I-HAB module

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The current set of cold plates on the ESA Columbus laboratory module of the International Space Station have their origin in the cold plates that were developed for Spacelab and also used for the European Retrievable Carrier, Eureca. Considering the very challenging requirements on all subsystems to meet stringent mass targets for human exploration missions beyond LEO, there is a strong interest to have a design with the needed performance but at a lower mass.
Depending on the coolant and the flow, the cold plate is limited to a certain power density, but in order to be able to compare different options on the basis of common criteria, the maximum power density from past missions has been maintained. Nevertheless, if, with new technology, the new design is in a position to cope with higher densities, it is important and needs to be highlighted.
During this project the main objective was to design and test a representative cold plate with an average heat transfer coefficient at least 2200 W/K/m². For this, the project breaks down into 3 tasks:
• Technological choice, design and optimization of the cold plate
• Cold plate production and manufacturing qualification
• Experimental Characterizations (proof pressure test, NDI based on IR measurments, vibration tests and thermal tests)
Finally, the advantages and drawbacks of the cold plates are highlighted by comparison with thermal design options. The paper concludes with an outlook on further development and integration of thin cold plate.

Thermal Control / 15

Mini Mechanically Pumped Loop Modelling, Design and Tests for standardized CubeSat thermal control

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With the miniaturization of space-borne sensors and the introduction of small propulsion modules, more powerful payloads are anticipated to be used in small satellites. Therefore, new thermal concepts are required to cope with the increasing thermal dissipation and the resulting negative effects. This presentations shows a new thermal control concept to thermally standardize small satellites with power dissipation problems and making them thermally independent of their orbits.

The thermal design concept is a small Mechanically Pumped Loop (MPL). The MPL concept provides a low mass and volume thermal control solution which uses little power (<1W) and operates with high reliability. The presentation will cover the current status of the development of the MPL, including results of a prototype MPL which has demonstrated a continuous heat transport of 20W. The presentation will conclude with the envisioned development path as well as an introduction of the companies involved in future MPL development.

Thermal Analysis / **12**

A NOVEL ADJOINT BASED THERMAL CORRELATION TECHNIQUE USING SIMCENTER 3D SPACE SYSTEMS THERMAL

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During the design phases of a spacecraft development, a thermal model of the spacecraft is created that is used to predict the operational temperatures under a defined set of terrestrial and space environments.This thermal model involves a large number of inputs coming from a large number of sources. Some inputs, such as the thermal conductivity of a material are well defined and subject to small variability,especially when modeled as temperature dependent. Other inputs are subject to greater uncertainty,these include:

1. Surface optical properties. These are usually taken from handbooks listing emissivities and absorptivities of different surface finishes.
2. Conductance across bolted joints or across composite joints. These are often taken from handbook data that cover very specific cases and applied to a broad range of situations.
3. MLI effective emissivity. This is typically handled using worst case values (high values for cold case,low values for hot case) as the actual value is a complex function of MLI materials, area, layers,stitching and penetrations

While some recent advances and demonstrations have been made in model correlation techniques, the computational overhead of varying many parameters to find an optimal set still prevents fast and effective model correlation. The most time-consuming step of such a computation is computing the sensitivities of the correlation function to the different combinations of input parameters.
Indeed, the computational effort of many other correlation technologies requires a large number of model runs that can scale anywhere from a factor of N to 2N, depending on the method, where N is the number of design variables that could be changed in a model.

In contrast, by using the adjoint sensitivity method, first-order sensitivities of the correlation function to all the design variables can be computed with just two runs: a so-called "forward calculation" and an "adjoint calculation". These sensitivities can be used to estimate new design variable conditions at which new forward and adjoint problems can be solved, to minimize a functional which measures the error between the simulation and test or in flight data.

The goal of this paper to present the fundamentals of the adjoint correlation method implemented: solution of governing equations, solution of the adjoint equations, calculation of the gradient vector, and updating the design variables.

Some preliminary results on a few "real-life" steady-state and transient models will be presented together with some metrics of computational gains.

Thermal Analysis / **33**

STEP-TAS status update

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Thermal Analysis / **35**

DESIGN OF A THERMAL ANALYSIS TOOL FOR PRELIMINARY RADIATOR SIZING ON THE MOON

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In recent years, a focus of space exploration has shifted again to the surface of the Moon. There is a reborn interest of the study and utilization of the Moon. In this context, thermal engineers have to design space hardware for operation in the lunar environment. Detailed thermal analyses of hardware in the lunar environment requires complex thermal models and powerful software packages. This work aims to simplify and support the work of the thermal engineers in the preliminary phases of lunar mission thermal designs. Focusing on the Moon and with the objective of being user friendly, simple and reliable, this work is intended to allow the thermal engineers to perform an efficient thermal preliminary study in this environment.

Thermal Design / **3**

Thermal design, analysis, testing, and contact conductance characterization for a 27U satellite avionics assembly

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Thermal testing and validation of the satellite components are critical during the satellite development phase. In general, thermal contact conductance and heat flow path on the satellite components are verified through simulations and by performing thermal vacuum tests. In this paper, detailed thermal modelling, analysis, and testing of a 27U microsatellite's avionics assembly are described. X-Band transceiver and a few in-house designed boards such as Command and Data Handling (CDH), Electrical Power Systems (EPS), and Payload Interface boards (PIB) are put together in a stack and integrated into a custom-designed aluminium casing for integrity and better thermal conduction. All the avionics boards in the stack are held in place using Kooler guides at both of its shorter edges to aid heat transfer from the boards to the casing. In addition to that, a thermal strap is used from the CDH to the aluminium casing to keep it within an acceptable limit during peak operation. The 27U satellite named ARCADE (Atmospheric Coupling and Dynamics Explorer) has two scientific instruments and an RGB imager as payloads and it has a 1U Iodine (I2)-based Ion thruster to perform Very Low Earth Orbit (VLEO) operation. The satellite is expected to be launched in 2022 from Polar Satellite Launch Vehicle (PSLV). The avionics in the satellite is designed to go through different mission scenarios as different payloads operate at different durations. The actual on-orbit mission operation power profile is simulated inside the thermal vacuum chamber and on the ground to verify thermal contact conductance for some of the critical contacts.

Cube Sats / 26

RADCUBE Thermal Analysis, Testing, and Correlation

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Electronic systems can be adversely effected in space due to the radiation environment. Due to the available space-qualified devices often lacking the necessary performance requirements set by the satellites' onboard softwares, commercial off-the-shelf (COTS) products are used more and more often. Testing of cosmic ray sensitivity is very challenging on Earth's surface, thus an alternative approach is used: the RADCUBE satellite measures the cosmic radiation bombarding its sensors, while also constantly conducting measurements to determine if the onboard electronics show any discrepancy during their operation. The satellite entered orbit on 16th August 2021, and is currently orbiting Earth in a Sun-synchronous orbit with an LTDN of 10:30h, an altitude of 541/501 km, and an eccentricity of only ~0.0028. This quasi-circular orbit poses a challenging thermal environment for the satellite and its electronics, and this paper gives an overview of said thermal environment's prediction and tasks involved in the qualification of the RADCUBE satellite. First, the orbit of the satellite and the necessary Solar parameters are described. Secondly, the paper explores the creation of the thermal mathematical model and the predicted temperature values for its subsystems. Creating a sufficiently detailed TMM with optimal run-times was a challenge in itself, however, the greatest task was modelling the different stages of mechanism deployments, taking into account the initiation of the satellite's subsystems and their varying dissipations, and thus determining the quasi-transient commitioning phase after the first hour of satellite deployment. Then, the planned testing procedure of the PFM satellite is described, detailing the adversities experienced during the initial Thermal Balance Test, and how the manual operation of the Thermal Cycling Test was conducted. Lastly, the correlation of TMM with test data is presented, an important lesson on how testing data can show a simulation model's shortcomings, with other lessons learned throughout the project.

Cube Sats / 31

QARMAN reentry CubeSat: thermal analysis supporting mission failure investigation

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QARMAN is the "QubeSat for Aerothermodynamic Research and Measurements on AblatioN" of the von Karman Institute of Fluid Dynamics (Belgium). It is the world's first CubeSat designed to survive atmospheric re-entry. The main aim of the QARMAN mission was to demonstrate the usability of a CubeSat platform as an atmospheric entry vehicle.

QARMAN is a 3U CubeSat whose thermal design is based on a front cork-based ablative thermal protection system, and on internal heavily-insulated survival units protecting key equipment. It was launched in December 2019 and deployed in orbit from the ISS on 19 February 2020. It was operated for 5 months, demonstrating proper functioning of the main subsystems. QARMAN unexpectedly stopped transmitting on 14 July 2020.

An extensive failure analysis has been carried out with the support of ESA experts. The last received beacons showed increasing temperatures for OBC, UHF, and ADCS. Mission analysis (ran with STK software) showed that this peak of temperature coincide with QARMAN being exposed to constant sunlight (instead of the typically alternating 60 min sunlight / 30 min eclipse). This pointed towards a thermal-induced failure caused by an extended sunlight period. This scenario was further investigated by running extensive thermal analyses with ESATAN-TMS software, including model correlations based on TVAC and orbital data, and prediction of thermal behavior over the period of interest. The thermal analysis did not permit to conclude with certainty on the root cause of the signal loss failure but batteries can be considered the most at risk, reaching the upper part of their nominal range and being a critical element of the system.

The proposed presentation will introduce QARMAN and its thermal design, before detailing the failure analysis. It will emphasize the post-mission thermal analysis process, which was based on sometimes scarce data and required strategies to overcome the limitations of ESATAN-TMS (not permitting the propagation of orbital elements). The conclusions will be shared and opened to discussions and suggestions.

Thermal Analysis / 18

TMM Reduction using Machine Learning Techniques

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A recurrent industrial problematic lies in integrating sub-models into full and complex models, such as adding a spacecraft model into a launcher model. Thermal nodes clustering is currently proceeded manually by thermal knowledge from the technical expert, taking a substantial amount of time.
One of the milestones of the PhD funded by Dorea about Model Reduction for Space Thermal Simulation includes the study of state-of-the-art machine learning and deep learning algorithms, notably clustering algorithms (e.g.: k-means, spectral clustering, mean-shift). Deep learning being a subset of machine learning, the main difference between them is how feature extraction is handled. For usual machine learning algorithms, the user manually chooses relevant features, check whether the output is as required, and adjust the algorithm if this is not the case, which seemed relevant for this study. For deep learning algorithms, however, features are extracted automatically, and the algorithm learns from its own errors.
The idea detailed here consists in elaborating a proof of concept about automatic clustering of thermal nodes into average nodes (according to TMRT terminology) via machine learning. Depending on the AI method chosen by the user, the number of clusters (consisting of a grouping of thermal nodes), can either be the input or the output of the clustering techniques.

The first naive approach considers four parameters for each point associated to a thermal node: the coordinates of its centre of mass (x,y,z) and its associated temperature T for a given configuration at a fixed time step. Then clustering machine learning algorithms from the scikit-learn library are tested on these input data, resulting in different clustering configurations. The results induced by the reduced models are compared and discussed with the original calculations case.
If the results of the concept are encouraging, a tool that considers multiple configurations over a complete orbit could be developed.

Thermal Analysis / 30

ESATAN Thermal Modelling Suite – A New Rapid User Interface

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ESATAN-TMS provides an advanced thermal modelling environment for the thermal analysis of spacecraft and launch vehicles. The suite is continually being enhanced to meet current and future requirements of space projects, and to support the specific needs of thermal engineers. This presentation will focus on a new user interface enabling rapid development and implementation of customized operations within ESATAN-TMS Workbench.

2-phase technology / 5

Preliminary design of a mechanically pumped cooling system for active antennae

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The satellite telecommunications industry is currently undergoing significant evolutions. Future communication satellites need to accommodate a rapidly growing demand in data transfer, combined with more flexibility. For example, there is a strong need for Very High Throughput Satellites capable of delivering up to Tb/s over wide coverage areas and an active phased array antenna is a powerful enabler to achieve that. However, cooling of active antennas requires the use of a highly efficient thermal control system because it has many heat sources (hundred or more), high local heat fluxes (20W/cm^2 at evaporator interface), high overall dissipation (around 10 kW), and isothermal requirements on the amplifier chain. These conditions are very difficult to solve with current thermal control solutions (e.g. heat pipes or loop heat pipes), but require a two-phase mechanically pumped fluid loop (MPL). In a MPL, a pump circulates a fluid which evaporates when it absorbs the waste heat from the active antenna. In the EU funded IMPACTA project, a demonstrator for such a MPL is being designed and built. This presentation describes the preliminary design for this demonstrator, including the fluid selection and tests on evaporator samples.

2-phase technology / 8

Lessons Learned from Testing a Large Pulsating Heat Pipe Embedded in a Carbon Fibre Sandwich Panel

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Carbon fibre reinforced polymer (CFRP) composite sandwich panels are becoming commonplace in satellite designs due to their high strength and low mass. While excellent for the mechanical engineer they create difficulties for the thermal engineer due to their poor thermal conductance. This presents problems for a traditional satellite architecture where units are mounted on a panel and the conductance of the panel is used to disperse heat.
A solution to solve this problem while maintaining the strength and mass benefits of CFRP is to embed a pulsating heat pipe (PHP) within the sandwich panel. Using such a device promises to raise the in-plane thermal conductivity of a CFRP panel significantly.
A PHP and panel with an area of 1 m2 and thickness of 18mm was designed in a collaboration between Argotec, the University of Pisa and 5M. The project was commissioned by ESA. The PHP consisted of a meandering tube with 12 turns with a centrally located evaporator section on one face and the condenser located on the other face. A PHP breadboard was tested with two different working fluids, acetone and acetone with water, with different filling ratios and in horizontal and vertical orientation. The EM panel was tested in horizontal and vertical orientations in a thermal vacuum chamber.
This presentation describes the lessons learnt during the breadboard PHP testing and engineering model PHP testing.

2-phase technology / 14

Experimental and numerical study of a SiC-Ammonia heat pipe

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The increasing demand in image quality provided by forthcoming observation missions requires both the need to use very low-CTE materials for focal planes, such as Silicon Carbide (SiC), and the need to accommodate electronics as close as possible to the detector. Such a highly integrated focal plane thus implies an efficient Thermal Control to drain the dissipated power and ensure a high temperature stability at detector level. One solution could be to design a focal plane with embedded grooved heat pipes which would drain power and homogenize temperature. A first step is then to demonstrate that such embedded heat pipes can be manufactured inside a SiC focal plane and work properly.

In the frame of a CNES Research & Technology activity, co-funded by CNES, a SiC-based heat pipe has been manufactured and assembled by Mersen Boostec, and characterization tests have been performed in CNES premises after filling it with ammonia. Besides, a simple thermal model was developed and compared to experimental results.
This presentation gives an overview of the manufacturing process and the main results obtained during the experimental campaign.

Thermal Design / 28

Assessing the Influence of Plate Mechanics and Flatness on Performance of Dry Thermal Interface Solutions in Space Systems

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Spacecraft thermal interface selection has traditionally been driven by an over conservatism that has ultimately built in excess cost, assembly time, and suboptimal performance into builds for the past few decades. Machining tolerances, waviness of panels, and large area interfaces that bow or warp when bolted all combine to create interfaces that can have substantial out of flatness and gaps when assembled. Driven by a need to make reliable contact in these interfaces, liquid thermal solutions such as liquid silicone rubber or thermal greases have found widespread adoption in many spacecraft thermal interfaces despite significant downsides of working with these materials, including low conductivity, excess installation times and difficult rework, the possibility of pump out or bolt torque loss, and the potential for contamination and debris generation. Dry interfaces such as gaskets and gap pads can address the concerns of the liquid solutions including easier install and rework along with good thermal performance. However, adoption of these materials in many applications is hindered by an uncertainty regarding the ability to make and maintain contact in interfaces that are not fully flat. Thicker dry gaskets can help with making contact over larger areas, but thick gaskets are also often beset with challenges related to compression set that can result in torque loss at the bolts, potted insert pull out, and loss of contact upon thermal cycling. This work will discuss the performance of a unique, very low compression set thermal gasket for spacecraft thermal interfaces based a composite platform of vertically aligned carbon nanotubes anchored to an aluminum substrate. Using this low compression set form factor as an example interface structure, we present a first principles model based on Euler-Bernoulli beam theory that can accurately predict contact area and thermal conductance in vacuum for plates with a range of inherent curvature, bolt spacing, and plate waviness. We show experimental validation of contact area and conductance predictions for the carbon nanotube based gaskets as well as the influence of thermal cycling on the ability of the dry gasket to maintain contact. Lastly we discuss a novel layering strategy that enables targeted contact area enhancement in regions that otherwise would not make contact with a dry gasket, significantly opening up the viable application space for these carbon nanotube based gaskets.

Thermal Analysis / 9

Prediction of the Thermal Conductivity of Foam Insulations by a Surrogate Model

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Foam insulations are important thermal control elements for cryogenic upper stages. One of these, called "External Thermal Insulation" (ETI), was developed at ArianeGroup GmbH in Bremen for first use on Ariane 6. In particular, the thermal conductivity of the current ETI configuration has been characterized by tests. Further developments of the ETI are planned, where the thermal conductivity of new foam configurations will be predicted on the basis of the already available information and upcoming characterization measurement to be defined.

For the prediction of the thermal conductivity of new foam configurations, the method of "Surrogate Modeling" is applied. The Surrogate Model is constructed on the basis of the data points, reproducing as accurately as possible the "input-output" behavior. As an interim step, the data points of the sampling plan are complemented with theoretical points derived from a model based on physical relations. On the long run, the most relevant theoretical points will be replaced by additional characterization measurements. The thermal performance of a new ETI configuration in an atmosphere with a relevant helium content is studied.

Thermal Analysis / **27**

Modelling a polar lunar landing site with ESATAN-TMS

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The ongoing project PROSPECT is aiming to land a drill (ProSEED) and a lab (ProSPA) on the surface of the Moon with the Russian Luna-27 mission planned for 2024/2025. The objective is to detect and quantify the presence of sub-surface ice in South Polar regions of the Moon. The environment is thermally challenging given the wide range of lunar surface temperatures and the varying lighting conditions. Furthermore, only a few details of the Russian lander are available. In addition the landing site and local illumination conditions are not fully defined.

The instrument requires the samples to stay below 150 K between sample acquisition until they are sealed in an oven. The drill which takes the samples is connected to the lander interface. Its temperatures are driven by the lander interface plate temperature and the radiative environmental conditions, i.e. direct solar illumination, IR heat flux from the lunar surface as well as radiative exchange with the lander.

In this study, we focused on the use of ESATAN-TMS to model the orientation of a lander on the surface of the Moon accurately. We identify several ways of accommodating the movement of the Sun over the horizon over the course of a lunar day and performed a set of sensitivity analyses to define the operational window of the drill.

Thermal Analysis / **7**

Validation of a Spacecraft HARness Evaluation tool (SHARE) using black-box optimization

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The harness sizing for space applications is driven by derating rules, which are specified in international standards and in particular the ECSS-Q-ST-30-11C Rev 1 (2011) , "Space Product Assurance, Derating EEE Components", relevant for a wide range of European space projects. The respective standard, concerning wire and cable derating, is based on tests conducted in the 50's and 70's and known to be rather conservative, resulting in significant design margins and thus unnecessarily increasing harness mass. The presentation will focus on the validation of the Spacecraft HARness Evaluator (SHARE), a new tool to perform thermal analysis and enable mass optimization of spacecraft harness wires and cable bundles. SHARE is made available to European Space Industry to support harness design optimization and derating analysis. Validation of SHARE is performed using the test data that was collected during an ESA study "Improved design and use of electrical harnesses (ESA Contract No. 4000116112/15/NL/PS) that had the objective to reassess existing spacecraft harness derating rules and promote the use of simulation tools to optimize harness sizing. Following this study an update of the respective ECSS-Q-ST-30-11C standard on EEE components derating has been initiated in 2020. Validation of SHARE is performed using two half sets of test data collected during the previous ESA study. This comprises 534 test cases in total, both single wires (417) and bundles (117). For single wire correlation the emissivity per wire is used as (the only) correlation parameter. For bundle correlation the bundle-to-enclosure radiation (scaling factor) as well as the wire-to-wire contact conduction are used as (the only two) correlation parameters. For both single wires as well as for bundles the RMS error of the overall maximum temperature is used to drive the

correlation. The correlation is performed by iteratively minimizing the RMS Error by means of Black-Box optimization. This optimization approach is very well suited to optimize non-analytic problems that involve time consuming evaluations. It is concluded that, for the investigated test cases, the 68% interval and the 95% interval of the overall prediction accuracy of the maximum temperature is given by:

Single wires:
68% interval: -4.0/+4.2℃
95% interval: -9.3/+8.5℃

Bundles:
68% interval: -3.3/+3.2℃
95% interval: -9.1/+8.3℃

The validation and development of the SHARE tool is funded by ESA in the frame of the Technology Development Element (TDE) programme under ESA Contract No. 4000132783/20/NL/FE.

Thermo-Elastic / 13

Innovative approach for Thermo Elastic Testing of a full scale Spacecraft

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BIOMASS was selected as the 7th Earth Explorer mission and will be the 4th Core Earth Explorer Mission. The overall objective of the mission is to reduce the uncertainty in the worldwide spatial distribution and dynamics of forest biomass to improve current assessments and future projections of the global carbon cycle. BIOMASS P-band SAR will enable the first global scale, systematic measurement of forest biomass, providing global maps of forest biomass stocks, forest disturbance and growth.
BIOMASS pointing budget is one of the mission's demanding requirement: the precise knowledge of the Payload pointing direction is fundamental for the scientific observations' success.
One of the contributors to the overall pointing budget are the Thermo-Elastically induced Deformations (TED) caused by the temperature gradient along the satellite structure when subject to the mission's environmental loads, whose estimate in Space applications is typically predicted by means of Finite Element Modelling.
In the frame of BIOMASS design and verification process, an innovative thermoelastic test at ambient pressure has been designed and successfully executed with the goal of obtaining an experimental feedback of the as-builts structure response, which has been then compared to the FE model predictions.
Scope of the test has been the application of a set of known boundary conditions comparable with the predicted flight thermal gradients and to measure, by means of photogrammetry and laser trackers techniques, the BIOMASS structure's overall deformations under such loads. The collected displacements and rotations measurements have been used to identify the correlation factor between experimental data and FE model predictions.
This presentation addresses the TED test setup description and the measurements results, both in terms of thermal mapping and deformations response.
BIOMASS test instrumentation is presented, and the measurement system choices justified; all the test phases are then detailed and finally the correlation criteria to reach the goals illustrated.
Test outcome and post-processing analyses are presented; final correlation of both Thermal and FE models is then described.
The objective and conclusions of the completed campaign are discussed with the scope of providing the engineering community audience the lessons learned, the advantages, the encountered criticalities and the challenged experienced in the frame of an innovative full scale Thermo Elastic test

approach to experimentally determine the behaviour of medium sized satellite structure.
It had been demonstrated how the BIOMASS structure was successful to undergo a thermoelastic campaign at ambient pressure, which is an innovative approach able to reduce the complexities of a Thermal Vacuum setup, especially concerning the deformation measurements on a large mechanical structure.

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JUICE Spacecraft Thermal Balance Thermal Vacuum Test

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JUICE (JUpiter ICy moons Explorer) spacecraft will provide a thorough investigation of the Jupiter system in all its complexity with emphasis on the three potentially ocean-bearing Galilean satellites (Ganymede, Europa and Callisto) and their potential habitability. It will carry the most powerful remote sensing, geophysical, and in situ payload complement ever flown to the outer Solar System. The payload consists of 10 state-of-the-art instruments. One of the main design drivers of JUICE mission is the low solar illumination received at Jupiter. which drives the thermal control, that is designed to cope with hot and cold environments. The thermal control has to cope with a large variation of external environment during the mission (Sun flux from 3323 W/m² in the inner Solar System down to 46 W/m² in Jovian environment) and long eclipses of up to 4.8 hours.
The thermal verification of the Spacecraft included early test of a scale 1:1 Thermal Development Model in cold and hot environment, including the use of a Solar Simulator. In June/July 2021, the Spacecraft Flight Model was tested during 4 weeks, including 5 thermal phases and 2 functional tests. The presentation will give a synthesis of the main outputs of the test and a preliminary assessment of the thermal model correlation with the test data.

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Design and Development of the SXI Thermal Balance Test

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Design and Development of the SXI Thermal Balance Test

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The Soft X-ray Imager, or SXI, is one of four instrument and experiment packages on the SMILE spacecraft. SMILE is a joint ESA/CAS science mission due for launch in 2024. SXI is a wide-field lobster-eye telescope using micropore optics to spectrally map the location, shape, and motion of Earth's magnetospheric boundaries, including the bow shock, magnetopause, and cusps, by observing emission from the solar wind charge exchange process.
The SXI Telescope is equipped with two large X-ray-sensitive CCD detectors – located in the optical bench behind the radiator – covering the 0.2 keV to 2.5 keV energy band, and has an optic field of view spanning 15.5° × 26°. SXI is developed, built, and calibrated at the University of Leicester (UoL),

UK, with contributions from institutions throughout Europe. The University of Leicester lead the design and manufacturing of the complete thermal test GSE. Space Acoustics are part of the Swiss consortium which provides the radiator thermal subsystem, MLI design and instrument thermal lead. The UK Space Agency (UKSA) funded the SXI MLI, thermal testing and elaborate thermal test GSE, partly in response to technical/programmatic and travel challenges from the pandemic. ESA TEC-MTV team have been very active in supporting the SXI thermal engineering since 2017 and made significant contributions to the STM test engineering.

SXI detectors operate at around -115℃ and are cooled by a large space-facing radiator which is part of the Telescope, the other side of the SXI is sun exposed. A passive thermal control system with heaters keeps the CCDs near the optimum operating temperature to mitigate against the effects of radiation damage and maintains the detectors above their survival temperature limit. SXI operates in a highly elliptical Earth orbit, a heavy shutter covers the detectors to protect from radiation during passage through the Van Allen belts. Stable temperature conditions throughout the long observations phases is required. The thermal design of the SXI is quite challenging, achieving the low and stable detector temperatures within the constraints of the mechanical design, SC installation and mission parameters. The thermal engineering of SXI began in 2017, a key stage is the STM thermal test which began preparation in 2020, the test started in August 2021 in the 2.2 m diameter x 2.2 m length thermal vacuum chamber at Airbus in Stevenage.

The subject of this presentation is the design, development and operation of the thermal test hardware for the SXI STM thermal balance test. The challenges of the test were mainly driven by the requirement to validate the thermal analysis model in a range of mission relevant conditions and to reproduce the thermal boundaries and orbit conditions as accurately as possible. The pandemic restricted on-site access to the test to a few days for set up, the test operation needed to be performed remotely from Leicester. The design and development of this complex real-time remote control and monitoring for both SXI Instrument and Thermal Test GSE thermal control, utilising conventional heaters and sensors was part of the test development work and is explored in the presentation.

The STM thermal balance test is performed in a large chamber with LN2-filled shroud covering most of the internal surface. The UL-manufactured and designed GSE provides the thermal boundaries, comprising a baseplate and detailed representation of the platform module equipment with all surfaces temperature-controlled to reproduce the interface temperatures and radiative conditions of space hot/cold operational, cold survival and transient phases. Sun-side thermal loading is provided by a heater enclosure. The SXI Instrument STM comprises a comprehensive replica of the flight Telescope, mass/thermal dummy electronics units and flight-representative harnesses. The platform module and GSE is well-insulated with MLI to limit the heat leak into the chamber and parasitic heat incident on the radiator surfaces. Detailed analyses of the test setup were used to support the GSE design, and will be described in the presentation.

A criterion was to achieve very similar temperatures for all parts of the SXI in the test to the predicted in-orbit cases, and in-orbit analyses were compared with models of the test setup, which were improved iteratively. The SXI thermal control system, using both nominal and redundant operational and survival heater patches on the large radiator, will be operated during the test and the data used to verify sizing. A high density of temperature sensors is used to support an accurate model correlation, their placement was optimised with the thermal models. Some components were unavailable for the test, in this case accurate dummies were designed and produced, using representative materials, geometries and surface coatings. All harnesses were present and exactly reproduce the current flight hardware designs.

The test set up was developed with the possibility to re-use for the PFM tests, the wide range of thermal cycling and accurate thermal balance conditions achievable with this equipment will be of value in the qualification of the flight unit and the experience gained in operating and evaluating the STM test should provide an improved and low-risk test for the PFM next year. First results from the operation of the STM test and correlation with the GSE thermal design models will be presented and initial lessons-learned discussed.