European Space Thermal Engineering Workshop 2022

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ESA/ESTEC

Book of Abstracts

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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 / 38

An enhanced Earth InfraRed flux and Albedo model based on real data

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Within the last years, a larger number of spacecraft have been launched in Low Earth Orbit (LEO). The current trends show that it is continuously increasing, with a growing part for light CubeSats. Most of the LEO spacecraft are dedicated to Earth observation, and they can feature relatively large instrument openings and/or low thermal inertia, especially for the CubeSats. This usually makes the payloads or the entire spacecraft thermal behavior particularly sensitive to the Earth environment, for both the albedo and the Earth emitted infrared fluxes. In parallel, the development of numerous Earth climate monitoring missions has provided more accurate and detailed data about the Earth albedo and infrared flux in the last two decades. It appeared recently that this data can be used to feed statistical survey of the real thermal environment as viewed from spacecraft in low orbit depending on their orbital parameters. For this purpose, ESA have developed an internal tool that, for a given orbital position, generates incident infrared and albedo flux values based on real measurements available daily, generating a sizeable number of parametric environmental flux results. A systematic series of simulations have been run with these real data to cover circular orbits ranging from 100 to 800 km altitude and with various inclinations. The emphasis was particularly put on the Sun Synchronous Orbits (SSO) and how their Local Time at Ascendant Node (LTAN) has an impact on the perceived Earth environment. This presentation will explain briefly the method of calculation and will present how the worst cold and hot Earth environments were identified for different types of orbits. It will eventually present some ranges of perceived albedo and perceived Earth temperature for the short and long term as a function of the altitude, the inclination and the LTAN for the SSO.

Thermal Analysis / 25

Thermal analysis of hyperspectral optical instrument with emphasis on electronics heat dissipation

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Thermal analysis of hyperspectral optical instrument with emphasis on electronics heat dissipation

Thermal behavior of any optical instrument requires thorough analysis – either to prevent it from negatively affecting optical properties or to ensure operations safety.

An under development hyperspectral imaging optical instrument (OI) designed to Intuition-1 nanosatellite was subdued to thermal numerical analysis as well as preliminary experimental investigation.

In this work an attempt was made to create numerical model of mentioned optical instrument. Three cases were analyzed:

- Behavior in Earth's atmospheric conditions while pointing OI at Sun.
- End of detumbling process on orbit with sun passing through diagonal of OIs field of view.
- Identification of maximum time of consecutive Earth imaging in orbit.

Those thermal scenarios were simulated in Simcenter FloEFD software. This tool was first tried in such application by company's thermal team. Based on that, we would like to share with engineering community the pros and cons of the FloEFD utilization to challenges which we were facing. Highlights list presented below is covering specific software topics which we were facing on.

Highlights:

Utilized software has been used to:

- Setup of optical properties (wavelength dependent refractive index, absorptivity and emissivity etc.)
- Setup of thermal properties (material and contact resistances, etc.)
- Earths radiation simulation with diffusive light source and defined sunlight spectrum
- Solar radiation simulation with sunrays direction based on position and time on Earth
- Time-dependent study with parametrically changing boundary conditions and mesh

Optical instrument sub-elements and the whole OI were preliminarily tested, and experiments results used in attempt to perform numerical analysis correlation. lysis correlation.

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SATELLOGIC FLIGHT THERMAL MODEL CONCEPT AND IN ORBIT VERIFICATION AND VALIDATION STRATEGY

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Satellogic is a company that produce satellite earth observation images. Looking for making Earth Observation imagery accessible and affordable to drive better global decision-making.
The Satellogic satellite earth observation constellation is currently made up for twenty six operative satellites and planned to growth to sixty three satellites in 2023, one hundred thirty nine in 2024 and two hundred two in 2025.
The design and requirements verification of our satellites requires of a high standard technological engineering flow and the use of complex simulation tools, commercial and in house tools.
Satellogic have been development a process of satellites thermal design and its verification based in the use of Space System Thermal analysis tool, internal tools and a Verification and Validation Plan that is executed in orbit, development this own concept to use a satellite as a flight thermal model (FTM).
The capability to use the space as a big laboratory gives to Satellogic an strong capability to improve the thermal design and technology push of our satellites with a constant feedback of flight information, given us reliability and low cost of test compare with the space standard industry.
The purpose of this presentation is to present the Satellogic thermal design flow, made up by thermal, analysis cases and FEM requirements definition, power condition sequence and orbit maneuvers generation tools. Finally a presentation in detail about the results of the satellite thermal design verification and validation strategy using a satellite as a Flight thermal model (FTM) and the Maya thermal correlation tool will be presented.
All the design flow is based on the use of a Space System Thermal as a thermal analysis and design verification tool.

Thermal Control / **18**

Development of a compact high-effectiveness recuperator for a space 40 K Reverse Turbo-Brayton cooler

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A space 40 K Reverse Turbo-Brayton (RTB) cooler is currently under development in Europe to enable a variety of cooling needs, including vibration-free cooling of sensitive detectors and improvement of low-temperature cryochains. The performance of an RTB cooler relies on the effective heat exchange in its recuperator. In this context, a novel high-effectiveness mesh-based recuperator concept has been developed in a collaboration between ESA, CERN and University of Twente. The mesh-based design was already constructed for on-ground particle accelerator applications and an effectiveness of over 99 % has been experimentally demonstrated. A numerical model was created to predict thermal performance of such a recuperator and its reliability for neon as a working fluid was experimentally validated. In this work, three potential recuperator designs for the space RTB application are presented. The designs were sized to fit the stringent requirements from ESA, amongst which an effectiveness of 99 % with a recuperator mass of under 2 kg. A prototype of the recuperator was manufactured and subjected to vibration testing at ESA's Mechanical Systems Laboratory. Further, the recuperator has undergone leak and pressure tests at CERN. The experimental results of these tests are presented and future development directions are outlined.

Thermal Control / **47**

Smart Heaters

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Electrically heated temperature control is a widely used concept in spacecraft thermal control. Currently this technology has two main limitations: the use of many cables when using a large number of heaters, and limitations when reconfiguring the temperature setpoints in-flight. The "Smart Heaters" is an autonomous and self-standing electronic control system that can overcomes the limitations of traditional temperature control systems. The main objectives of the "Smart Heaters" system are therefore: autonomous control of the temperature, in-flight power and temperature reconfigurability via telecommand and reducing the system complexity minimizing its harnessing.
In this project, flexible solutions have been sought to adapt the system to missions with different requirements (i.e., Deep space mission or New Space constellations), as well as to different spacecraft sizes (i.e. Cube sats or satellites). For this reason, a modular design based on a microcontroller with sensors, power control electronics and heaters has been developed. Using this design, multiple heaters will be independently controlled, maintaining temperature setpoint configured via telecommand. In turn, a function to control each heater maximum delivered power will be enabled, being reconfigurable in-flight via telecommand.

Thermal Control / **42**

The Thermal-Structure design issues on a cryostat for a milli-Kelvin TES sensor tests

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The X-IFU instrument, for mission ATHENA, use TES (Transition Edge Sensor) sensors in its focal plane, which require temperatures of tens of milli-Kelvin in operation. Therefore, the focal plane needs an extremely efficient thermal isolation. The complete detector assembly (focal plane, cold electronic, and the close refrigerators for the thermal conditioning in the assembly),
perform such thermal isolation, from 2K to milli-K. The very low conductive suspension of the focal plane and the TES detection characteristics does relevant the dynamic behaviour of structure, which is converted in TES temperature, thus in the detection efficiency. Levels of micro-g at low frequencies (< 300Hz), implies variations of temperature of micro-K, enough to disturb the detection.
INTA is designing a cryostat for on ground characterization of the XIFU detector assembly. It should provide enough volume (circa 0.1 m3) with thermal interfaces a 2K. The mechanical interface should be compatible with a frequency spectrum bellow of 10-6 g at frequencies bellow of 300Hz, to warrant temperatures fluctuations below of micro-K. The cryostat isolates and cool down the detector assembly (up to the interface temperature), by means of two intermediate thermal-structural shells cooled by pulse tube refrigerators up to 4K, while a Joule-Thomson refrigerator put the final interface of 2K. As it has been mentioned, all the cryostat structure, as well the thermal hardware, shall isolate the detector assembly from the vibrations induced externally at the cryostat: seismic vibration (coming from earth, close transport or operations on the room), and vibrations transmitted by the pulse tubes refrigerators and vacuum system pumps. We will present the solution propose for thermal isolation: holding systems and thermal anchors that shall be compatible with the dynamic requirements, and give a reasonable cool
down time, around a week. Flexible thermal links and thermal switch shall be designed as such effects.

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LiDeR – A Deployable Passive Radiator

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Due to increasing payload electronics power consumption, today's spacecrafts often require generally larger payload radiators as the spacecraft body can provide. The use of deployable radiators seems to be the next logical step to achieve the required enlargement of the radiative area. Large deployable radiators based on two-phase heat transportation systems are today available, but these systems are technically complex and therefore not suited for smaller and cost-efficient spacecrafts, especially in future spacecraft constellations. Therefore, the innovative passive deployable radiator system LiDeR (Lightweight Deployable Radiator) has been developed, incorporating a very cost-efficient but also very high thermal conductivity panel. This panel is based on graphite foils sandwiched between hooked metal sheets which enable the high out-of-plane conductivity required for the radiator functionality.

The paper will present the outcome of an accompanying material investigation campaign, the results of mechanical shaker tests on a full-size breadboard level as well as breadboard performance demonstration in a thermal vacuum chamber. Since the results are very promising, the authors will present and discuss the extensive test program which has been set-up to gain further confidence in the technology by material test data and material model refinement.

Thermal Design / 8

High Performance Thermal Straps with Enhanced Conductivity for Space Application

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As thermal components make an important constituent of the spacecraft, constant development and optimization of such parts is needed. Within the H-PERTS project, HPS-RO focused on developing High Performance Thermal Straps. These parts represent thermal management solution, offering a combination of mechanical decoupling and thermal transfer.

Because the main goal of HPS-RO was to enhance conductivity of the thermal straps (with respect to the existing products), graphene sheets represented the focal point of the work. Such material has excellent thermal properties, but is not yet extensively used inside the EU. Through Development and Testing of the Graphene Sheets Thermal Straps, the following achievements were identified:

- Improved thermal behavior of the straps by more than 10% compared to selected benchmark for a temperature range between 130K and 173K.
- Significant mass reduction from 300 g (targeted mass) to 129 g.

The presentation will cover the main steps of the project, emphasizing the technical challenges in the development process encountered by HPS Romania.

Thermal Design / 9

Thermal Design of a Spaceborne Deployable SAR Reflector

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The presentation deals with the thermal design of a deployable reflector which is part of a spaceborne SAR payload.
The different sections and components of the payload will be presented and the approaches to deal with the challenges to their thermal design.
The design comprises for instance 3 different composite configurations with different resin systems and manufacturing processes to adapt the design temperature ranges to the different predicted environments.
Also the different coatings and surface treatments of components for thermo-optical property optimisation will be shown, as for instance sand-blasting for infrared emissivity optimisation for sun-exposed metallic surfaces.
The thermal design close to neuralgic interfaces as adhesive layers with limited thermal design range will be explained as well as material choice measures at interfaces to minimise heat loss at temperature sensitive components.
The trade-off based Multi-Layer-Insulation design concept at different payload sections will be presented, as well as the design of the thermal control system in the frame of heater sizing and temperature set-point definition.
Also the aspect of temperature dependant waveguide dissipation as input for the thermal analysis will be demonstrated.

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Mars Sample Return: Thermal Design of the Earth Return Orbiter

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The physical return of samples from Mars has been a top priority of the international planetary science community for over a decade. A wide consensus is held on the fact that a mission which enables the analysis on Earth of samples returned from well-characterized sites on Mars would allow the greatest return for key scientific objectives, such as understanding the evolution of Mars climate and geology, searching for evidence of extinct and extant life and past habitability, and preparing for eventual human exploration. NASA and ESA are currently collaborating to coordinate a joint Mars Sample Return (MSR) campaign, capable of delivering a variety of soil samples collected on Mars for analysis on Earth. This international campaign should comprise three missions. NASA Mars 2020 rover (Perseverance) is already on the Mars soil performing the initial sampling and caching samples. The following three proposed missions entail the following elements: a fetch rover that will collect the samples left by Perseverance, a landing platform with a rocket to launch the samples into Mars orbit, a dedicated spacecraft (named Earth Return Orbiter) capable of capturing the orbital sample and returning it to Earth.
The Earth Return Orbiter (ERO) mission is characterized by a payload composed of two elements: a sample handling payload to perform the capture and bio-sealing of the Orbiting Sample (OS), and

the Earth Entry System (EES). Following a transfer to Mars, the ERO spacecraft will be captured into Mars orbit and spiral down to reach a low Mars orbit in time to support the data relay of the lander entry, descent and landing as well as the following surface mission. Once the OS is ready to be launched into Mars orbit, ERO will adjust its orbit in order to provide coverage of the ascent vehicle launch. The ERO will then detect, rendezvous with, and capture the OS, before transferring it safely to the EES. On the return to the Earth, ERO will release the EES on an entry trajectory before performing an Earth avoidance manoeuvre itself. After touchdown on Earth, the samples are transferred safely to a dedicated sample receiving and curation facility.
This presentation deals with the thermal design of the Earth Return Orbiter (ERO), with a focus on the European modules, describing the design challenges, current status and future activities planned in the development of the Thermal Control Subsystem (TCS) of the spacecraft.

Thermal Analysis / **21**

Systema-Thermica

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This year, the latest Long Term Support Version of Systema has been issued. The last active one was Systema 4.8.3P3, and it is now replaced by Systema 4.9.2.

The V4.9.2 version of Systema-Thermica has already been released and is available to users since September 2022. This new version provides some enhanced ergonomic features affecting the model creation process, such as choosing between local or global referential to apply transformations when using the gizmo and using drag and drop in the model tree.

Moreover some STEP-TAS improvements have been added, following the line of work that is in progress since 2020. Among other features, material phases and sentinel value are now supported.

Finally some improvements on the Python API, now embedding an extensive Python 2.7.18 distribution, with several packages for scientific computation and applications (matplotlib, pandas…). The console changed as well, and is now based on Jupyter, with a large number of options provided (such as auto-completion, embedded help and method descriptions).

Thermica embeds also new capabilities such as modelling a source of UV or IR emission with a Solar lamp and exporting the Solar Zenith Angle.

2-Phase / **17**

Micropump array for two-phase mechanical pumping loop

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To dissipate large amount of heat two-phase (2-Φ) mechanical pumping loops (MPLs) are often required. Compared to their passive counterparts, such as heat pipes, 2-Φ MPLs are suitable for high heat dissipation, distributed payloads and can improve the uniformity of surface temperature.
One of the main issues in the implementation of MPL on a CubeSat platform is the difficulty in miniaturisation of the pump, the failure of which directly results in a failure of the cooling system.

To successful integrate a MPL into a CubeSat - a micropump must have several important characteristics - highly compact formfactor, excellent reliability, energy efficient and an ability to withstand high working pressures above 10 MPa.
To overcome these issues, a novel micropump based on a patented counter-wound solenoid coil technology was developed in a five-array manifold, producing 46 kPa and 150 ml/min, this system was subjected to vibrational shock, high pressure (>15 MPa) and the fluidic characterises were examined at each testing stage.
A 2-Φ MPL system using Novec 7100 as working fluid was used to measure the heat dissipation that could be achieved with the manifold system as a function of input power to the manifold (0.3-1.5W), dissipating up to 325 W (15.3 W/cm3); additional the heat dissipation was also examined as functional number of pumps in the manifold - 1, 3 & 5 units, dissipating 200, 290 & 325 W respectively.

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Radian: Thermal analysis software in the cloud

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Radian is a thermal analysis software conceived to provide agility to engineers, both at modelling and computing processes. Our software is accessible through a regular web browser and counts on a scalable network of computing resources in the cloud. Thermal analyses are supported by the Databank, a catalogue of satellite components, materials, surface treatments, orbits, and attitude configurations. Importing and exporting thermal models compatible with other CAD and thermal analysis tools is also in development.

The underlying simulation engine reproduces the orbital environment and the thermal solution. Detection of penumbra, multibody eclipse, or telescope pointing are some of the featured aspects of the simulated conditions. Thermal models are based on lumped-parameter networks, linked by conductive couplings (supported by contact detection), and radiative couplings (computed by ray-tracing).

In December 2019, FossaSat-1 became our first case study to reach orbit. Since then, 15 satellites have reached orbit supported by our analyses, and all of them have successfully reported back thermal telemetry that correlates with the predicted ranges and margins.

2-Phase / 11

Development of a Pulsating Heat Pipe for Deployable Radiator Application

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The increased use of high-power payload electronics in virtual all classes of spacecraft require generally larger thermal radiators as the spacecraft body can provide. The use of deployable radiators seems to be the next logical step to achieve the required increase in radiative area. Two technologies to design deployable radiators are presently known, which occupy the high and low end of the radiator performance scale: (1) Large deployable radiators based on loop-heat-pipes (LHP) are, due to the inherent technical complexity and high recurring cost, best suited for high-power telecoms. (2)

Passive radiators based on high-conductive materials, such as pyrolytic graphite foils, are low-cost units. But due to the finite nature of the thermal conductivity in solids, these types of radiators have generally lower specific performance and may be typically employed in small sized spacecraft.
For the large number of medium sized spacecraft, we observe that a design methodology for deployable radiators is missing, which exhibit attractive recurring costs and would cover a thermal performances regime between the mentioned LHP and passive radiators. In order to fill this gap, we started the development of an innovative deployable radiator with integrated pulsating heat pipe (PHP), which would distribute the waste heat, coming via a flexible thermal link from the spacecraft body, over the radiator area.
The technology of pulsating heat pipes has been extensively studied during the last decades for many terrestrial and space applications. Although PHP use the phase change between the fluid states of liquid and vapor for heat transfer, they are much simpler as classical heat pipes or LHP, since a capillary structure for condensate return is not necessary. Fluid passages are small (1 to 2 mm in diameter), leading to thin, low-mass radiator plates. In addition, several (low-pressure) liquids can be selected as working fluid, which avoids design efforts for a high-pressure compartment as known from ammonia systems. Meanwhile it has been verified that performance of a LHP in horizontal position during ground tests is well comparable to in-orbit performance. An important task is to verify PHP operation with radiative cooling without adiabatic section, i.e., a cooling method with low heat flux density. Such an operational condition has not been investigated in the past.
We will present and discuss the development, design and testing of several demonstrator radiator units with embedded PHP having the following characteristics:
Construction:
• Material: Graphite/Polymer compound
• Two plates with integrated fluid passages are adhesively bonded
Dimensions:
• Plate dimension: 125 x 400 mm
• Heater area: 125 x 25 mm (each side)
• Cooling area 125 x 375 mm (each side)
• Number of fluid passages: 12 (6 turns)
• Plates with circular passages (2 mm diameter) and square cross section (2 x 2 mm)
Fluid: Acetone and Ethanol
Test program:
• Heating by Kapton heater
• Cooling by radiation from both sides in a vacuum chamber against a shroud temperature of 200 K
• Tests of PHPs with different fill rates, inclination angles, and input power
We summarize the very successful test program, discuss open issues and the next development steps.

The project is co-financed by the European Union within the EDRF Program. Project ID: LURAFO3015A

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An Approach to Thermal Modeling and Analysis with Systema - Thermica

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Airbus Systema-Thermica is widely used in the European Space sector for thermal design and analysis for years. This presentation provides a brief look into the thermal processes for system level thermal analysis encompassing geometry building, thermo-physical and optical properties definition, TMM generation, and environment definition. In this presentation we address the modelling approaches and underlying assumptions, as well as their implementation in Systema.

This work also introduces some additional checks on the complete thermal models to ensure their validity, similarly to the model checks for structural finite elements models. It mainly includes mass check and conductance check through a GL matrix at global and local levels.

Furthermore, some unique examples of thermal models are shown where multiple mission phases and pointing are considered in the same analysis; analysis considering transient dissipation of components based on the pointing, eclipse, and sun exposure. Additionally, modeling of dynamic kinematics for a body is shown.

Finally, some small pointers are provided that are useful while working with Systema/Thermica.

2-Phase / 5

Chemical Compatibility of Various Working Fluids with Additively Manufactured Materials for Two-phase Cooling Systems.

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Chemical compatibility between the main components of two-phase heat transfer devices is of critical importance for correct operation and stability throughout the devices' operational lifetime. The use of incompatible fluid-metal combinations can lead to corrosion and/or the generation of non-condensable gas (NCG), both of which result in reduction in heat transfer performance or complete device failure.

In order to verify working fluid and material compatibility, life-testing experiments are being conducted across a wide range of fluid-material combinations, with a particular focus on additively manufactured materials using the laser powder bed fusion process (PBF-LB/M). As this is a relatively new technology, the material's compatibility with different fluids must be demonstrated before they can be used in future space applications. This work includes the design and manufacture of multiple thermosyphon devices, followed by ongoing long-term characterisation through gas plug testing. This involves applying an isothermal temperature to the device evaporator and monitoring, over an extended period of time, any change in condenser temperature, indicative of NCG generation. The project aims to provide recommendations of the successful fluid-metal combinations to the community.

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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 thermal 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 2023

2-Phase / 26

Development of a Two-Phase Mechanically Pumped Loop for Active Phased Array Antennas

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The development of Active Phased Array Antennas (APAAs) is a key enabler to effectively accommodate the growing demand of data transfer in commercial telecommunication satellites. A highly efficient and integrated thermal management system is required so as to reject the waste heat produced by the antenna's Solid State Power Amplifiers (SSPAs).
The development of such a thermal control system presents a number of technical challenges, chief among them being the large number of heat sources involved (typically ranging from 100 to 1000, with varying duty cycles), the need for spatial and temporal isothermal conditions across the set of SSPAs, as well as a low thermal gradient between the SSPAs and the working fluid, high total heat dissipation (10+ kW), high heat flux (20+ W/cm^2 at the evaporator's interface) and large distances between the radiator and the payload, among others.
Spacecraft thermal control systems based on Heat Pipes (HP) and Loop Heat Pipes (LHP) are currently approaching their practical limits in high-power telecommunication satellites, being no longer capable of meeting the thermal control requirements of large platforms (e.g. high-throughput satellites); as a result, the interest in Mechanically Pumped Loops (MPLs) and two-phase pumped loops in particular has increased significantly in recent years as the latter are remarkably well suited for applications involving large heat loads, transfer of thermal energy over large distances (e.g. distributed payloads), high heat fluxes and payloads with tight temperature stability requirements.
An international consortium led by AVS is currently developing an ammonia two-phase MPL for APAAs within the frame of the IMPACTA project (an EU H2020 funded activity). The present paper provides an overview of the project and its current state.

Thermal Design / 12

Thermal Design of the AMS-100 Cosmic Particle Detector at L2

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The next generation magnetic spectrometer in space, AMS-100, is designed to be operated for at least ten years at the Sun-Earth Lagrange Point 2 [1]. Compared to existing experiments like AMS-02 on the ISS, it will improve the sensitivity for the observation of new phenomena in cosmic rays by at least a factor of 1000.
The magnet design for AMS-100 is based on high temperature superconductor tapes, which allow the construction of lightweight solenoids to be operated in thermal equilibrium with the environment at a temperature of about 60 K. The magnet system consists of a central solenoid surrounded by a compensation coil to enable the attitude control within the vicinity of the solar magnetic field.

The main challenge for this kind of spacecraft concept is the thermal design. Similar to the James Webb Space Telescope, a large sunshield is used to shield the cryogenic magnets from direct sunlight.

Furthermore, the location of the particle detector inside the central solenoid creates demanding thermal boundaries. This particle detector is operated at a temperature of about 200 K, which will be controlled by a two phase cooling system connected to a dedicated radiator.
Multiple iterations of the design using ESATAN-TMS have led to a thermal model, which fulfills the specifications and details will be shown in this presentation.

[1] S. Schael et al., https://doi.org/10.1016/j.nima.2019.162561

Cube Sats / **32**

Cubesat Data Processing Unit (DPU) thermal management - from concept to testing phase.

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Intuition-1 is the cubesat mission that start is planned for 2023. The 6U satellite is designed to observe Earth by using the self-designed hyperspectral instrument. The gathered data is going to be processed on the low earth orbit by on-board Data Processing Unit (DPU). The data processing is utilizing the neural networks in the space environment as a standard operational mode. This process is computationally expensive and hence thermally demanding. The size of DPU is not bigger than 1U and the expected maximum power dissipation is 15 W. Due to that fact, the thermal control of the electronic device must cope with the high-power density.

In the study, we present the development and verification process of the thermal control system designed for DPU. The main design challenge was to create the safe and reliable heat path from the main electronic power sources to external radiator making the system thermally independent from the spacecraft structure as much as possible. For fulfilling these goals, the detailed numerical model of the DPU was developed in ESATAN-TMS with particular focus on modelling the PCBs and the thermal resistances of electronic components. The verification of the DPU included the Thermal Balance Test performed in thermal-vacuum chamber (TVAC) preceded by thermal cycles in climatic chamber. Its purpose was to verify the operation of the thermal control system in the simulated orbital environment. The results confirm the proper thermal design of TCS, but also show the unintentional behavior and ways of managing it. The obtained data from tests was used for correlating the thermal numerical model in a range of mission relevant scenarios to confirm feasibility of the space mission plan.

The presentation of this topic will be first time show to the public and it sums up the development process of DPU with emphasis on the thermal control system. It describes the TCS design, its numerical equivalent and the verification process, together with issues and lesson learnt on each process stage. Facing such thermal challenges for such electronic boxes can be of interest to the engineering community.

Thermal Design / **13**

European Contribution for Lunar Gateway – overview on Thermal Control System

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The Lunar Gateway is a small, human-tended space station orbiting the Moon that will provide extensive capabilities to support Artemis campaign. Built with the international partnerships of ESA with NASA, CSA and JAXA, Gateway's capabilities for supporting sustained exploration and research in deep space include docking ports for a variety of visiting spacecraft, space for crew to live and work, and on-board science investigations to study heliophysics, human health, and life sciences, among other areas. Gateway will be a critical platform for developing technology and capabilities to support Moon and Mars exploration in the coming years.
ESA main contributions to the lunar gateway are the International Habitation Module (I-HAB) and the European System Providing Refuelling Infrastructure and Telecommunications (ESPRIT).
I-HAB is a habitation module capable to accommodate up to four crew members for one month duration that is designed to be fully thermally independent: i-HAB Thermal Control System is based on two internal mechanical pumped loops that collect the internally generated heat coupled with two external loops that are used to transport the heat to a set of two deployable and orientable radiators wings; the internal loops have dedicated derivations that allow the thermal connection and a bi-directional heat load sharing with the adjacent modules. The overall I-HAB TCS is design to manage up to 10kW of heat dissipation.
ESPRIT is actually composed by two different elements: the HALO Lunar Communication System (HLCS) mounted outside the NASA provided habitation module HALO, providing commutation capability with the moon surface in two different bands and the European Refuelling Module (ERM), providing refuelling capabilities through additional xenon and hydrazine capacity for use in the PPE's (Power and Propulsion Element) ion engines as well as an internal habitation area with observation windows.
HLCS thermal control is purely passive, based on OSR covered axial grooved heat pipes radiators, but needs to face quite unique environment, with high radiations and possible contamination derived from the lunar dust taken in orbit by the landers that are supposed to docked on the Gateway after being landed on the Moon surface.
ERM thermal control is also mainly based on passive means, but also include a thermal compressor, used to transfer Xenon from the internal tanks to the PPE, that requires a dedicated mechanical pumped loop to provide the high temperature fluctuations (from -120dC to + 150dC) needed to achieve the requested performances.
The presentation will give a high-level overview over the ESA contributions to the Lunar Gateway, with particular focus on the thermal control system and the unique challenges that this mission request.

Cube Sats / **33**

Thermal Engineering of the Orbital Whereabout Locator

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The OWL system is a beacon signal transmitter capable of determining the location of the satellite post-deployment in case of a shared launch and communicating that location towards the Ground Station. The major aim of OWL unit development was to create a platform and mission-independent in-orbit tracking equipment that is easy to integrate into every CubeSat and fulfils its major purpose even if the host satellite is in trouble. The unit is built up of 3 major subsystems: an EPS (Electrical Power Supply), an OBC (OnBoard Computer) controls a GNSS antenna, which determines the unit's position, and a COM/ANT (Communication, Telecommand, Telemetry, Antenna) module, which makes the system functioning independently from the host satellite. The OBC also controls a GNSS antenna, which determines the unit's position.

The unit fits inside the standard tunacan volume defined for CubeSats (⌀64x36[mm]), which enables the use of this system for satellites that have occupied payload bays, requiring only an electrical interface connector and a total of 4 fasteners as mechanical interface. As simple as the unit seems at first mechanically, just as complicated are its launch and in-orbit thermal environments. The purpose of this unit is to function even - or rather, especially - on Dead-On-Arrival satellites, so it has to be extensively analysed and tested. Vibration testing within a large acceleration spectra, as well as a high number of mechanism tests in different temperatures shall be conducted, to make sure that there is very low risk of unit failure.

As an optional, external unit that is planned to be mounted on satellites of different size - or even the fairing or third stage of launcher systems -, the thermal environment can vary greatly, thus, at first a research was conducted to determine possible thermally worst-case orbits. As this showed that a considerable number of satellites inhabit all the different orbits, from LTDN 0h to 12h, the worst cases can indeed be on the most and least illuminated orbital planes around Earth. Thus, 2 orbits were determined as to be analysed: dusk-dawn (LTDN 6h), and noon-midnight (LTDN 12h). The altitude of orbits was set to be 400[km], as it increases time spent behind the Earth during cold case orbit, or Albedo heat received from the Earth for the hot case orbit. Lastly, orientation was set as random thumbling for 2 cases; and as 'True Sun pointing' for a 3rd also hot case, where the OWL was pointed towards the Sun for maximal solar radiation.

After the unit and its orbital parameters are explained, the detailed Thermal Mathematical Model and its creation process is described in this paper, together with the planned Thermal Vacuum Chamber tests.

Thermal Design / 10

ROSE-L SAR Instrument Thermal Design

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The presentation deals with the thermal design of the SAR Instrument of the ROSE-L Copernicus Mission.
The thermal design of a SAR instrument is very challenging for needing to be in line with a maximum possible heat discharge into space via radiator (often the same as the RF radiator) to keep the high dissipative Front End units in line with the requirements and at the same time, the heater power demand must remain in a reasonable range.
The presentation will comprise the design of the thermal subsystem with respect to applied thermal hardware as coatings, foils & isolation, dissipative unit placement, interface management, etc. as well as performed trade-offs in order to determine the optimal thermal design.
Also the results of thermal confidence tests performed with structure mock-ups to determine the conductivity along the thermal path from dissipative Front End unit to thermal radiator will be presented.

Cube Sats / 34

YPSat Thermal Analysis, Design, Integration & Testing

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YPSAT (Young Professionals' Satellite) is a CubeSat-style project led entirely by young professionals across multiple ESA establishments. It will launch on the maiden flight of the Ariane 6, currently

scheduled for April 2023. The goal of the mission is to capture image and video of key phases of the flight, including fairing separation and several CubeSat deployments. It will also capture in-orbit imagery of the Earth. To achieve this, YPSAT carries a primary payload of two wide-angle, high-definition cameras developed by Scanway. Secondary payloads include a magnetometer built by a student team at Hasselt University and a PocketQube with deployable antenna developed by the amateur radio community. Support subsystems include COTS OBDH, EPS, and COMMS, as well as custom-built launch detection and payload interface boards. All units - aside from the AMSAT PocketQube and the two cameras - are enclosed within an aluminium panel structure. AMSAT is mounted to the interface plate, outside of the main structure. The cameras are mounted on the top panel and are shielded from the space environment by MLI. The structure is attached to the ballast on the Ariane 6 upper stage via an aluminium interface plate - and remains so for the entire duration of the mission. There is also an MLI blanket covering the entire structure. The ballast onto which the structure is mounted weighs approximately 1.7 tonnes. For this reason, measures are taken to maximize the conductive coupling between the individual units and the ballast, thereby dampening temperature fluctuations during eclipse entry and exit. Given the constraints on time and resources, the thermal design is kept as simple as possible. The thermal architecture therefore consists exclusively of passive hardware. This presentation describes in more detail the thermal analysis, design, integration, and testing activities completed since early 2022.

Thermal Analysis / 19

Methodology for electrical harness thermal modelling in a global system thermal analysis

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For miniaturized thermal systems or thermal systems with limited energy, the harnesses heat leaks can be the major concern both for flight or test harnesses. In this frame, and based on test results, a methodology has been identified to adopt an appropriated reduced thermal modelling of the harness taking into account both conductive and radiative heat transfers. The actual aim is to provide to thermal engineers the keys to simulate accurately and easily the harnesses heat leaks of miniaturized thermal systems in a global system thermal model without consume a large amount of nodes (where a detailed thermal modelling of all harnesses is impossible).
This reduction is based on radiative and conductive thermal properties of the harness, the routing and the thermal radiative environment. First, a theoretical approach will be confronted to test results already presented in ESTEW 2021 in the paper "characterization test of thermal harnesses". Secondly, a complementary new test will be presented in order to provide other harness heat leak thermal behavior knowledge especially on the routing. This work is a partnership between CNES and EPSILON performed in the frame of the MMX Rover CNES/DLR project.

Thermal Control / 7

Novel Graphene-based Thermal strap

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Within the ESA's Science Program related to the Athena (Advanced Telescope for High Energy Astrophysics) mission the possibility of applying graphene-based thermal straps for cooling the scientific instrumentation on board the satellite, specifically the Wide Field Imager (WFI), was investigated. Graphene-based thermal straps could potentially replace the current baseline design relying on heat pipes for cooling the WFI due to the excellent properties of graphene in terms of lightweight, flexibility and thermal conductance. The aim was to design and develop a graphene-based thermal strap for the cooling the WFI instrument. Critical functions and performances were verified on a full-scale Breadboard in a relevant environment for the WFI application. The developed graphene-based thermal strap was shown to exhibit extraordinary properties with respect to lightweight, flexibility and thermal conductance when compared to conventional metal-based solutions. Comprehensive testing of the mechanical, thermal and cleanliness properties and durability of the developed strap and related materials were made to verify that the strap conforms to the various requirements set by ESA in relation to the Athena space mission, specifically for thermal management of the WFI. The thermal conductance value was found to even exceed the best commercial solution. Novel test setups and procedures for thermal, vibrational and particulate testing were developed to increase confidence in the test results. Critical functions and performances were verified on a Breadboard in a relevant environment for the WFI application reaching TRL-5. Moreover, the developed strap design can be applied, and if needed re-dimensioned, for other space and non-space applications where similar properties are desired. The next step will be to commercialize the technology together with an industrial partner.

Thermal Analysis / 35

Using co-simulation to improve the modeling of thermal management devices

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Spacecraft thermal management is a complex endeavour that requires expertise from many different domains and employs several different strategies. Heat pipes are a common device used to move thermal energy from one part of the system to another. Modeling heat pipes can be very complex due to the inherent two-phase nature of the heat transfer. While systems-level models and correlations can be used for modeling heat pipes, the true three-dimensional nature of the heat transfer is not captured. Conversely, modeling the process fully in 3D can be both cumbersome and time-consuming. In this presentation, we demonstrate a way to connect system models and 3D models. The combined models are then solved in co-simulation mode, where each respective solver performs the calculations under its purview and exchanges data with the other at specific interfaces and times. The solvers communicate directly with each other. Data mapping and interpolation is employed at the interfaces to enable data exchange between surfaces in the 3D model and point data used in the system model components. This co-simulation approach allows us to leverage the strengths of each solver to gain more insight into the system dynamics. We present an example case of a mechanically driven heat loop and show how the inclusion of the 3D model helps to improve the results. We discuss the challenges inherent in modeling physics with very different time constants and the strategies we employed to mitigate them, including parameter sensitivity studies. We conclude with a discussion on how the model data may be improved, such as accounting for orbital heating and methods to accelerate thermal radiation computations for orbits.

Thermal Control / 22

Radiator Shadowing System (RSS) to save dissipation power

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The Airbus Defence and Space Eurostar NEO development program has qualified a new system to cover OSR in order to limit the thermal rejection into space dissipated inside the spacecraft. During critical phase of the satellite lifetime as the Electrical Orbit Raising (EOR) phases or chemical transfer, an important part of the available electrical power is used to heat up the payload units to maintain them in their thermal limits.
Using the RSS allows to limit this important power dissipation and reducing the solar array and/or battery size. Moreover for EOR case, the power saved by the RSS make the phase last shorter.
The RSS qualified design is based on one single Rotary actuator driving two foils in both direction. Foils are wrap around winding module. Two main position can be set, one called "stowed" when foils are fully rolled around their winding module and "deployed" (as shown in the figure above) when covering the OSR.
The qualification model demonstrates the ability of the RSS to operate outside the satellite in a large temperature range (-90℃/+160℃) and for a life time covering the telecom mission needs. Moreover, mechanical (vibration and shock) test campaign was performed successfully.
The RSS qualified version is able to cover around 3,3m² in deployed configuration. The dimensions can be adjusted depending on the mission or on the satellite size

Thermal Analysis / 37

Effects of lunar dust deposition on radiator performance for Moon exploration missions

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This work aims to provide thermal engineers a set of empirical equations between dust deposition rates and the modification of thermo-optical properties of radiators for lunar surface missions.

For the thermal engineer involved in the design of hardware dedicated to operating on the lunar surface, lunar dust is one of the biggest challenges. The smallest fraction of the sharp-edged small dust particles easily adheres to technical surfaces. There are natural and artificial sources which cause the dust to be levitated on the surface of the Moon. Not only the landing or roving of vehicles stirs up and moves lunar dust, but also naturally occurring electrical charge differences. For the thermal engineer the presence and movement of dust means a modification of thermo-optical properties of thermal control surfaces. The thermal control surface in the focus of the present work are radiator surfaces, i.e., one specific white paint (AZ93) and one Second Surface Mirror tape (AgFEP), due to a limited data set from literature.

Currently there is a missing link between the dust deposition rates and the modification of radiator surfaces reported, in literature. Literature on dust deposition is based on flight data and concerns natural lunar regolith, whereas the literature on radiator modification is scarce and the studies were performed with lunar dust simulant materials. The present work is bridging this gap for radiator sizing in early design phases.

The solar absorptivity of radiators is much more affected than their IR emissivity, due to the high emissivity of radiators and the lunar dust alike. The modification factor for the solar absorptivity varies from 1.1 to almost 6 for dust deposition of 100-600 μg/cm2, but depends on type of radiator coating, radiator substrate, and the conversion assumptions between natural regolith properties and lunar dust simulant. The uncertainty associated with the results will be presented along with an approach to combine the results with common aging related modifications.

The conducted study was based on literature data. It is meant as a first steppingstone toward design guidelines for 'dusted end-of-life" properties for thermal control coatings for thermal engineers. Further material science based in depths investigations are necessary and are currently initiated at ESA, to have more robust modification factors for upcoming missions to the Moon.

Thermal Control / 30

Cost Savings & Performance Benefits of Carbice Nanotube Satellite Thermal Interface Solutions

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We present an analysis of the cost savings and performance benefits delivered by Carbice® Space Pad, a carbon-nanotube-based thermal gasket, for spacecraft builds. We show a 62% net savings in the Integration Assembly & Test (IA&T) and Thermal cost in a typical satellite build, supported by an independent analysis performed by a large space prime. IA&T cost and schedule reductions are measured against wet install and can be delivered by using Space Pad for all satellite assembly interfaces. Carbice® Space Pad delivers valuable labor cost savings and performance improvement by taking advantage of a unique combination of excellent thermal properties and mechanical properties as a result of its structure - vertically aligned carbon nanotube forests bonded to both sides of an Aluminum core. The aligned carbon nanotubes not only provide high through-plan thermal conductivity, their elasticity also allow reliable thermal contact during cycling, providing low thermal resistance in application. The Aluminum core keeps nanotubes intact, enables a form factor that is easy-to-use and fully reworkable, while contributing to in-plane thermal conductivity. The resulted Space Pad is operable over a wide range of interface pressures, ranging from very low pressure up to over 1000 psi. This combination of thermal and mechanical properties delivers a technology that enables satellite designers to incorporate full functionality into the system payload without the shortcoming of existing thermal solutions.
There are two classes of materials that dominate spacecraft interfaces today: liquid solutions like particle laden silicone RTV and gap pads like graphite or particle laden gap fillers. The problems with RTV are numerous. First, it has a low thermal conductivity, limiting its ability to remove heat from on board electronics. Furthermore, the application process is time consuming (and therefore costly) when accounting for the time needed to prep surfaces, mix, precisely apply and cure the material. After curing, RTV is not reworkable, so when components must be removed from after initial testing it must be scraped manually from the flight vehicle and the underlying surfaces often need to be re-polished. Furthermore, this scraping process can generate conductive foreign object debris hazards. Gap pads like graphite or particle laden gap fillers come in the form of gaskets that can be cut to size reducing some of the installation burden. However, these materials suffer from irreversible compression set after installation. As a result, the gap pads can lose preload or in some cases dewet entirely from the interface as it expands and contracts thermally. This three factor combination of component deformation, inelastic gasket compression and thermal cycling can transfer stress to the fasteners resulting in gradual pull out of the inserts that mount the components to panel structures in the spacecraft.
Considering the strengths and weaknesses of the thermal interface materials available in the market today, Carbice Space Pad represents a no-compromise solution, having the benefits of both liquid and solid without any of their downsides.

Thermal Analysis / 14

Thermal Sizing of a Lunar Rover using Simcenter 3D

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As the decommission of the International Space Station approaches, all eyes are set to the Moon as the next scientific hub for space exploration. Under the Artemis program, partners all over the world are developing missions to collect data and prepare the return of humans on the surface.

To support efforts for thermal analysis of lunar space systems, a sizing thermal model of a lunar rover was developed using SimCenter 3D Space System Thermal. This model demonstrates the strategy to perform the analysis of a lunar rover using the software. Several Moon surface models of different complexity are presented, and their accuracy is verified against measured data from the LRO Diviner mission. Furthermore, all analyses are done without resorting to custom user subroutines, making the sizing strategy accessible to users without a programming background.

This presentation will provide an overview of the model and show the results of various sizing cases. The evolution of collected solar energy for several Artemis candidate landing sites will be presented. The results will be evaluated during transient roving operations. The required initial energy to ensure night survival under different boundary conditions will be shown.

Thermal Control / 4

Development of a miniature heat exchanger for mechanically pumped loop systems for active thermal control of CubeSats

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The relatively high power density of CubeSats results in large amounts of heat generated that needs to be dissipated to prevent overheating of a satellite's components. At present, passive thermal control means are used to resolve CubeSats thermal issues, however, as these satellites evolve, advanced active Thermal Control Systems (TCS) will be required. Especially the novel CubeSat propulsion systems require dedicated TCS for the propulsion unit and the corresponding electronics.
A promising type of TCS for CubeSats was determined to be the Mini-Mechanically Pumped fluid Loop (Mini-MPL). One such system has been developed at the Royal Netherlands Aerospace Centre (NLR), which consists of a single phase fluid loop that is used for component cooling. One of the important components of this system is the interface (I/F) with the Payload.
Three custom designed Miniature Payload Heat Exchangers (MPHX) are presented. During the design phase, a tool which is able to evaluate the cooling performance of different MPHX models has been built. Using this tool, the three best designs in terms of cooling performance have been identified: the offset strip fin heat exchanger, and two straight channels configurations with respectively triangular and trapezoidal cross sections.

The heat exchangers are produced through additive manufacturing (using the Direct Metal Laser Melting method) which allows for greater flexibility and customization of the designs. The models are tested in a pumped fluid loop at the NLR's Thermal Management Facilities to confirm the results predicted in the design phase as well as feasibility of the DMLM fabrication method.

Thermal Design / 39

The Mode Selector Mechanism (MSM): a bi-stable cryo-actuator operated at 4.2K

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The Mode Selector Mechanism (MSM) is a bi-stable cryo-actuator operated at 4.2 K developed by Centre Spatial de Liège. The MSM development started as part of the far -infrared spectrometer SAFARI on the ESA SPICA space telescope. It takes place now in the preparation and anticipation of next generation cryogenic missions.
The MSM is characterized by its ability to switch an optical part such as a mirror between two defined positions at ambient as well as at cryogenic temperature. The particularit y of this bi-stable actuator is the capacity to ensure a passive locking, in order to eliminate electromagnetic interference sources. The actuator is also optimized regarding the energy dissipated during actuation. For that reason, specific elements such as ultra-thin magnets and metallic additive manufactured parts are included in the actuator.
In this talk, we present key aspects of the thermal design and the driving parameters to get an actuation at 4.2 K. The thermal demonstrator models in preparation will be presented as well to better know the properties of the key items thermally dependent (coil wire resistivity, pivots springs torque, thin magnets remanence). This includes the design of the cryostat, the measurement method at 4.2 K, and the status of the breadboard activities with first results.

Thermal Testing / 15

Foil Heater Hot Spot Characterization

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A common hardware used by thermal engineers in spaceflight projects are polyimide (Kapton®) and all-polyimide foil electrical resistance heaters. Typical applications range from thermostat-controlled survival heaters, operational heaters, to test heaters (either to simulate internal or external heat dissipation sources, for example radiators).
Same as with any other aerospace hardware, also heaters can fail, however as the standards for the de-rating of heaters are very strict, this rarely happens in flight model (FM) hardware. It happens more frequently in test heaters. The most common origin of a failure on foil heaters are gas inclusions or local delamination. In the first instance such failures lead to local hot spots. The hot spots are elevations of temperature above the local average temperature of the foil heater.
The present activity, funded by the European Space Agency, aims at start the process of developing a standardized non-destructive test method for the correct integration of foil heaters by the use of IR cameras. The tasks performed covered: literature review of non-destructive inspection methods, IR NDT trade-off and technical assessment of relevant IR camera and measurement set-up parameters, perform relevant tests aiming at identifying a possible threshold for acceptance/rejection of a heater installation.

Thermal Design / 24

Development and qualification of ECLAIRs Instrument Thermal Control System using Variable Conductance Heat Pipes

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SVOM (Space-based multi-band astronomical Variable Objects Monitor) mission objective is a thorough monitoring of Gamma Ray Burst (GRB) phenomena. Based on a collaboration between France (CNES: French Space Agency) and China (CNSA: China National Space Administration and CAS:

Chinese Academy of Science), the SVOM payload includes four scientific instruments (ECLAIRs and MXT provided by CNES, GRM and VT provided by CNSA/CAS) installed on SVOM spacecraft. On Earth, several telescopes and a data center contribute to GRBs observations in addition to SVOM payload. This paper covers the ECLAIRs instrument, designed to detect GRBs autonomously in near real time in the X-Gamma ray energy range, and then to quickly transmit to the ground telescopes their direction in the universe. After a GRB detection, a change of the spacecraft orientation points the other instruments in the GRB direction. Therefore, the ECLAIRs TCS (Thermal Control System) main constraint is to allow ECLAIRs instrument to detect GRBs whatever the attitude and the position of the spacecraft on its orbit. Indeed, the ECLAIRs TCS copes with a large variation of external environment during the mission with low heating power allocations. Thus, the ECLAIRs detection plane thermal bus uses Variable Conductance Heat Pipes (VCHP) with a regulation loop, in order to minimize heating power consumptions and to allow temperature control on the detectors. The presentation of the ECLAIRs instrument TCS highlights its development, validation and verification with TCS full qualification before instrument delivery to the SVOM spacecraft.

Thermal Testing / 27

Thermal Testing of a Spaceborne Deployable Reflector (SAR Antenna)

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The presentation deals with the thermal testing of a deployable reflector which is part of a spaceborne SAR payload.
The different challenges, solutions and lessons learnt of the QM thermal vacuum test will be presented.
Due to the design of the deployable reflector, three different cavities – one external and two different internal sections – needed to be qualified simultaneously. Due to the challenge of meeting component temperature extrema on the one hand and the average temperature extrema of the long waveguide structure due to thermo-elastic reasons on the other hand, an antagonistic environmental control has been developed and applied which will be explained in the presentation.
Also the challenge of meeting and monitoring thermo-elastic distortion requirements for the RF waveguides during the test is presented.
Concluding, lessons learnt of the thermal vacuum test are outlined, comprising the difference between theory and practice i.e. between test predictions and testing, as well as the monitoring and preventing of an uncontrolled mechanism deployment during the test.

Thermal Testing / 31

Thermal balance test and model correlation of the PLATO front end electronics unit

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The Plato normal front end electronics (N-FEE) unit is an iso-statically mounted structure with high radiative coupling to the telescope cavity. The mechanical mounting consists of thermally isolating

Ti6Al4V blades, which result in a high dependency on radiative heat exchange with the telescope to dissipate the heat generated by the PCBs. Previous attempts to correlate the N-FEE thermal model were unsuccessful, due to the lack of representation of the radiative environment during thermal cycling tests. The successful correlation of the N-FEE thermal model was critical due to violations in temperature limits for various PCB components, as well as an uncontrolled TRP at the PLATO camera level. Mitigating the former issue will result in complications with the latter, and vice versa. As a result, a dedicated thermal balance test setup was conceived to recreate the flight-like mechanical and thermal couplings of the N-FEE. This required the design and commissioning of a radiative test cavity that is controllable for a range of temperatures with little variation to the temperature across the cavity, as well as a conductive mounting that can be simultaneously controlled to highly contrasting temperatures. The characterisation of the conductive and radiative interfaces of the N-FEE were necessary in order to derive strategic instrumentation locations and create the correct representations in the thermal model. Artificial test cases with high heat injection from different sides of the conductive interface were introduced in order to aid with model correlation. It was found that the dependence of the N-FEE on radiative heat exchange resulted in the model correlation being extremely sensitive to the magnitude of heat injected, where a small error in the heat distribution created a large discrepancy in temperature predictions. The design and commissioning of the test hardware is presented, along with the planned test phases and results. The techniques used to correlate the thermal model are discussed, and the yielded temperature predictions are compared to the readings of 36 different sensors attached to the N-FEE during thermal balance testing.

Thermal Design / 48

SVOM MXT Instrument: Thermal Control System Design and Verification

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SVOM (Space-based multi-band astronomical Variable Objects Monitor) is a mission developed within a Sino-French cooperation context and dedicated to the detection, localization and study of Gamma Ray Bursts (GRBs) and other high-energy transient phenomena.
Four scientific instruments (ECLAIRs and MXT provided by CNES: National French Space Agency, GRM and VT provided by CNSA: China National Space Administration), operating in different wavelengths, constitute the flight segment of the mission. A ground segment (several telescopes and a data center) contributes also to this GRB observations.
This presentation addresses the MXT instrument, developed by CNES in collaboration with different scientific partnerships (CEA, MPE, LAL and the University of Leicester) and dedicated to the observation of GRB afterglows in the soft X-ray band.
SVOM is a Low Earth Orbit mission with a specific pointing law thanks to which the spacecraft can quickly change its orientation in order to observe GRB events as soon as they occur. This leads to a very variable and unfavorable external environment for low and stable temperatures.
Indeed, the MXT detector (CCD) needs a temperature at -65 °C or lower. Passive cooling cannot achieve such a low temperature. As a consequence, Thermo-Electric Coolers (TEC) insure the additional active cooling. This leads to a significant heat dissipation to be evacuated. A thermal bus with propylene heat-pipes transports this amount of heat from its source to a radiator.
Moreover, optical performances (alignment and focus), derived from scientific observations needs, require high performances in terms of temperature stability and uniformity.
The presentation focuses on the Thermal Control System of the MXT instrument, and more specifically on its design, validation and verification.

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JUICE (JUpiter ICy moon Explorer) thermal model correlation

and final flight thermal predictions

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JUICE - JUpiter ICy moons Explorer - is the first large-class mission in ESA's Cosmic Vision 2015-2025 programme. Planned for launch in 2022 and arrival at Jupiter in 2031, it will spend at least three years making detailed observations of the giant gaseous planet Jupiter and three of its largest moons, Ganymede, Callisto and Europa.
The JUICE spacecraft 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.
JUICE spacecraft 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 JUICE thermal control is designed with the objective to minimize the impact of the external environment on the spacecraft through high efficiency Multi-Layer Insulation. Minimizing heating power demand especially during science and communication phases and minimizing hardware mass is a constant concern and solutions are found to build to a maximum extent a robust and passive thermal design supplemented by heaters.
JUICE Spacecraft performed its Thermal Vacuum and Thermal Balance Test in 2021. This presentation will focus on the thermal model correlation after the thermal test and will present the overall final flight thermal predictions.

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E-TEST Prototype Ultra-cold vibration control

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E-TEST is an innovation project in the frame of the Einstein Telescope, developed to validate technologies regarding sensitivity at low frequency and contactless cooling of a large suspended cryogenic silicon mirror.
The prototype will be tested in our FOCAL6.5 vacuum chamber, one of the main CSL's environmental test facilities used for space instrumentation.

One of the E-TEST experiment's goals is to cool a suspended mirror to 20K. To avoid transmitting vibration to the payload, it has to be mechanically decoupled from the rest of the cryostat. Therefore, CSL has developed two intertwined radiator-like structures to maximize the radiative exchanges.

The design of such a structure in a compact envelope and the thermal modeling performed with ESATAN to assess the cooling time until steady-state conditions are explained. In particular, the approach to deal with uncertainties related to the decrease of the emissivity with the temperature of usual black paint used in space applications, thermal properties of less common materials and state-of-the-art solutions are presented.

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Progress in Development of a Dust-Resilient Active Radiator for Lunar Applications

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The design of active radiators for the lunar surface is influenced strongly by extreme temperature variations, risks associated with highly abrasive lunar regolith and thermal cases including those with high IR backload from the surface of the Moon as well as the long lunar night.

For hot cases during the lunar day, surface temperatures are higher than the radiator operating temperatures. Zenith pointing is often preferable, but not always possible. If not suitably protected, the high lunar surface IR backload could result in a 'run-away' effect in radiator sizing. In configurations where it is not possible to mount the radiator to be zenith pointing, the IR back-load from the lunar surface needs to be minimised by constructive means. Zenith pointing radiators can be more impacted by direct solar irradiance, though this factor is more relevant in lunar equatorial regions and becomes less problematic towards the Lunar Poles.

The cold case on the lunar surface is driven by the duration of the lunar night. There are regions close to the Poles with almost permanent sunlight and also with permanent shadow. Yet, on average the lunar night is 14 Earth days in duration for most latitudes. These long duration thermal cycles necessitate an active control to 'close' the radiator and minimise heat rejection during the cold phase.

The development of an active radiator of the thermal shutter type is described, being led by ESR Technology under ESA Expro+ funding, with the support of Almatech SA, Spacemech Limited and Space Science Solutions Limited. 2 initial concepts were developed with working prototypes built, including an alternative solution based on a flexure-based louvre device, in addition to a thermal shutter device. A thermal analytical model was developed in Python, to study the relative benefits of the thermal shutter and louvre devices according to the lunar latitude and orientation of the radiator as it is required to be as universal as possible to support applications on landers, rovers, ISRU and other science instrumentation packages. This analysis was a key input to the overall trade-off analysis that resulted in the selection of the thermal shutter device, which was favoured for higher overall field of view, potential for lower mass and high reliability due to overall mechanism simplicity.

The current design baseline will be presented, highlighting key thermal design choices and thermal capabilities predicted for this device as well as the mounting approach taken. A brief overview of the mechanism design will be provided to demonstrate the dust-resilient approach for this device, as it is intended for EL3 lander and related surface applications.

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pySINAS: New STEP-FEM overlap module

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pySINAS is a python version of the SINAS tool that was developed by ESA in recent years. This tool is normally used to map temperatures from lumped parameter based thermal analysis results to a

finite element model to calculate the structure's thermo-elastic response. Since the development of the simplified python version of the tool, the number of pySINAS users has grown yet many have found the generation of the overlap input file (correspondence of FEM elements to thermal nodes) an insurmountable task for large and/or complex models. A new pySINAS module has been developed that will automatically generate the overlap file in a simple and efficient way.

This presentation will provide a practical example of the usage of this module. The objective of this example is to use it as a quick start guide of the module and to highlight the module's main benefits and limitations.

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EnVision Aerobraking Maneuver Simulation with ESA Thermal Analysis Tools

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Aerobraking manoeuvres make use of upper atmosphere passes to decelerate a spacecraft. While this technique can considerably reduce delta-v requirements and allow for increased S/C dry mass, aerobraking subjects external spacecraft surfaces to intense thermal loads. Detailed analysis of the spacecraft thermal behaviour is therefore critical to ensure effective braking manoeuvres while safely avoiding damage to the spacecraft due to overheating.
Typically, maximum allowable peak heat fluxes and total aerobraking pass heat loads are calculated from CFD analyses. However, this calculation technique is decoupled from the spacecraft thermal model. To analyse the impact of aerobraking fluxes under different S/C angles of attack for ESA's EnVision mission to Venus, an aerobraking flux was directly integrated into the spacecraft orbital thermal simulation. Aerobraking fluxes were applied to the spacecraft using UV emitter shells, harnessing the ray-tracing capabilities of ESATAN.
This method allows for a much faster simulation of aerobraking orbital temperatures compared to a full mapping aerothermal fluxes from CFD. Compared to conservatively applying the maximum expected aerobraking flux to all exposed surfaces, this method captures key physical phenomena like angular dependence of aerobraking fluxes and self-shadowing phenomena which are characteristic of the flow regime in the upper atmosphere of Venus.

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ESATAN Thermal Modelling Suite - A new thermo-hydraulic Interface

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ESATAN-TMS provides an advanced thermal modelling environment for the thermal analysis of spacecraft and launch vehicles. The thermal 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 a new integrated solution for thermo-hydraulic analysis within Workbench. This presentation will outline the development of this new interface.

Opening / 2

Closure

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Closure of the workshop