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Book of Abstracts

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MetOp-SG SCA Instrument Thermal Design and Verification

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The SCA instrument on MetOp-SG SatB is a 6 beam pulsed real aperture C-band (5.355 GHz) radar in a lambda shaped antenna configuration that measures the Earth's surface backscatter for each resolution cell from three different directions. The measured backscatter are transferred to wind vectors / soil moisture etc. via Geophysical Model Functions and are used to support Numerical Weather Prediction (NWP) and ocean state forecasts at regional and global scales through the provision of surface wind vector measurements.
Airbus DS GmbH Friedrichshafen acts hereby as SCA Instrument Prime with Airbus DS S.a.U. Madrid as responsible for the SCA Antenna Subsystem as SCA Core Team Member.
The paper gives an overview on the thermal design and thermal verification approach of the SCA sub systems, from electronic units, front-end electronics up to the thermal design and verification of the antenna system.
The antenna subsystem is hereby qualified in a classical approach with a STM qualification test campaign and subsequent acceptance testing of the PFM, FM2 and 3.
It is shown, which trades have been conducted to come to the final thermal design and how the qualification is performed in view of the large size of the antenna in deployed configuration and the requirements on minimized variation in thermo-elastic deformation over the orbit and over the season.

Thermal Design / 48

Thermal design and thermal verification tests of the Solar Orbiter Heat Shield

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Solar Orbiter is the next solar-heliospheric mission in the ESA Science Directorate. The mission will provide the next major step forward in the exploration of the Sun and the heliosphere investigating many of the fundamental problems in solar and heliospheric science. One of the main design drivers for Solar Orbiter is the thermal environment, determined by a total irradiance of 13 solar constants (17500 W/m2) due to the proximity with the Sun. The spacecraft is normally in sun-pointing attitude and the main barrier to protect the satellite from severe solar energy is the Heat Shield. The Heat Shield is mainly composed by a panel aimed to provide a support and the interfaces with feedthroughs and doors for the Remote Sensing Payloads. The insulation from the extreme external environment is guaranteed by high and medium temperature MLI blankets. A thermal verification campaign of the Heat Shield STM (Structural Thermal Model) has been performed in the second quarter of 2014 to verify the thermal design and to correlate its thermal mathematical model. A first Thermal Balance test in vacuum was performed in May in the ESTEC Large Space Simulator where the heat Shield was subjected to solar fluxes of 6 and 10 solar constants. A second Thermal balance Test was performed in IABG solar simulation test facility in June where solar fluxes of 1.34 and 0.41 solar constants were used.
This paper will describe the Heat Shield thermal design, the Thermal Balance Tests performed to verify the thermal design and the relevant TMM correlations, and the latest H/W modifications for flight.

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Thermal Design, Analysis and Validation Plan of the Thermal Architecture for the SMILE Satellite Payload Module

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SMILE (Solar wind Magnetosphere Ionosphere Link Explorer) is a collaborative science mission for the investigation of the solar wind interaction with Earth magnetosphere in order to further understand the Sun-Earth connection. SMILE is a joint science mission between European Space Agency (ESA) and the Chinese Academy of Sciences (CAS) for which Phase CD activities are currently ongoing.

SMILE satellite would be launched into a Highly Elliptical Orbit (HEO) that would allow observing the specific regions in the near-Earth space where these interactions occur. To achieve its goals, SMILE satellite consists of a Platform (PF) composed by the Propulsion Module (PM) and the Service Module (SVM), both provided by CAS, and a Payload Module (PLM), which is provided by ESA. The PLM accommodates the SMILE scientific instruments, the PLM Control Unit and Power Unit, the memory and the X-band communication system.

The Thermal Architecture is in charge of providing the PLM (including the instruments and the interfaces with the SVM) with the necessary means, functions and support to achieve the requested science performances by maintaining appropriate thermal conditions (temperature ranges, thermal stability and gradients, among others) for all the mission phases and operating conditions. The PLM thermal design concept, for what concerns the interface with the Platform, will be based on thermal decoupling from the PF thermal environment. The interface couplings (conductive and radiative) will need to be minimised by design to a suitable level and verified by analysis.

This presentation aims to provide a general description of the Payload Module concept for the SMILE satellite and a comprehensive description of the thermal design, analysis and future validation plan of the Thermal Architecture of the SMILE Satellite Payload Module (PLM), including the relevant

thermal interfaces with the Platform and the Instruments. It also focuses on the related cooperative aspects with the Chinese Academy of Science.

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The ATHENA Spacecraft - Thermal Design aspects

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The ATHENA Spacecraft is the next ESA Science Large class mission. It is a 7-ton spacecraft with two instruments and a 12 meters-long focal length, to be launched in 2031 by Ariane 6, and it will achieve unprecedented X-ray imaging and spectroscopic capabilities, for the benefit of High Energy Astrophysics.
A brief introduction to the Spacecraft and mission is presented, followed by a description of the thermal design aspects in different sub-systems of the spacecraft, such as the SIM - Spacecraft Instrument Module and the two instruments XIFU and WFI, the MAM - Mirror Assembly Module, the FMS - Fixed Metering Structure and the Service Module.

Thermal Control Technologies / 10

Application and Testing of Self-Limiting Heaters for Satellite Thermal Control

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Within this paper the possible application of self-limiting heaters for satellite thermal control is presented. The focus is put on Minco's SmartHeat SLT™ technology, which relies on the positive temperature coefficient effect and represents an affordable and highly promising heater solution. The investigation consisted of a detailed laboratory thermal test campaign and subsequent thermal analyses.
The test campaign presented in the paper was oriented on the ECSS and ESCC standards and comprised thorough active and passive characterizations, infrared camera measurements as well as a thermal vacuum test setup. Special attention was put on the cyclic performance of the SmartHeat SLT™ technology and its self-limiting set-point temperature.
As an example the thermal analyses of a propulsion thermal control system gave promising results for the comparison of self-limiting heaters and regular heaters. Moreover, the power adaptation to local conductive influences could be demonstrated and a more uniform temperature distribution on the fuel line was achieved.

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ADMATIS radiators and MLI: from development and qualification to flight

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This presentation will focus on several solutions of radiators, some with various shapes, coatings and extended temperature range, which have been developed and qualified by ADMATIS, before to be implemented on instrument (Sentinel 2 MSI, CHEOPS) and launched. Innovative CHEOPS radiator end-to-end testing will be presented, as well as Sentinel radiators flight data. The presentation will also introduce MLI developed and qualified by ADMATIS, including the MLI foreseen for one of JUICE sensors.

Thermal Control Technologies / 5

Thermal Control Louvers application using Rosetta heritage

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Louvers are thermal-control elements that have been used in different forms on numerous spacecrafts. They are devices which mask a high-emissivity radiator with a low-emissivity surface. As the temperature of the panel changes, blades angles also changes, changing the radiative flux exchanged between panel and deep space. The actuators are calibrated to cause the associated blades to be fully open and fully closed at specified temperatures.

In the frame of Rosetta project (space probe launched in 2004) a total of 15 louvers assemblies were designed and manufactured by SENER. These louvers were tri-metallic, spring-actuated, rectangular-blade louvers.
In 2019, SENER was requested to adapt this technology to a new mission. The design concept remains the same but temperature operational ranges and sizes need to be updated. The number of operation cycles along the mission is also different, new mission requires 2000 life test cycles while in Rosetta mission only 200 cycles were applied.
In order to reduce the associated risk to this long life operation, Rosetta hardware, stored at SENER premises since 2004, has been submitted to a life test at the very early stage of the project.

This presentation includes a description of the Rosetta louvers design and performances. Then, modifications implemented to adapt the louvers design to the new mission are also explained. Encountered design problems and test plan implications derived from modifications are also included. Finally, comparison between Rosetta louver performances observed in 2004 with results obtained in 2019 before and after the 2000 cycles life test are presented and discussed.

Thermal Control Technologies / 60

Two phase - Mechanically Pumped Loop (MPL) development

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This 2-phase thermal sub-system has been developed in the frame of Spacebus Neo Platform program.

Thermal Analysis and Software Tools / 30

Methods to Improve Thermal Test Efficiency (MITTE)

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Thermal testing is part of the verification process needed on a space system. This task is time consuming and thus expensive due to both the thermal inertia and the complexity of a system level verification in an environment representative of the flight mission worst cases (vacuum and temperature). These constraints require efficient methodologies and associated tools covering the whole process:

- Test preparation, especially instrumentation or test sequence definition;
- Test execution, especially test monitoring and real-time test shortening;
- Test exploitation, especially model correlation.

The presentation will focus on the last developments involving the temporal and spatial extrapolations, the Infrared camera usage and the natural convection modelling in an industrial context. The activity has been deployed in two space projects to prove its feasibility. The use of Infrared data measurements has been exploited to extrapolate the temperature field based on the thermal model information.

Thermal Analysis and Software Tools / 16

Simulations of formation flying maneuvers of two spacecraft in ESATAN-TMS based on the development of a MATLAB/Simulink tool for defining the required inputs.

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The selection and analysis of the thermal worst cases is one of the critical points in the thermal design of a spacecraft. Typically, a limited number of scenarios are sufficient to cover the configuration of the mission and the orientations and orbit conditions when they are simple but in some cases, more specific configuration is needed.
In the case of Proba-3 ESA's IOD mission, the possible scenarios are much more complex because the mission is composed of two spacecraft that perform formation flying maneuvers. During each orbit are performed more maneuvers than other missions perform in their entire lifetime. In addition, a very precise definition of the pointing and relative position of the spacecraft at specific moments of the orbit is needed to represent correctly the shadow of one spacecraft over the other.
Additionally to the complex maneuvering scenario and the pointing changes, has been checked that ESATAN is not able to change the Sun's Declination during the simulation, not representing the correct Sun position, impacting directly the generation of the correct shadows.
In order to generate the adequate inputs to perform the Thermal analysis in an automated way to cover the different scenarios, a MATLAB/Simulink tool has been implemented. This tool also takes into account this ESATAN's limitation in the Sun positioning and generate the correct ephemeris to model the shadows in an accurate way.

The generated ephemeris and pointing angles have been introduced in an ESATAN-TMS 2017 radiative case and checked by means of shadow maps. The correct definition and implementation has been possible thanks to a close cooperation between the Mission/System Engineering team and the Thermal Engineering team.
In addition to the ephemeris, the thermal dissipations of all the units and the relative position of units' moving parts have been also introduced in thermal analysis. Moving parts analysis is especially important in the case of the Proba-3 primary payload, designed to open the door only at specific times during the orbit to operate in the umbra conditions generated by the shadow of the other spacecraft.
The presented process has been carried out to generate all the thermal use cases needed for the definition of the thermal control subsystem of a very challenging mission as Proba-3 ESA's IOD mission.

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Flight correlation and characterisation of Sentinel-2A/B satellite thermal behavior

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The Sentinel-2 mission is part of the EU Copernicus program. Today, it counts two polar-orbiting satellites, S-2A & S-2B, placed in the same sun-synchronous orbit and phased at 180° to each other. Two more satellites are expected to be launched in the near future. Launched since June 2015 for S-2A and March 2017 for S-2B, these satellites provide high resolution and multi-spectral images of the Earth but also a large amount of precious in-flight data regarding the thermal behaviour of both the platforms and the instruments.
In order to exploit these data, a joint in-flight thermal correlation and characterisation exercise has been carried out by Airbus Friedrichshafen and Airbus Toulouse (lead by ESA). This presentation will describe the main challenges and conclusions of this activity focusing on the satellite point of view (instrument results will be presented separately), including:

- Development of the mathematical model, the execution of the thermal tests in different facilities (IABG and ESTEC) and the corresponding correlation activities.
- Methods for analysing in-orbit data for the whole lifetime of a system, including study of thermal behaviour and effective use of both the platform and the instrument
- Comparison of behaviour between models (S-2A versus S-2B)
- Integration of in-orbit data into thermal simulations
- Correlation of thermal models with in-orbit measurements
- Summary of the lessons learned from the project for the future programs.

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Flight correlation and characterisation of Sentinel-2A/B MSI instrument thermal behavior

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The Sentinel-2 mission is part of the EU Copernicus program. The Multi Spectral Imager (MSI) is the main instrument of this mission and aims at providing high spatial resolution and multi-spectral images dedicated to the monitoring of land and coastal areas. The instrument owns 13 channels in the visible/near (VNIR) and short wave infrared spectral range (SWIR). Silicon carbide is used to ensure highest stability on the telescope and the SWIR detector conductive coupling to its radiator via a cold finger. One of the main challenges is to passively control the SWIR focal plane assembly at 195 K while the rest of the instrument is finely regulated at room temperature.
Taking benefit from about 4 years of precious data on Sentinel-2A (launched in June 2015) and 2,5 years on Sentinel 2-B (launched in March 2017 on S-2B) a joint in-flight thermal correlation and characterisation exercise was carried out by Airbus Friedrichshafen and Airbus Toulouse (lead by ESA).
This presentation will describe the main challenges and conclusions of this activity focusing on the instrument point of view (satellite results will be presented separately), including:

- Methods for analysing instrument in-orbit data during the whole lifetime of a system, including study of thermal behaviour of the instrument
- Comparison of behaviour between instrument models (S-2A versus S-2B)
- Integration of in-orbit data into thermal simulations
- Correlation of thermal models with in-orbit measurements and discussion on how the thermal validation sequence on ground could be improved
- Summary of lessons learned from the project for future instruments

Thermal Analysis and Software Tools / 15

Parametrisation of a Thermal Model with ESATAN Thermal Modelling Suite

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ESATAN-TMS provides an advanced thermal modelling environment for the thermal analysis of spacecrafts 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.

Model parameterisation is a powerful feature to help simplify model definition, making the model more readable - reducing the likelihood of errors and streamlining the process of updating the model as design changes occur. In addition, parameterisation of the model allows easy configuration and running of thermal cases. Parameters are available during the thermal solution, allowing sensitivity / parametric studies to be performed, along with post-processing of results.

To meet the complex modelling demands of Customers, all geometric properties can now be specified for selected surfaces, faces and volumes.

This presentation will outline the latest capabilities of ESATAN-TMS to support these requirements.

2-Phase Heat Transport Technology / 46

On-orbit Experiment of Oscillating Heat Pipe and Loop Heat Pipe

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It is becoming increasingly difficult to meet the challenging thermal control requirements of modern spacecraft missions with only existing thermal control devices such as conventional heat pipes. An oscillating heat pipe (OHP) and a loop heat pipe (LHP) are effective methods to overcome some of these thermal control constraints. Research and development of the OHP and the LHP has been conducted for a long time in Japan. As a result of the R&D activities, a technology readiness level (TRL) of OHP and LHP are improved. To adopt the OHP and the LHP to the thermal control system of spacecraft, the thermal characteristic under the micro-gravity condition should be examined in advance. An on-orbit experiment of an OHP was conducted utilizing a small satellite and an on-orbit experiment of a LHP radiator was conducted on International Space Station (ISS). An overview and test results of both on -orbit experiments will be presented in this presentation.

2-Phase Heat Transport Technology / 19

Development of a Novel Positive Displacement Pump for Mechanically Pumped Loops

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A novel positive displacement pump for spacecraft thermal control is being developed by AVS Added Value Solutions within the frame of ESA's ARTES programme.

The most critical component of a Mechanically Pumped Loop (MPL) is the pump; a failure of the pump directly results in MPL system failure. Therefore, the reliability and lifetime requirements for the pump are extremely severe, resulting in a rather challenging pump design and development.

The PDPump is a diaphragm pump with passive reed valves. The pump has been sized in accordance with the current needs of thermal control systems for large telecom platforms.

The main requirements for the PDPump are:

- 15 years of continuous operation
- Working fluid: ammonia (also compatible with other fluids)
- Nominal volumetric flow rate: 100 [L / h]
- Nominal head: 1.5 [bar]
- Nominal inlet pressure: 50 [bar]

- Operational temperature range: -20 to +90 [°C]
- Tolerance to the presence of vapor at the pump's inlet.

The novel design of the PDPump offers significant advantages from a tribology point of view in comparison with other known concepts (e.g. rotodynamic pumps, gear pumps, etc.). Rotodynamic pumps present additional drawbacks, including poor efficiency at low speeds, more difficult regulation and lack of self-priming capability. In contrast to rotodynamic pumps, positive displacement pumps offer several advantages, such as almost independent flow rate and pressure rise characteristics, self-priming capability, the capacity to handle large fractions of vapor, and reduced leakage problems (specially with diaphragm pumps).

The sizing of the PDPump has been carried out by means of a combination of analytical models for the critical elements, numerical models for the overall pump behavior and FEM analyses and CFD models for detailed design.

The critical elements of the pump have been verified at Breadboard level, including dedicated test rigs for the actuator, the pumping mechanism and the valves. The test data, in combination with the dynamic mathematical model of the pump and the FEM and CFD analyses, has been used as an input for the EM design. Performance tests at Breadboard level have already demonstrated a flow rate capacity of 100 [L / h].

In addition to the aforementioned tests, dedicated chemical compatibility tests and ultra-high cycle fatigue tests have been performed.

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Systema-Thermica

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The Long-Term Support version of Systema-Thermica V4.8.3 is released and available to users. This new LTS version was warmly welcomed by the users. It includes many features such as the convection module, improvements of the user experience and model exchange features. Minor corrections were implemented in the first patch of this LTS version, the V4.8.3P1, released in fall of this year.

The next official release Systema-Thermica V4.9.0 is currently planned for spring of next year. In this future version, the Orekit library will be embedded into Systema-Thermica. This refactoring will ease the import of trajectories and attitudes defined in other software and will enhance the accuracy of in-orbit computations.

Moreover, the Systema UI ergonomics will be improved. We believe that this continuous effort throughout the versions will contribute to a better user experience on the long term.

In Systema V4.8.3, the Python API is now more accessible. It embeds a Python console directly in the UI as well as user-defined toolbars to access your own Python scripts. Systema V4.9.0 will enrich the capabilities of the API regarding the kinematics and trajectory aspects.

Thermal Analysis and Software Tools / 14

Post-processing of Thermal Model Data with ESATAN Thermal Modelling Suite

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ESATAN-TMS provides an advanced thermal modelling environment for the thermal analysis of spacecrafts 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.

Post-processing of the thermal and radiative results is a significant part of the overall thermal modelling process. Clear presentation of data not only helps the understanding of model and result data, but also helps towards model validation, reducing errors and rework. The ability to visualise the thermal connectivity of the model – or specific parts of the model – is a powerful mechanism to understand its thermal behaviour, particularly looking at heat flows. A key driver is to provide the data to the thermal engineer when they want it and in the form they need it.

This presentation focuses on how ESATAN-TMS helps the thermal engineer work effectively, viewing model data, iteratively updating the model definition and regenerating reports and charts for immediate visualisation of results.

2-Phase Heat Transport Technology / 33

Minimising Temperature Gradients Within an Optical Support Plate Using Active Thermal Control

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In recent years, Argotec, a technology provider of passive thermal control systems based on the use of two phase systems, has carried out research and development, creating different passive thermal control systems in the aerospace and industrial field. Thanks to these starting skills, the 2-PHASE (Passive Heat exchange for Aerospace and Earth applications) project has been developed, with the help of the Piedmont Region, between Argotec, Thales Alenia Space and OPTEC.

In collaboration with OPTEC, a leading designer of optical instruments, an innovative telescope cooling system has been developed, built and tested to operate in harsh environments using Peltier coolers and heat pipes. OPTEC has identified a way to improve the image quality of an on-ground telescope by eliminating thermal distortions on its optical support plate. The system uses an array of seven Peltier coolers controlled by an algorithm to accurately control and stabilise the temperature of the optical support plate within its operating temperature range. Each Peltier cooler is connected to a heat pipe which transports the waste heat to a fan cooling system.

A cooling and stabilisation system has been constructed, integrated with a telescope and tested. The presentation will describe the cooling and stabilisation system design, the test setup and initial results of the test campaign.

Thermal Testing / 41

A synthesis of 3D MLI efficiency test in ESTEC Thermal Lab

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This presentation will focus on MLI efficiency testing using 3D configuration (cube of various size, cyclinder), how they differ from flat MLI test (calorimeter), how they compare with the reality, at system level, and what are the main parameters driving the efficiency (size, shape, number of layers, materials…).

Thermal Analysis and Software Tools / **25**

Toward The Integration of Aero-Thermodynamics and Space Debris Re-entry Capabilities within ESATAN-TMS

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In the latest years the situational awareness on man-made space debris and the application of mitigation guidelines has grown very rapidly. The need of reducing the global space debris population orbiting in the low earth orbit has led to the necessity of developing new satellite design techniques and drivers. At the satellite end-of-life, the object usually undergoes an atmospheric re-entry, and the harsh environment (hypersonic velocity and extremely high heat and structural loads) can cause the complete destruction and ablation of the object and its components, making the adoption of a controlled re-entry unnecessary. The Space Debris Mitigation Compliance Verification Guidelines defines the requirements of Human Casualty risk associated with an uncontrolled re-entry scenario, which can be assessed simulating the re-entry scenario with different software, such as SCARAB (spacecraft oriented), or DRAMA (object oriented), and different others.
These software commonly estimate the aerodynamics and aerothermodynamics during the re-entry with different degrees of simplification, via hypersonic local panel inclination methods.
These software allow the simulation of break-up events during the re-entry with different levels of accuracy, estimating the ground footprint location, along with surviving mass of the re-entering spacecraft fragments.
All the software currently used for simulating the re-entry of spacecraft and space debris require the ad hoc modelling of the satellite and its components; this research aims at integrating a software commonly used at system level for thermal engineering purposes (ESATAN-TMS) with a set of subroutines for performing the atmospheric re-entry analysis, trajectory propagation, impact ground footprint estimation, and human casualty risk evaluation. Such implementation would
facilitate the system integrators to use the same Geometrical and Thermal Mathematical Model for both: thermal system level analysis and re-entry casualty risk evaluation. Such advantage would allow different disciplines to work on the same models with the same software.
In order to perform such implementation, different modules programmed in FORTRAN will be required: state vector dynamics propagation (i.e.: trajectory propagation), aerodynamics and aerothermodynamics, spacecraft break-up, fragmentation, shape evolution, progressive destruction of equipment models, ground footprint and casualty risk estimation. This work is largely based on previous research works and the implementation of the open source software for aerothermal re-entry analysis developed at the University of Strathclyde in the recent years.

Thermal Analysis and Software Tools / **49**

Development and verification of a linear conductor generator with different triangle calculation methods

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In the frame of the creation of a thermal software tool at the FH Aachen a conductive calculator has been established in the form of a MATLAB program. The motivation was the implementation of star coupling links. Generally, the proper calculation of linear conductors is a crucial part of the analysis process and determines the quality of the results to a large extent. For the time being, the focus in this work has been set on quadrilaterals and triangles. The difficulty lies in the proper calculation of the conductors in combination with the differing shapes of the discretization. The results obtained from analytical methods, commercially available tools as well as the methods developed in the course of this work clearly identify a common trend. Especially problematic is the calculation of triangles as they are not easily described by analytical means but they are significant to the variability of the model discretization. Hence, they are inevitable. The quadrilaterals produced mostly satisfying results but among the highly deformed quadrilaterals divergences could also be seen.

Still, it appears that the impact of triangles is much greater. As a result, the major focus of this work is on triangles to reduce the errors they impose. In this work a new method to calculate triangles has been developed and is currently being verified and tested along with multiple others. One of those is especially suited for quadrilaterals developed in the course of a diploma thesis at the TU Munich and another general method was developed earlier on in this project which uses the geometric center as a reference. While the latter two methods heavily depend on the geometry of the thermal nodes, the method developed in this work for triangles uses a different approach. The triangle is being tightly suspended in the middle of a rectangle as shown in Figure 1. Doing so divides the rectangle into two quadrilaterals adjacent to the triangle in the middle. Those and the outlining rectangle are analytically solvable and thus the conductor of the triangle can be deduced. Repeating the process along every edge results in a system of conductors that can be converted into an equivalent system of conductors originating from a non-geometric center to each edge using the general equation for star couplings.

For the proper verification of the methods, simple shapes like the strip shown in Figure 2 yield the advantage of an analytical solution and thus are used for the verification. Further the shapes are discretized by a fine mesh and processed using the FeMap internal steady state solver. These results are included in the verification and used as a reference as well. For additional testing more complex shapes are considered now using FeMap as the reference as analytical solutions of these are difficult to find.

The results of the work and a demonstration of the current state of the developed program will be shown in the presentation.

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Figure 1: A triangle suspended in quadrilaterals along each edge

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Figure 2: Two equally long strips with the same properties and heat loads but different discretization

Thermal Testing / **4**

HGAMA SOLAR SIMULATION TEST

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The ESA Solar Orbiter (SOLO) is an interdisciplinary mission to the Sun. It consists of a single spacecraft, which will orbit the Sun in a moderately elliptical orbit, using a suite of advanced Remote-Sensing and In-Situ instruments to perform a detailed observation of the Sun and surrounding space. Due to the nature of the mission, the spacecraft will get as close as 0.28 AU from the sun, providing the closest ever views of the star, and hence, exposing the different subsystems to very high temperatures. The performance of representative thermal tests under these conditions has been one of the most challenging tasks of the qualification and acceptance test campaigns of the different subsystems, requiring novelty solutions to fulfil the demanding requirements.

SENER is contractor for the delivery of the High Gain Antenna Major Assembly (HGAMA) subsystem. This subsystem is a high-gain dual-axis steerable antenna assembly that provides main uplink and downlink communications between the Solar Orbiter spacecraft and Earth.

When the antenna is deployed it is not protected by the heatshield of the spacecraft and hence it is directly exposed to the sun, having to withstand radiation fluxes of 17,000 Watts per square meter when the satellite reaches the closest point to the star. The intense radiation and high temperatures to which the equipment is exposed has been a technical challenge, not only from design point of view but also for the qualification test campaign. The purpose of the qualification thermal vacuum test was to represent the extreme flight conditions experienced by the antenna using a solar simulator. The levels of solar flux density needed for the test, and the size of the equipment made particularly difficult to find a facility to fulfil the requirements. Some of the most critical points were:

- Test predictions
- Definition of the test thermal cases and set-up
- Location definition and installation of thermocouples
- Infra-Red cameras management during test
- Difficulty of monitoring temperatures above 300ºC

The presentation starts with a brief introduction to the mission, followed by an overview of the subsystem, its components and thermal design main aspects. The content is then focused on the Thermal Balance test and the correlation of the thermal model. To conclude, a list of lessons learned during the test campaign will be presented and discussed.

Thermal Analysis and Software Tools / 38

TROPICS: An interface between OCDT and ThermiCalc for accelerated thermal design

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Abstract
An interface between the MBSE tool OCDT and the thermal analysis software Thermisol is proposed. Goal of this new interface is to automate and accelerate iteration cycles within early mission design studies, following the new space approach.

Abbreviations
ESA - European Space Agency
MBSE - Model Based system engineering
OCDT - Open Concurrent Design Tool

S/C - Spacecraft
TCS - Thermal Control System
TMM - Thermal mathematical model
TROPICS - TheRmal OCDT Parameter InterfaCe Script

In the framework of phase 0 and A studies, the concurrent design approach has become state of the art within the European space industry. The design philosophy of this concept is based on fast iterations and decision making of all subsystems. ESA applies this approach for phase-0/A studies at the Concurrent Design Facility (CDF). These fast iterations require a dedicated tool for data exchange among the responsible subsystem experts, the system engineers and the customer. An open-source tool which fulfils this purpose is OCDT, which is used and developed by ESA. This data model is used to exchange and store parameters, which describe the spacecraft's specification for every subsystem and high-level mission information. Such parameters are for example mass, mode-depending power consumption and temperature limits.

The thermal subsystem has various interfaces to all other subsystems of a spacecraft and therefore strongly relies on their inputs during an early design phase. On the other hand, the power subsystem requires inputs from the TCS. All these corresponding parameters can be modelled and exchanged by using OCDT.

The TROPICS interface enables the user to generate a simple TMM directly from system model and to perform first design calculations like radiator and heater sizing by extracting relevant data from OCDT. This process is illustrated in the figure below.

In order to use TROPICS, the modelling of the S/C in OCDT must follow certain rules defined in a model methodology, which allows to ensure the connection and correct interpretation of the model-data by the TROPICS interface. This methodology is designed to not restrict the S/C model in OCDT to other modelling aspects.

The model philosophy introduces a parameter called "thermal node" on the 4th level of the OCDT model, also known as the equipment level. This parameter is used to collect physical parameters (heat capacity, dissipation, …) and map them to the nodes of the TMM, which forms the common ground for both models. The TROPICS interface then uses these nodes to semi-automatically setup up a thermal mathematical model in Thermisol, to perform basic thermal design calculations. Subsequent design iterations can be computed based on the above described model setup.

Having the task of setting up a simple TMM performed early in a study allows to prepone the study model iterations including the thermal subsystem. This accelerates the design process by having early and fast iterated thermal design parameters.

The thermal subsystem specialist of an early mission study is now able to react fast to changes in the system and to communicate the impact on the TCS back to the other subsystem specialists and the system engineers by transferring the Thermisol results directly back into OCDT. "What-if" scenarios can be performed without implementing major changes to an extensive TMM.

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Thermal Testing / **21**

Contact conductance of copper based brush thermal connections

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The contact conductance of copper based brush thermal connections were investigated. Results show a significant increase in heat transfer as compared to purely radiative connections during a cool down from +20 ℃ to -180 ℃. Derived contact conductance values are higher than for common slip-rings or ball bearings.
Two possible applications initiated the interest for copper based brushes. First there are science instrument designs with moving carousels and low temperature requirements which could be cooled down by cryo-coolers. Here brushes could close the connective link in certain positions of the carousel, using the already present motorisation of the carousel in order to avoid further mechanisms. A second application is the increase in cool down velocity when moving from a purely radiative to a conductively supported cool down in a test facility for fast thermal cycling over a very wide temperature range.
Conductive links between moving and static components are always associated with large uncertainties in thermal analysis. Thus, in order to reduce this modelling uncertainty, a test set-up was designed to test the conductive link of a custom copper based brush and eventually compare it to similar conductive links such as rotor-stator interactions in slip-rings or ball bearing contacts.

Thermal Analysis and Software Tools / 44

MetOp SG MWI On Ground Calibration Targets: thermal analysis, design and development

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The MicroWave Imager (MWI) Instrument is part of the payload complement of the MetOp-SG Satellites type B. MWI is a conical scanning radiometer (scan speed of 45 rpm), with multiple frequency channels covering the frequency range from 18.7 GHz to 183.3 GHz. The MicroWave Imager will provide precipitation monitoring as well as sea ice extent information.
The On Ground Calibration Targets (OGCT) are temperature controlled microwave blackbodies allowing the MWI instrument RF stimulation with a known reference for the on-ground radiometric performance and calibration tests either in thermal-vacuum conditions or in ambient conditions. The instrument will be calibrated on ground with temperature accuracy better than 0.3 K, before flight.
For the thermal-vacuum tests two OGCTs are required: a Thermal-Vacuum Earth Target (TVET) that is a variable temperature target simulating the variable brightness temperature of the measured scene (e.g. from 80K to 335K) to be placed in front of the instrument main reflector and a Thermal-Vacuum Cold Sky Target (TVCT) that is a fixed temperature target to be placed in front of the Cold Sky reflector simulating the cold sky temperature (<80 K). An Ambient Cold Sky Target (ACT) is required to perform tests in laboratory at ambient conditions, with the challenge to maintain a liquid nitrogen temperature in a standard pressure environment.
The thermal design of the OGCTs is described and the results of the thermal analysis are presented. The attention will be focused on the challenges of developing the thermal model of the different targets, since a very high accuracy is requested in terms of temperature gradients, at first, and brightness temperature knowledge as the final aim. The objectives of the design and analysis activities

have been to construct robust, easily usable thermal models of high detail to address these challenges. In this framework, the thermal model is extremely important. In fact, during the tests it is not possible to put any kind of sensors on the targets surface because it is very fragile and, anyway, they would affect the measurement. In addition, other measuring systems have been deemed not suitable. Hence, the reliability on the thermal model has to be quite high.
The challenges concerning the present thermal modelling are mainly due to computational limits: in fact, the targets are composed of a very huge number of elements whose temperature difference and gradients knowledge has to be precise as much as possible. In other words, this can be seen as dealing with a very large number of nodes and shapes. The geometries have been built using the Systema Thermica Python API and a 32-core workstation in order to deal with such heavy thermal models; this is the best solution to generate these targets for a total number of more than six thousands absorber pyramids for the TVCT and more than one thousand for the TVET, taking into account that a reasonably fine mesh is quite important. The two vacuum targets will be simulated with the instrument in test configuration and rotating at nominal speed.
Concerning the ambient target, the thermal development design concept will be described, supported by a conservative thermal analysis performed on a small sample, estimating the convection contribution.
Finally, concerning some MWI frequencies, the results in terms of brightness temperature are presented and matched to the requirements.

Thermal Testing / 12

SAOCOM 1A TVAC and a low-power/hi-sensitivity thermal case study

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The SAOCOM satellites (1A and 1B) are two twin L-band SAR satellites for earth observation. Each satellite weights 3.000kg and main dimensions are 10m wingspan and 3.5m high.
This program is developed by the Argentine Space Agency CONAE as a customer and INVAP as Prime Contractor.
SAOCOM 1A was successfully launched in October 2018 and then began its observation and acquisition phase. Both satellites will operate in a constellation jointly with the four COSMO-SkyMed satellites, developed by Italian Space Agency (ASI). They make up the so-called Italian-Argentine Satellite System for Emergency Management (SIASGE).
During 2017 the SAOCOM 1A assembling, integration and complete qualification test was done at INVAP facilities in Bariloche, where the TVAC test was one of the most challenging test performed by the thermal team.
This presentation shows how the TVAC test of the service platform was carried out, from the point of view of the Thermal Control Subsystem. Key aspects of the thermal balance cases, initial predictions, test results and finally mathematical model correlation are shown.
A second part of the presentation is dedicated to a problem found in the thermal design after the TVAC test during the model correlation. This problem involved a Reaction Control Thruster (RCT) and was particularly interesting because its thermal balance involved a few watts but at the same time it showed a great sensitivity to temperature. Sun trapping due to RCT support MLI configuration and nozzle, in simultaneous with a high resistivity thermal path to satellite structure resulted in a significant over temperature at thruster valve. Some aspects of the troubleshooting sequence are presented, the solution adopted together with some anecdotes and results in flight.

SAOCOM 1A with its SAR Antenna fully deployed during a test (2017)

Thermal Testing / 47

Sentinel-1 thermally activated Separation Bracket

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The presentation deals with the design, function and qualification process of a thermally activated separation bracket. This new principle was developed for Sentinel-1 C&D in order to support the satellites demise and thus avoid satellite parts hitting the ground after re-entry.
The principle is based on a soldered cup-cone fixation between antenna and bus. During re-entry, as soon as a temperature of around 140℃ is reached at the fixation, the separation bracket is activated and "unsolders", thus the antenna is separated from the bus. This configuration reduces significantly the risk of satellite components hitting the ground after re-entry.

Small Satellites and CubeSats / Analysis / 7

A Modular Approach to Thermal Modelling of CubeSats in ESATAN-TMS

Authors: Arne te Nijenhuis[1] ; Hugo Brouwer[2]

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With the CubeSat market expanding and with CubeSats entering the high-performance domain (to 6U, 12U and 16U) the thermal problems of CubeSats get more prominent. A result of the shift towards high-performance missions leads to stricter thermal requirements as the power density increases and the usual low cost thermal design strategies appear insufficient.

An innovative modular thermal approach is developed in this research. In order to provide relevant input for improved thermal design of CubeSats, the presented research is initiated by ISIS in cooperation with NLR, to introduce a fast modular approach for thermal orbital modelling using ESATAN-TMS. This approach will aid in defining the thermal criticalities and developing solutions.

A key characteristic of this innovative modular approach is that the thermal submodels are made interchangeable and easily scalable, allowing for fast thermal analysis for LEO missions. The geometry of a CubeSat can quickly be adapted by implementation of submodels of thermal components, standard units and payload units in the CubeSat-frame model. A library of thermal submodels has been created, based on geometry and thermal characteristics, which will be presented.

The introduction of standardized thermal submodels for CubeSat systems results in fast thermal orbital analysis and quick evaluation of thermal design strategies. For verification of the standardized submodels, we propose dedicated thermal vacuum and thermal balance tests of CubeSat structural components and units. In case the submodels are validated with test results, they allow for more accurate thermal analysis and improved evaluation of thermal design strategies for CubeSat systems. In this way, for the first time, CubeSat thermal engineering can be executed by making use of verified models and data, which has been lacking throughout the community. Hereby, the confidence in the thermal analyses performed for CubeSats is significantly increased.

Thermal Design / 50

Flexible External Insulation (FEI) at ArianeGroup Bremen Development - Qualification and Application

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ArianeGroup Bremen has started the development of Flexible External Insulation (FEI) already within the HERMES program in the eighties. In the meantime a complete FEI product family was developed and qualified which covers a temperature range from 300℃ to 1100℃. The FEI with its excellent performance w.r.t. reusability, low mass, simple inspection and maintenance, is the favorable TPS for the leeward-side of any space transportation system.
Now the Flexible External Insulation is integrated on ORION service module rear side.

Small Satellites and CubeSats / Analysis / 8

Modular Parallel Micro Pump for Adaptive Thermal Control of CubeSats

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With the CubeSat market expanding and with CubeSats entering the high-performance domain (to 6U, 12U and 16U) the thermal problems of CubeSats get more prominent. A result of the shift towards high-performance missions leads to stricter thermal requirements as the power density increases and the usual low cost thermal design strategies appear insufficient.
To further support the higher power density, the need for Mechanically Pumped Loops (MPL) becomes more and more relevant for CubeSats as a possible solution. Current MPL are typically used for larger satellites, and in the range of multiple kW's, which make them rather expensive, and heavy weight.
In essence a smaller loop is possible, however, the availability of a smaller space approved pump becomes a necessity, and due to redundancy needs, current pumps are aimed at the larger satellite market, making them too heavy, and too expensive for cubesats. The lack of a suitable pump is basically a dealbreaker for the implementation of MPL's in CubeSats.
To solve this, NLR has been developing a Modular Parallel Micro Pump. This pump consists of several piezo driven smaller pumps, which can be stacked in different configurations to achieve the flow and pumphead desired. In this presentation we want to share the results achieved for several configurations, and discuss our next steps.

Small Satellites and CubeSats / Analysis / 55

Radiative Surface Properties of a Trihedral Array for Lunar Thermal Control Applications

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The increasing trend towards higher power electronics and the rapid growth of the smallsat industry has led to increased heat dissipation requirements for spacecraft thermal control systems. In this study, an investigation of a trihedral geometry is performed in order to determine its potential as an effective radiator panel for passive thermal management. This form aims to minimise the negative effects of environmental radiation while maximising the heat transfer to deep space.

A radiative thermal model is developed which calculates the thermal energy balance on participating surfaces, taking into account all sources of environmental sources of radiation experienced on the lunar surface. Results are presented for a preliminary model consisting of an array with 7 trihedral elements. The orientation of the faces and the compounding shading effects of surrounding elements causes a change in the effective surface properties. The selection of the optimal configuration is a trade-off between minimising both incident solar irradiation and radiation view factor to the lunar surface.

Thermal Design / 9

Development of Variable Emissivity Coating for Thermal Control

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For years the use of variable emissivity devices and coatings has been envisaged by the academic and industrials space actors. The aim is to overcome the drawback specific to constant thermo-optical coatings with regard to the variation of heat load during the mission and so to maximize the heat rejection capacity and to minimize the heating power budget. The most promising of these coatings are based on thermochromic (TCH) and electrochromic (ECH) materials.
Thermochromic materials can be adjusted to behave as poor emitters at low temperature, and good emitters at high temperature. As such, they are proposed as smart elements capable of supporting thermal control on board of spacecraft, without the need of any electronic feedback or electromechanical actuation, and, therefore, at zero power costs. The solutions proposed for TCH smart radiators are pretty heterogeneous, and range from sintered tiles, to sol-gel paints, to vacuum thin-films.
Another promising approach is based on electrochromic devices. Common ECHs work in the visible spectrum and modulate transmitted or reflected light intensities upon application of voltage. The advantage of ECH for space application is achieved by adapting the infrared emissivity of a surface by application of a low power electrical potential.
In an ongoing R&D activity funded by ESA and CNES the TCH multilayer tiles are based on VO_2 technology developed with industrial means and ECH devices are based on encapsulated conducting polymers. In this presentation the various approaches in order to design, manufacture and test

TCH and ECH materials as well as variable emissivity radiator breadboards will be discussed. Some coupons and materials issued from this activity will also be presented.

Small Satellites and CubeSats / Analysis / 6

The Application of a Thermal Mathematical Model during Lander Operations on the surfaces of Small Bodies

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Landing on small bodies like asteroids and comets is an extreme challenging operation. The unknown thermal and physical properties of the surface after a multi-annual journey in deep space require a high degree of flexibility for operations planning and execution during the landing and consecutive on-surface mission phases.
The presentation describes the planning and analysis loop used to establish and execute the operations for two of these landers, the comet lander Philae on 67P/Churyumov–Gerasimenko and the asteroid lander Mascot on Ryugu, by the DLR Lander Control Centre in Cologne in collaboration with the other mission partners.
This planning and analysis loop, focusing on power and thermal aspects, is mainly built by the Thermal Mathematical Model (TMM) of the respective lander interacting with an Operations Planning Tool, which e.g. translates the planned operation in dissipation profiles for all relevant nodes of the TMM. Moreover as one of the reason for thermal analysis during operation is the life extension of the batteries, the TMM is prepared with a detailed electrical and thermal model for the batteries and their management and, in case of Philae, it is also interacting with a Solar Array Illumination and Power Prediction tool.
In addition, to plan long-term surface operations, the TMM needs to include a dedicated and flexibly adaptable comet or asteroid surface model because, as especially seen during the post-landing operations of Philae, the impact factor of the real environmental conditions found after landing is considerable.
On the other hand the TMM needs to support its alternating application between moving and resting on-surface configurations as required by Mascot, the Mobile Asteroid Surface Scout.
The presentation shows details of the necessary TMM preparation in order to optimize its application during real-time operation.

2-Phase Heat Transport Technology / 13

Compact and lightweight two-phase pumped cooling system with 3D printed aluminium components

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The amount of waste heat that is generated in electronic components in aerospace application is increasing because of higher electrical power demands. As a result, conventional cooling methods are not able to maintain the electronic component below its maximum temperature. For this reason, a two-phase Mechanically Pumped Fluid Loop has been developed for high-power electronic components in a commercial aerospace application. These electronic components generate a waste heat of 1200 W that is divided over several hotspots while the temperature gradient over the component has to be kept to a minimum. The developed cooling system uses R245fa as refrigerant and is made from aluminium components produced with additive manufacturing. The use of this novel

production technique results in an unprecedented low system mass (2.5 kg) and small system dimensions. Measurements show that the system has an excellent thermal performance and is able to cool 2400W.

Thermal Analysis and Software Tools / **24**

Challenges implementing a stratospheric balloon ascent phase in ESATAN-TMS

Authors: David González-Bárcena[1] ; Javier Piqueras[2] ; Arturo González-Llana[2] ; Ignacio Torralbo[1] ; Isabel Perez-Grande[1]

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When developing a stratospheric balloon mission, the Thermal Control Subsystem (TCS) plays an important role for a successful mission. From a thermal point of view, in this kind of flights the payload faces extreme environmental conditions very similar to the ones found by spacecrafts. At float altitude, radiation dominates heat exchanges with the environment because convection effects can be considered neglectable. Because of that, thermal analyses are usually performed in a similar way, dimensioning the TCS for a hot and cold extreme cases in steady-state conditions. Thus, ESATAN-TMS, as the standard tool of the European Space Agency (ESA) for thermal analysis of space systems, seems an appropriate tool for stratospheric balloons thermal analyses. Nevertheless, there are some particularities during the ascent phase of this kind of missions that make the ESATAN-TMS implementation a challenge to overcome. Indeed, the changing environmental conditions, the convective effects and the variable geometry of the balloon skin are some of the main difficulties. A complete thermal analysis of a stratospheric balloon has been performed in ESATAN-TMS, in the context of SUNRISE-3 mission. Such analysis includes not only the traditional worst case scenarios, but also a full transient ascent phase thermal analysis, all based in real Earth observation data.

Thermal Analysis and Software Tools / **37**

Machine learning algorithms to develop predictive thermal tools for spacecraft simulations

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In this presentation, we detail a novel method for coupling thermal modelling tools (Simcenter 3D Space Systems Thermal) with machine learning (ML) algorithms to develop predictive thermal tools for spacecraft simulations. Additionally we utilize a model reduction method to reduce the complexity of the models which can then be mapped back onto the original high fidelity models. The ML are trained on existing or generated simulation data and used as a predictive tool to drive thermal physics solutions without the need to explicitly resolve the conductance networks over the entire lifetime of the simulation, thus greatly reducing the burden to run explicit simulations.

With some examples, we illustrate that we are able to maintain fidelity of the underlying thermal physics with a number of different ML algorithms for the predictive methods and additionally are

able to capture the behavior of the 'real' models by mapping the reduced ML results back on the original
model. This opens the door to facilitate hybrid ML / thermal simulation methods for spacecraft simulations thus reducing the burden of running large models over a large parameter space. We conclude by outlining the pros and cons of this method and our future direction for the hybrid ML / thermal simulation coupling.

2-Phase Heat Transport Technology / 31

Medium LHP state of the art

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Loop Heat pipe is an efficient heat transfer system based on the liquid-vapor phase change phenomena. A LHP consists of an evaporator, a condenser, a compensation chamber (also called reservoir), and transport lines. For many years, EHP/Airbus have implemented several developments, in collaboration with product users, to simplify and robustify its application and improve its performances: start-up, inhibition, characterization of ground vs flight performances, subcooling improvement, spacecraft environment impact.
Nowadays, Airbus & EHP collaborates with Thales Alenia Space on new R&D projects, in order to become an European leader on LHP products.
The following presentation provides a concise overview of the last developments and tests realised on LHP² in order to have a product available on the shelves and easy to integrate from S/C system perspective:

- Start-up mastering
- Performance improvement and regulation at equipment level
- E/W radiator application using LHP for telecommunication satellite
- Deployable radiator with LHP
- LHP heritage : on ground, in orbit and future satellite mission

2-Phase Heat Transport Technology / 32

A Separable Loop Heat Pipe for Cooling a Pressurised Cargo Module

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In recent years, Argotec, a technology provider of passive thermal control systems based on the use of two phase systems, has carried out research and development, creating different passive thermal control systems in the aerospace and industrial field. Thanks to these starting skills, the 2-PHASE (Passive Heat exchange for Aerospace and Earth applications) project has been developed, with the help of the Piedmont Region, between Argotec, Thales Alenia Space and OPTEC.

In collaboration with Thales Alenia Space an innovative use of a Loop Heat Pipe (LHP) has been studied, built and tested. Thales identified a need to transport a large amount of heat from within the human rated pressurised section of the enhanced version of the Cygnus PCM (Pressurized Cargo Module). To meet the project requirements an LHP has been designed which transfers large heat fluxes over long distances within a wide operating temperature range using a low-toxicity working fluid. The LHP consists of a compact evaporator equipped with fan-assisted heat exchangers to extract heat from the pressured section of the spacecraft. Feed-throughs are used to pass the LHP vapour and liquid lines through the pressure shell. Either side of the feed through is equipped with disconnect-able hardware to allow for an easier integration of the internal and external parts of the LHP. The heat collected at the evaporator is then dissipated by means of a meandering tube mounted to an existing external structural panel.

A loop heat pipe has been constructed and tested, with representative interfaces, in a vacuum chamber located at Thales in Turin. The presentation will describe the LHP design, the test setup and initial results of the test campaign.

Thermal Analysis and Software Tools / 54

First steps of numerical simulation using Artificial Intelligence

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As for the thermal simulation of a satellite, its design is crucial. It involves the integration in the thermal and mechanical model of reduced parts of equipment or supports (additive manufacturing) from 3D models finite elements. The goal of the thesis is the drastic reduction of 3D geometric models that minimizes the alteration of the physical properties (here the calculation of the view surfaces) induced by the model reduction during the numerical simulation.

We are currently working on **an approximation guided by view factors**. The aim is to design a geometric approximation method where each atomic simplification or optimization operation is guided by preserving the view factors of the reference model, rather than preserving the geometry. The ultimate aim being a radiative thermal computation on a "small" model made of a few hundreds of facets instead of millions of facets.
The next step consists in **a supervised learning of the geometric error metric** (using **deep learning**). Deep learning is a subset of machine learning (which is also a subset of Artificial Intelligence). In both cases, algorithms appear to learn by analyzing huge amounts of data. Deep learning processes data using computing units, called neurons, arranged into ordered sections, called layers. A stack of those layers form what we call a neural network, which is the kind of model we will use.
When working with supervised algorithms, the input data is labeled and has a specific expected result. We train a model to predict the labels of the given training examples. As training progresses, the predictions or classifications become more accurate. Our idea is to use deep learning as follows : from a database of expertly generated 3D models, we will design a supervised machine learning method using multiple layers to learn the geometric error metric able to govern an automatic approximation algorithm so that the resulting thermal simulation is as accurate as possible to a reference calculation.
We already developed and are still improving a software relying on a new hierarchical geometric data structure for the efficient computation of view factors, which allows us to have a precise reference case.

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JUICE (Jupiter Icy Moon Explorer) Instruments thermal control and interface

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JUICE (Jupiter Icy Moon 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 10 state-of-the-art remote sensing, geophysical, and in situ instruments plus one experiment that uses the spacecraft telecommunication system with ground-based instruments.
The main design drivers of JUICE mission are the very harsh radiation in Jupiter environment, leading to shield individually or collectively all the sensitive components, the stringent Electro-Magnetic Compatibility (EMC) requirements to fulfil the magnetic and electrical fields' measurement objectives and the low solar illumination received at Jupiter. This latter parameter drives both the size and technology of the solar arrays, and the thermal control, that is designed to cope with hot and cold environments. JUICE spacecraft thermal control has to cope with a large variation of external environment during the mission (Sun flux from 3300 W/m² in the inner Solar System down to 46 W/m² in Jovian environment) and long eclipses of up to 4.8 hours. Most of the instruments are thermally decoupled from the spacecraft and have to cope with such extreme environment variations but use as well Spacecraft resources such as heating power or, in some cases, thermally controlled cold fingers.
The presentation will focus on the thermal control of the different instruments principles and how the thermal interface between the sensors and the spacecraft is managed.

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Solution flexibility of HiPeR flexible radiators

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Airbus DS has been developing modular flexible radiator solutions through the use of laminated pyrolytic graphite material. These High Perfromance Radiators (HiPeR) are designed for ultra-lightweight thermal control and are scalable from nanoscale spacecraft (1U CubeSats) up to kilowatt level geosynchronous platforms.
HiPeR radiators are extremely versatile and can be used as a low mass replacement to existing radiators for backwards compatibility. Radiators can be made deployable, both with passive and with active means of deployment. For example, such radiators can be folded under stowed solar arrays and held in place by the already existing snubbers.
Radiative performance can be controlled during a mission through both geometric control and heat flow control. This eliminates the need for additional louvre-type systems. Alternatively, integration of dual purpose hinge systems and radiator surfaces to heat sinks is possible, with little impact on thermal efficiency because there is no loss through interfacing or moveable parts.
HiPeR technology can be used in combination with heat pumps to provide end-to-end thermal solutions for dissipating payloads. Some of these combinations of functionality have already been demonstrated in breadboard testing.
A summary of the state of the art of HiPeR radiators will be shown along with parametric studies demonstrating its scalability and associated mass performance efficiencies. Passive deployable systems using HiPeR can achieve up to 100W/Kg.

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Thermo-elastic test as part of ESA activity: Improvement of methodologies for thermo-elastic predictions and verification

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Stability requirements of current and future ESA projects are getting ever more challenging, with thermo elastic distortion and strength playing a dominant role on the final performance. Compliance to those requirements is usually verified only through analytical models that are not correlated with regard to their validity for thermo-elastic predictions, leaving not quantified uncertainties in the results and possible surprises in flight.
Thales Alenia Space started in 2017, under ESA TRP contract, to work on the improvement of the predictive capability of thermo-elastic analyses for distortion and strength and their verification, adopting a truly cross disciplinary approach between the thermal and mechanical domains.
The activity splits into four main steps, 1) collection of past lessons learnt, 2) identification, elaboration and implementation of methods able to improve end-to-end prediction and verification, both for analysis and test, of thermo-elastic behavior (strength and stability) of spacecraft structures, 3) demonstration of the identified methods on an application case including a test and 4) dissemination of these methods to the European space community, such that they can be implemented by any stakeholder.
This paper presents the results of the first three steps, focusing on the testing aspects and giving highlights on the activities to be completed at the end of this year.

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Correlation of a Thermal Model for Thermo-Elastic Distortion Predictions

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This work has been performed as a follow on to the ESA R&D activity Improvement of Methodologies for Thermo-Elastic Predictions and Verification (I-METER). In the framework of this activity, a thermal test was performed at the facilities of Thales Alenia Space in Cannes, France in early 2019, using the structure of the Iridium Next platform. The objective of this test was to generate thermal gradients on the spacecraft structure in order to capture various thermo-elastic behaviours. Data from this test will now be used to correlate thermal and mechanical models to produce better thermo-elastic distortion predictions. Test data was captured by discrete temperature measurement via thermocouples, infrared camera images of a single panel and two videogrammetry systems to measure the relative displacement of the structure under different thermal load cases. In order to make use of the test data, a number of correlation and data processing steps need to be performed together with the thermal mathematical model to prepare it for mapping to the structural FEM.

This presentation will focus on the correlation of the thermal model of the structure of the Iridium Next Platform used for the thermo-elastic test. More specifically, it will address some of the outstanding issues in the correlation to represent the temperature gradients seen during the test. In addition, it will also discuss the benefit of processing and manipulating the IR image data and mapping it to the thermal model to correlate gradients.

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Guidelines for accurate thermo-elastic analysis

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Thermo-elastic behaviour of spacecraft structures and payloads is often a critical design aspect due to the importance of dimensional stability (hence payload accuracy) and structural strength. The accuracy of thermo-elastic analysis relies to a large extent on the correct interplay between the thermal model, the structural model and the translation of the thermal results to the structural model.

Over the last years ATG-Europe has obtained extensive experience in the field and has previously presented on different parts of the topic [1,2,3]. The work presented at the ECSSMET 2018 1 considered different thermal mapping methods and showed the importance of an accurate thermal load definition. As part of a bigger ongoing study on true-to-life structures that assesses the accuracy and validity of the existing thermo-elastic analysis procedures, ATG is now considering this more extensively, in a wider scope and on a more realistic model by performing sensitivity studies on the main modelling parameters of both the thermal and structural model. In addition, various different thermal mapping methods are considered. Specifically, geometric interpolation, conductive interpolation, patch wise mapping and the prescribed average temperature method using SINAS [4] are used. These thermal mapping methods link the structural and thermal models together for various distortion and strength based performance parameters. More details on the technical aspects of the mapping methods can be found in 1.

This study extends on current papers by ATG, specifically 1, by analysing a more realistic structure, which is not merely an academic example, and a greater amount of load cases. This presentation will comment the two main conclusions obtained from the results of this study:

- Importance of temperature spatial gradient definition
- Effect of different temperature mapping methods on local temperature gradients close to high heat input areas

The main focus will be on the implication of thermal modelling practices in combination with the used mapping method on the TE performance.

REFERENCES

1 Temperature Mapping For Structural Thermo-Elastic Analyses; Method Benchmarking.
Menno Koot, Simon Appel, Samo Simonian.
Presented at the ECSSMET 2018, ESTEC, Noordwijk, The Netherlands

2 Thermal Conductor Generation For Thermal And Thermo-Elastic Analysis Using A Finite Element Model and SINAS.
Menno Koot, Simon Appel, Samo Simonian.
Presented at the ECSSMET 2018, ESTEC, Noordwijk, The Netherlands

[3] Accurate thermal mapping and Finite Element Model based Conductor Generation; extended method benchmarking guidelines
Menno Koot, Alexander van Oostrum, Iñigo Urcelay, Victor Sutii, Simon Appel
Presented at the ESTEW 2018, ESTEC, Noordwijk, The Netherlands

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SINAS Made Simple

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SINAS is a tool for mapping temperatures from lumped parameter based thermal analysis to a finite element model for computing thermo-elastic responses. The most recent major version of SINAS was developed for ESA in 1998. Since then not many companies have been using the software. One of the reasons is the software was quite cumbersome to use; many steps had to be performed which all required a steep learning curve.
pySinas is a python based replacement of most of the code of old SINAS suite. It combines various developments at ESA over the last years. With pySinas it is now possible to combine the full functionality of the many steps of SINAS into a single run with straightforward input and output files. It still offers the possibility to generate the intermediate files to allow for quickly mapping results of additional thermal analysis runs.
The presentation will provide a short summary of the methods behind SINAS followed by a short getting started instruction. Finally, information is provided on how to get a copy of pySinas. pySinas is free of charge for industry from ESA member states.

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SINAS: Benefits and points of attention

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The accuracy of thermal analysis relies to a large extent on the nodal discretisation and conduction calculation/definition in the thermal model. Traditional methods of conductor calculation use simplified analytical rules and can be very user intensive or require large simplifications. The work presented at ECSSMET 2018 1&2 and ESTEW 2018 [3] considering thermal mapping and FEM based conductor generation respectively, has shown how the software SINAS [4] can improve the accuracy of thermal and thermo-elastic analyses whilst possibly also reducing the user's workload.

Recent developments in the software have improved the accessibility of SINAS through a Python version with a unified interface. With these recent updates SINAS has become more available for the general public and therefore, an increase in the number of users is expected.
ATG has extensive experience using SINAS, including the new PySINAS interface. Through practical examples, ATG wants to provide guidelines and examples for the different possible uses of the python version of SINAS. These examples will highlight the benefits of software but will at the same time also focus on problems which are expected to be most relevant to new users of the software.

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1 Temperature Mapping For Structural Thermo-Elastic Analyses; Method Benchmarking.
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Presented at the ESTEW 2018, ESTEC, Noordwijk, The Netherlands

[4] SINAS IV: Interpolation of lumped parameter thermal node temperatures (from e.g. ESATAN) to thermo-elastic input data (with MSC. NASTRAN)
https://exchange.esa.int/restricted/sinas/

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Closure

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