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Methodology for the thermal analysis of instrumentation in Long Duration Balloon missions

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Abstract

The aim of the work presented is to apply the classical approaches considered in Space Thermal Design to the thermal analysis of instrumentation on board Long Duration Balloons (LDB). These systems, having some specific features, simply consist of stratospheric balloon payloads operating in a similar environment than in space missions. The followed methodology to obtain the worst environmental conditions and to develop the thermal analyses as the mission evolves from a system level is explained. All these considerations have been implemented in the context of the IMaX+ Electronic Unit as a part of SUNRISE III mission.

1 Introduction

Thermal analyses play an important role in the design process of any space mission. During the last sixty years, a large number of space activities have been carried out in an international context. They have provided a great evolution of the technology, which has reached a high level of complexity based on the experience acquired. In order to achieve the purpose of each mission, high reliability and safety requirements are needed.

Due to the harsh thermal environment spacecrafts have to stand during their operating life (vacuum, IR radiation, albedo, etc), actions should be taken in order to guarantee thermal requirements. For that reason, deep studies in both thermal environment and thermal behaviour of the considered systems must be carried out.

As it is said in [1], “The role of the thermal control subsystem (TCS) is to maintain all spacecraft and payload components and subsystems within their required temperature limits for each mission phase.” To guarantee so, many activities have to be done in pre-launch phases. The main objective of those activities is to predict how systems are going to behave in space and to ensure they are going to fulfil every thermal requirement.

Since the first flight of Sputnik-1, both analysis tools and technology to be implemented have changed radically. By that epoch, access to space was limited to government’s action. Nowadays, access to space has been opened to private industry and other institutions but it still is an expensive practice where over-sizing has no place. More and more exhaustive thermal analyses are being required as they can reduce considerably the risk assumed to be taken in a space mission. By doing so, uncertainties are reduced and a final design which ends up with over-sizing can be achieved.
Long Duration Balloons play a relevant role in the development of space technology. They are a less expensive way to access to space and to test instruments in a very similar environment. Besides, the possibility of recovering the payload after the flight brings the possibility of gathering valuable information to customers and also allows instruments reuse. Furthermore, stratospheric balloons are low cost platforms for scientific experimentation. LDB are flown with zero-pressure helium balloons reaching volumes up to 40 MCF and carrying payloads up to 2,700 kg to altitudes ranging from 36 km to 40 km [2]. Reaching that altitudes supposes an advantage in comparison with ground-based solar observation. Being above 99% of Earth’s atmosphere, wave front distortions due to atmospheric turbulence are virtually not existent [3]. Nevertheless, the ambient found at that altitudes, where the ambient pressure is lower than 300 Pa, are similar to that of space. Therefore, the convective heat transfer is negligible in most systems and the

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heat transfer to the ambient is mainly driven by radiation. Analysis should be performed in the same way; the extreme worst-case (hot and cold) scenarios are considered [5-7].

Driving and coordinating a thermal design process adds additional work to do related with different areas. The whole system is divided in several subsystems and the thermal design of each one is quite often carried out by different institutions. From a technical point of view, it is necessary to coordinate that work in order to ease the integration of each instrument in the system thermal model. In addition, the thermal environment affecting each instrument has to be derived from a system level study. By doing so, the thermal engineer in charge of performing each model can run several simulations to design a thermal control that fulfils the requirements.

The process of thermal design in space systems can be divided in various steps [1]. Firstly, a deep analysis about thermal conditions the spacecraft have to stand in orbit has to be done. Those analyses can be different according to the position and orientation of the system with respect to other systems, the Earth or other nearby central body, and the Sun [7-10]. Many parameters are involved in the definition of the worst environmental conditions the system must face. The thermo-optical properties and the conductive couplings of an instrument with the corresponding interfaces will determine the worst cases scenarios. In order to face this first step taking into account every single variable, a new methodology [5] has been used. As it is explained, worst operational case conditions have been obtained from real data collected from different Earth observation mission (EOS Terra, Aqua, Suomi-NPP, JPSS-1, etc.) [6].

Once determined the thermal environment, a representative model of the system with the considered units has to be developed. Extreme temperatures and the behaviour of the system under specified conditions can be extracted from this model. As it will be explained, a specific software for thermal modelling should be used [8]. From this model, the extreme environmental conditions for each instrument are obtained after a parametric study. Those conditions will be transformed in a practical format in order to facilitate the thermal analysis at each subsystem level.

The methodology followed to obtain the thermal environment at float altitude and the extreme cases at a system level is presented in Section 3. Then, how to provide the boundary conditions to be implemented in the thermal analyses of the different subsystems is exposed in Sections 4 to 6. Those boundary conditions are also evaluated to ensure a close adjustment to the environmental conditions expected to be found (Sections 7 and 8). The aim of the work presented here is to apply all these considerations to the thermal analysis of instrumentation on board Long Duration Balloons (LDB). The work done at a system level in the context of SUNRISE III mission and the followed methodology are presented and particularized to the thermal analyses of the Electronic Unit of IMaX+.

2 SUNRISE III

The first SUNRISE balloon borne telescope was launched in 2008 [3]. Due to its great success, a second mission, SUNRISE II, was launched in 2013 [10] and SUNRISE III is currently on its preliminary design phase. It is being developed in an international cooperation led by Max-Planck-Institut für Sonnensystemforschung (MPS). Instituto de Microgravedad “Ignacio da Riva” (IDR) is the responsible of the thermal design at a system level following the experience acquired in previous SUNRISE flights and other space missions. Moreover, as a part of Spanish consortium coordinated by Instituto de Astrofísica de Andalucía (IAA-CSIC), IDR is also responsible of IMaX+ Electronics Unit (E-Unit) thermal design.

SUNRISE III is a balloon-borne solar telescope which is going to be flown in a zero-pressure stratospheric balloon. Its main objective is the study of the structure and dynamics of the magnetic field in the Sun’s atmosphere as previous missions did. Operating in the stratosphere, image degradation due to atmospheric turbulence can be avoided. It also allows to gain access to the UV range down 300 nm.

SUNRISE III is expected to be launched from ESRANGE (Kiruna, Sweden) in 2021 performing a similar flight than in SUNRISE I and II. As well as in both previous flights, a launch during the summer period is required. This launch window allows SUNRISE to have uninterrupted solar observation because of the effect of the solstice near the polar circle. As it has been explained, these flights can reach a duration of 15 days, but SUNRISE flights have been limited to 5-6 day due to flight overpass regulations.

The geographic location of ESRANGE (67.96º N, 21.07º E) offers the balloons different capabilities depending on the launch window. Balloons launched on the winter period can be easily injected into the polar vortex. Due to the stratospheric winds are strong from W to NW, ceiling times of 5-10 hours can be reached. However, during the turn-around periods in late April and early May and second half of August, stratospheric winds are very low and irregular allowing the balloon to stay in the range of the base up to 3 days. Finally, launches during the summer period from

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May to mid-July are the most suitable for LDB. Stratospheric winds are very stable from the East allowing to perform flights of 7 to 15 days with latitude excursions not exceeding ±3º [11].

SUNRISE infrastructure can be divided in payload and gondola. On one hand, payload is split in these major components: Telescope, Post Focus Instrumentation platform with science and instruments, and the instrument control electronics. On the other hand, the gondola is the structure which carries and protects instruments and other necessary subsystems providing link between the payload and the balloon. SUNRISE I is shown in Figure 1.

Figure 1. SUNRISE I at ESRANGE during the launch.

IMaX+ will be an upgrade version of the IMaX instrument flown on SUNRISE I and II. It will also develop observations of the MgIb line at 517.3 nm formed around the minimum temperature. In other words, it will make images of the solar surface magnetic field after measuring the state of polarization of light within (alternate) two spectral lines. For that reason, IMaX+ shall work simultaneously as a high sensitivity polarimeter, a high resolving power spectrometer and a diffraction limited imager.

Electronics on IMaX were conceived to be divided on Main Electronics (ME), optical bench electronics (PE) and the harness. Everything was manufactured with commercial-grade, either off-the-shelf (COTS) or specifically designed components. For that reason, both ME and PE were located in pressurized vessels due to the quasi-vacuum conditions at float [12]. ME housing is shown in Figure 2.

Figure 2. Main Electronics unit of IMaX before the integration

Concept for electronics has been slightly changed for IMaX+ since not PE are going to be considered at this design phase. All electronics are expected to be placed in a E-Unit as the available capabilities of new technology allows to locate HVPS outside the optical bench with no potential danger to IMaX+ functionalities. It will be also pressurized because of the use of COTS not resistant to quasi-vacuum conditions. IMaX+ electronics concept on E-Unit can be

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observed in Figure 2.7. It will be composed by Data Processing Unit (DPU), Power Converter Module (PCM), Analog Mechanisms and Heaters Drivers (AMHD) and High Voltage Power Board (HVPS).

3 Methodology

The design process of Long Duration Balloon Missions is usually developed following the same methodologies used in the space industry. This consideration could be applicable to some subsystems since the requirements are similar. However, this is not the case of the Thermal Control Subsystem. Even though LDB present several similarities with the thermal environment found in Low Earth Orbit satellites, and the subsystem's objective is common, there are some particularities related with the thermal behaviour which makes the space thermal design methodologies not completely applicable to these systems. They are the following ones:

- LDB has a high residence time over an area and the local variability of the environmental conditions is not so high. For that reason, there are some parts of the payload which are small enough to follow a quasi-steady state during the flight. Depending on their thermal capacitance, the time constant of units and structures on a balloon gondola can range from 30 min to 3 h (shorter, but not much shorter than the residence time). This will depend on the time constant and the subsystem characteristic times.

- The duration of these flights can range from 7 to 15 days in the North Hemisphere during the Summer. As it was shown in [5], the variability of the environmental parameters along the year is high. The study must focus in the seasonal values in order derive the extreme cases from statistically treated data.

- LDB launched from ESRANGE during the Polar-summer move to the West due to predominating stratospheric winds in the East to West direction. Excursions in latitude are low and the thermal environment will depend on the location apart from the epoch. For that reason, the environment should be particularized to region where the flight would be performed. By doing so, seasonal events and the corresponding local characteristics are considered.

- During the orbit of a LEO satellite, eclipses determine the cold extreme cases since no direct solar flux exists on the system. In some cases, stratospheric balloons are exposed to similar situations. However, in Long Duration Balloons launched from ESRANGE during the month of June, no eclipses take place during the whole fight. When facing the problem of defining the cold extreme case of a LDB, it is necessary to take into account that the SZA for that case could not be the maximum one. There are instruments with different orientations and moving parts which can lead to other values.

- During space launches, satellites are isolated from the atmospheric environment inside the fairing. During the ascent phase of a LDB, equipments are exposed to critical conditions in terms of convection. The thermal behaviour of the system has to be studied in this phase in order to ensure the survival of every component due to the low temperatures which could be reached.

The methodology here proposed aims at considering all these particularities and helping the thermal engineer to face the design process from a system level. The thermal design must evolve as the whole design does and the thermal environmental conditions may change during this process. Following this methodology, an iterative process could be followed easily as the thermal environment depends on fixed parameters. The scheme shown in Figure 3 summarizes the main steps of the proposed methodology and the corresponding parameters.

When starting the thermal design process of a Long Duration Balloon payload, there are some specifications which define the mission as the launch window, the duration of the flight, the float altitude or the region to be flown over [3]. All of them will be the starting point to define the thermal environment. As it has been said, environmental conditions depend on many parameters and as it seems obvious and they can change depending on the overflown regions or the epoch.

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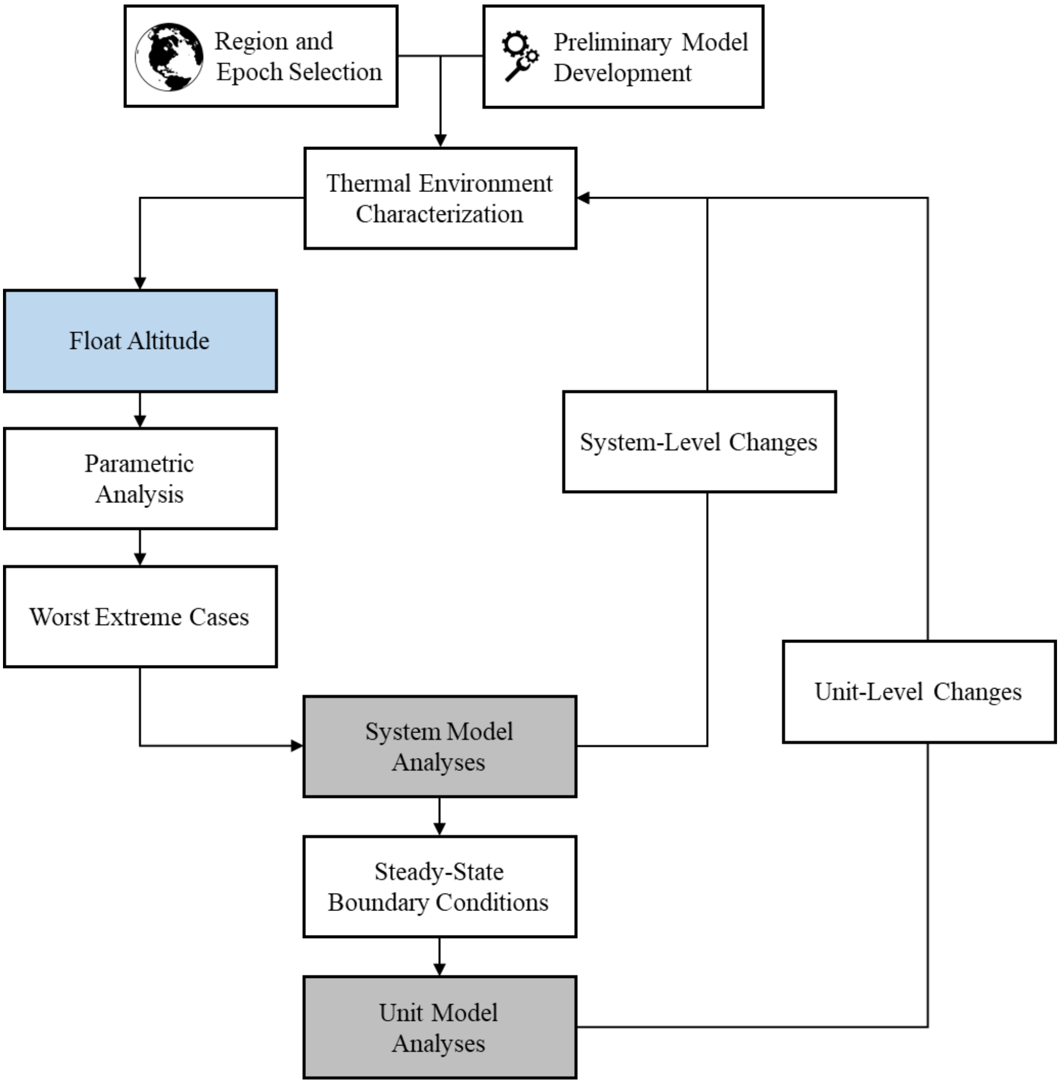

Figure 3. Scheme of the main steps of the proposed methodology.

During the last years, the characterization of the Earth behaviour in terms of energy transfer has become key field to understand our planet. Several space missions have focussed their objective in increasing the available data about it and many of them are currently going on in order to ease and improve the climate predictions [13]. These large sets of data are free access to every user, and they can be used for many purposes.

The CERES experiment (on board EOS Terra and Aqua observatories, the Suomi National Polar-orbiting Partnership (S-NPP) observatory, and soon, the Joint Polar Satellite System, a partnership between NASA and NOAA) is one of the highest priority scientific satellite instruments developed for NASA's Earth Observing System (EOS). For more than 30 years, the Science Directorate at NASA's Langley Research Center has shaped how scientists measure Earth's incoming and outgoing energy. CERES has helped to better observe and study Earth's interconnected natural systems with long-term data records [6].

Concerning the thermal balance of LDB flying at an altitude of around 40 km, three main fluxes and their corresponding reflections determine the behaviour of the system. The direct solar flux, the Outgoing Longwave Radiation and the albedo flux. The direct solar flux is the flux coming directly from the Sun, the OLR is the emitted radiation by the Earth in the infrared spectrum and the albedo flux is the fraction of the shortwave radiation which is reflected by the Earth and reaches the system. Not only these parameters vary with the epoch, the region and the daytime but also its influence over the system depends on its relative position with respect to the Earth and the Sun and the thermo-optical properties of the surface.

In order to consider the epoch, the region, and the daytime, OLR and albedo data extracted from the CERES database should be statistically treated. By doing so, potential worst cases could be derived to carry out the analyses. This study should be performed for two cases. In the first case, the steady-state corresponding to the float altitude where the system is considered to follow a quasi-steady-state during the whole flight due to its high residence time. In the second case, the transient state of the system during the ascent phase where the variability of the environmental conditions is high, and the convective effects could cause the system to reach the minimum temperatures of the mission.

The position of the studied subsystem with respect to the Sun, the Earth and other subsystems should be taken into account to derive the thermal environmental conditions at the float altitude. View factors with the Earth, the angle between the direct solar flux and the normal to the surface, and the shadows which could appear, should be quantified through a parametric analysis with a preliminary thermal model and/or analytically. By doing so, the influence of each parameter is considered. Moreover, the thermo-optical properties of the surface will be determinant in the selection of the worst thermal conditions as it is explained in [5].

During the first phases of the project, there is not enough information to build a detailed thermal model. However, using a preliminary layout and the expected envelopes and thermo-optical properties of the surfaces, it is possible to obtain the preliminary worst cases based in the real data statistically treated and particularized. As the process evolves, the thermal environment can be studied iteratively in order to keep the worst environmental conditions updated to the current state of the design. This work must be carried out from a system level to take into account the influence of the continuous changes in the subsystem positions, dissipated power or even in the mission characteristics.

Space missions and specifically LDB missions have usually been developed in a cooperative atmosphere where there is a collaboration between institutions. Coordinating the work to be done in this environment is a difficult task. Nevertheless, effective communication and the information flow is crucial. Regarding the evolution of the thermal control design process it is very common the thermal design is not performed by only one institution. Work is usually divided and the institution in charge of the system integration and analysis must provide the thermal boundary conditions for the individualized analysis. In case of LDB, those conditions would be the steady-state ones in order to analyse the float extreme cases and the time-dependant boundary conditions to analyse the ascent phase. By doing so, every change which affects the system level could be implemented and the boundary conditions could be updated as the project evolves.

4 Preliminary Model Development

The thermal design process at a system level starts with the development of a preliminary model through a specific software for thermal analysis. It would be based on the initial specifications of the system and it would not be necessarily too detailed. What it is important to be defined in the model is the relative position between components, the envelopes of every important part and the baseline for the thermo-optical properties. The main objective of this model is not obtaining information about temperatures but the quantification of the direct solar flux, the Earth infrared flux and the albedo flux. In this way, parametric analyses could be performed in order to obtain the environmental conditions during the flight which could lead to the maximum and minimum temperatures.

Nevertheless, understanding the behaviour of the whole system in a simple way is highly recommended to determine the variables which affects the system. To do so, a reduced analytical model could be useful. As it was done in [5] for the whole system, the analysis could be particularized to a subsystem knowing its main characteristics.

If a higher level of accuracy is required, a thermal model could be developed to study the influence of these variables. The model built for SUNRISE III was based in the design concept of SUNRISE I and II and adapted to this new version. It basically consists of a balloon-gondola system with the telescope, the PFI (Post-Focus Instrumentation) and the Electronic Units which are located in two racks. This configuration is shown in Figure 4. The E-Unit of IMaX+ has been set as a box for these preliminary analyses and the outer surfaces have been considered to be painted in white. The software ESATAN-TMS [14] has been used due to its relevance in thermal space design in Europe and the different capabilities that brings to the thermal engineer. ESATAN is a computer program intended to perform thermal analysis by the thermal network technique. It is capable of performing either steady-state or transient analysis with any degree of dimensional complexity. Any mode of heat transfer as radiation, conduction and convection can be implemented. It also has different features to perform a more detailed model. In order to formulate a set of coupled differential equations, a Geometrical Mathematical Model (GMM), which is shown in Figure 4, is discretised using nodes. In the same way heat fluxes are interpolated onto the discretised nodes. This results in the definition of the Thermal Mathematical Model (TMM). At this time, the model is ready to be solved with time or other dependency.

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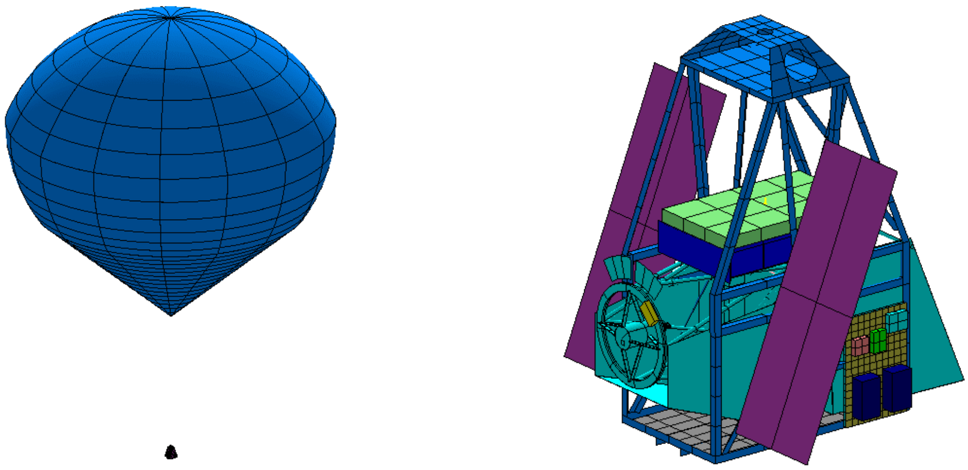

Figure 4. Geometrical Mathematical Model of SUNRISE III telescope born University

Once the thermal environment is defined in a way that parametric analyses can be performed, this model will show the behaviour of a considered system as a function of the different parameters.

5 Thermal Environment Characterization

When defining the worst (hottest and coldest) environment, selecting the most extreme albedo coefficient and OLR simultaneously would lead to an oversizing of the systems since it is not expected that both will occur at the same time. The reason why both maximum or minimum values cannot be used simultaneously is the fact the pairs (*a*, OLR) are partially correlated in such a way that high albedo values tend to be paired with low or moderate OLR values, and vice versa. For this reason, the classic method used to select the albedo coefficient and OLR pairs is based on the statistical analysis of satellite data [4].

The study carried out aims at understanding the influence of the balloon, the ratio α/ε, and the relative position on the selection of extreme environmental conditions. A new methodology has been proposed based on the one performed in [5]. It starts with the analysis of local satellite data with high spatial resolution and detailed time evolution from NASA's Clouds and Earth Radiant Energy System (CERES) [15]. The data were retrieved just for the area and epoch of interest. In this case, data consider the characteristics of stratospheric balloon missions launched from ESRANGE during the summer period.

In order to define the thermal environment at the float altitude, data has been extracted from CERES database. It corresponds to albedo and OLR data for the TOA of a region which covers both trajectories of SUNRISE I and II during the month of June from 2010 to 2017. The region covered includes latitudes from X to X and longitudes from X to X. Both trajectories are represented in Figure 5.

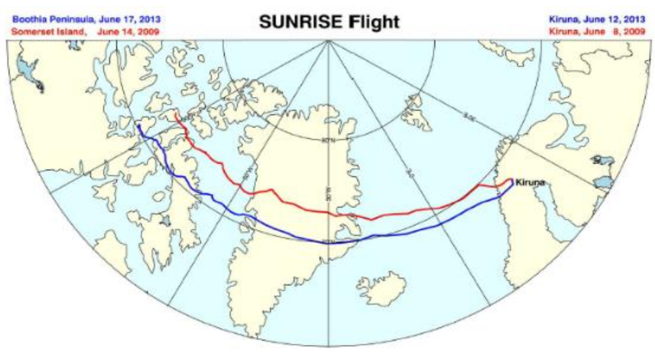

Figure 5. Trajectories followed by SUNRISE I (red) and SUNRISE II (blue)

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Data has been particularized to the flight area due to the high variability found between different regions. Values of albedo and OLR are strongly dependant on the surface type. Albedo would be higher over ice than over the ocean and OLR tends to be the opposite. That dependence is shown in Figure 6 for a sample date and time.

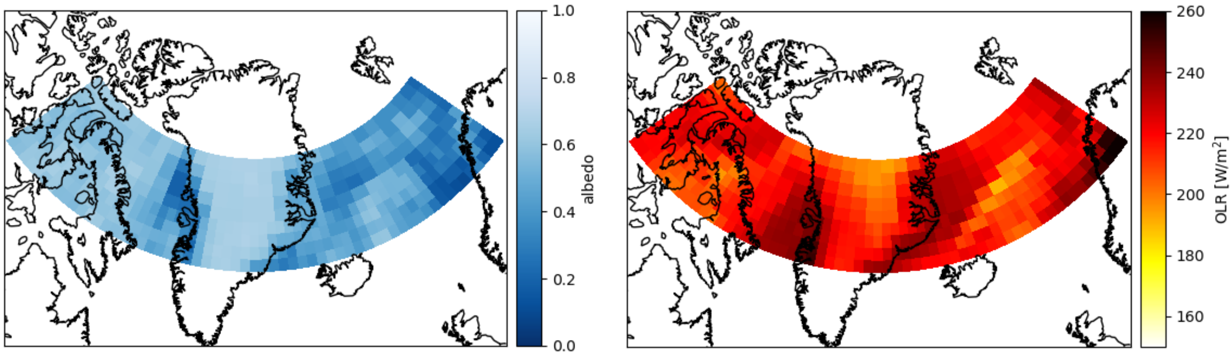

Figure 6. Albedo (reds) and OLR (blues) maps of the considered region at 10:00 AM UTC the 1st June 2010.

Data are also selected for the period of time of interest due to the high variability during the year as it is shown in Figure 7. For that reason, only data corresponding to the flight windows have been considered.

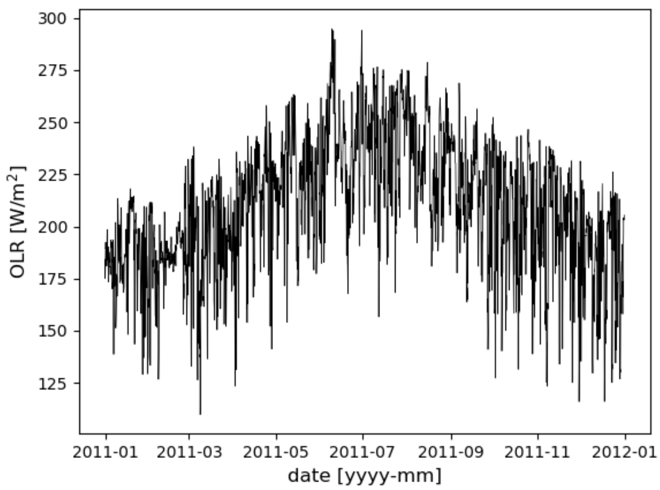

Figure 7. Evolution of OLR over ESRANGE in 2011.

As it is explained in [5], albedo and OLR are partially correlated. In order to select a possible pair of values, both should be treated as a 2D data distribution. The methodology used to obtain curves of potential worst hot and cold cases is the same that the method used in [5]. However, if a higher level of accuracy is required, another parameter should be taken into account. Data used in obtaining those curves also depends on the Solar Zenith Angle (SZA). The higher the SZA, the higher the albedo. This phenomenon occurs due to the angular models used in the estimation of the earth's radiation budget at the top of the atmosphere (TOA) from satellite-measured radiances. The correlation of used data with Solar Zenith Angle is shown in Figure 8.

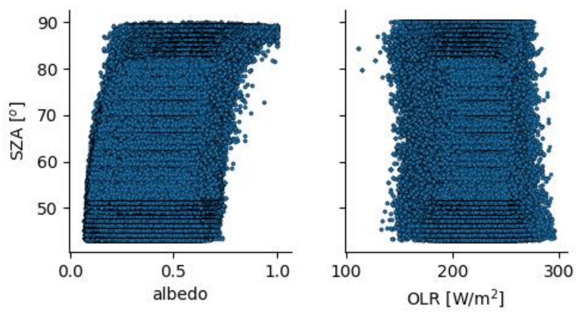

Figure 8. Correlation of albedo and OLR data with Solar Zenith Angle.

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Potential worst cases have been defined for several Solar Zenith Angle. Curves corresponding with the potential worst hot and cold cases have been obtained using the same criteria used in [5]. They represent points with a equal probability of finding points with a higher albedo and OLR for the hot case and viceversa for the cold case. Those points cause a higher or lower temperature on the system for the hot and cold case respectively. The 2D distributions for the lower and higher SZA in the region and epoch of study are shown in Figure 9.

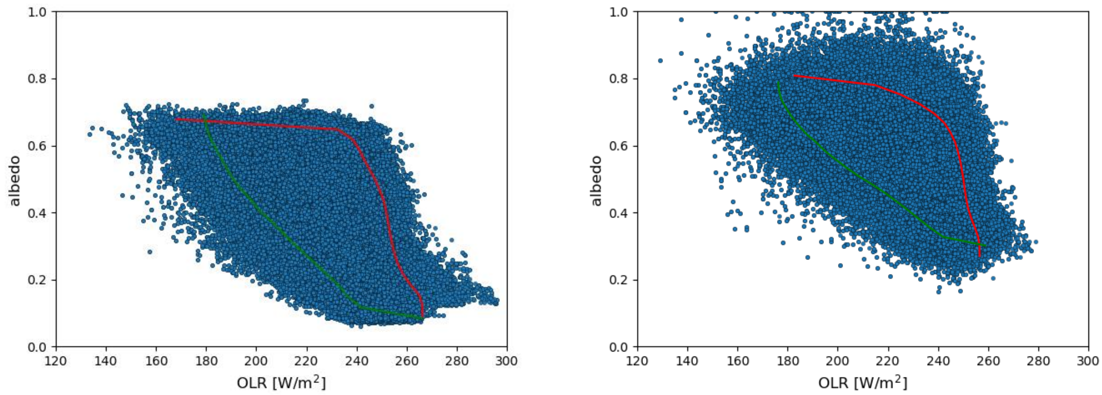

Figure 9. Albedo to OLR correlation for a SZA of 45.5º (left) and 87.7º (right).

The main advantage of using this methodology is the possibility of performing parametric analyses which allow finding the minimum and maximum temperatures in an easy way. In SUNRISE III mission these analyses have been done with the ESATAN TMS model and the results obtained for the E-Unit of IMaX+ can be shown in Figure 10. They consist in a surface which represents the maximum temperature (in the Hot Case) and the minimum temperature (in the Cold Case). Curves corresponding for the potential worst cases for different SZA have been used for these analyses. Those surfaces have been represented as a function of the albedo (and it paired OLR value) and the Solar Zenith Angle.

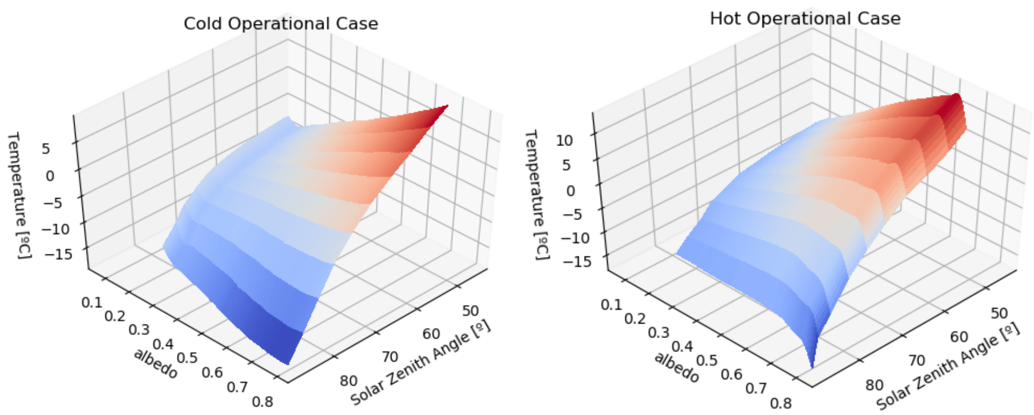

Figure 10. Environmental conditions parametric studies for the Hot and Cold Operational Cases.

The objective of these parametric analyses, as it is shown in Figure 3, is the definition of the worst extreme cases corresponding with the minimum and maximum points of both surfaces shown in Table 1. Those point will represent the values to be used for obtaining the boundary condition to be implemented in the subsystem analyses.

Table 1. Worst extreme cases vales for the E-Unit of IMaX+.

Parameter	**Hot Operational Case**	**Cold Operational Case**
Albedo	0.64	0.77
OLR [W/m^2]	237.5	176.5
SEA [º]	45.5	87.7

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6 System Model Analyses

Once the thermal environment has been properly defined and the worst extreme cases of an instrument selected, the boundary condition for analysing it separately should be obtained. As it has been said, the thermal design of a project as a LDB mission is usually performed by several institutions and the conditions for the analyses at a unit level should be defined at a system level.

The way these boundary conditions are obtained consists in the analysis of the whole system with the extreme cases conditions of every subsystem. However, not only the environmental conditions drive the temperature of a unit. The conducive interface and the radiative environment also affect it. For that reason, defining the dissipated power of the nearby instruments, its thermo-optical-properties and the expected envelopes, improves the real environment the unit is going to find.

However, at the initial phases of the project, that information is not completely defined, and the system design is not closed. An iterative process should be followed in order to update the boundary conditions considering every change in the nearby elements or the characteristics of the mission. Working with the parametric methodology presented in this paper, work to be done could be reduced significantly compared to traditional methodologies.

6.1 Boundary Conditions

After a thermal environment implemented in the analyses of the whole model, heat loads and blackbody equivalent temperatures are obtained in a way that the system can be individually analysed. Heat loads include albedo, QA, direct Sun, QS, and Earth infrared, QE, radiation [16].

- The direct Sun heat load of the thermal item (node *i*) is,

$$QS_i = \alpha_i A_i G_S \cos\eta \tag{1}$$

where η is the angle between the normal to the considered surface, $\vec{n}$ and the Sun direction; α_i and A_i the absorptance and the area of the node i respectively and G_S the Solar irradiance.

- The albedo heat load of the thermal item (node i) is,

$$QA_i = \alpha_i \, a \, G_S A_i F_{iE} \cos\theta \tag{2}$$

where F_{iE} is the view factor from the node *i* to the Earth and θ is the Solar Zenith Angle.

- The Earth infrared heat load of the thermal item (node i) is,

$$QE_i = \varepsilon_i A_i F_{iE} \sigma T_E^4 = \varepsilon_i A_i F_{iE} q_E \tag{3}$$

where ε_i is the infrared emissivity of the node *i*; T_E the equivalent temperature of the Earth and q_E the OLR.

Every face of the E-Unit of IMaX+ will be analysed discretising fluxes for each face. Otherwise, blackbody equivalent temperature, $T_{S,r}$ of the thermal item (node *i*) with respect to the environment (group of nodes E) is defined by ESATAN [17] as:

$$\left(\sum_{j\in E}\left[\sigma GR_{ij}\right]\right)\left(T_i^4 - T_{S,r}^4\right) = \sum_{j\in E}\left[\sigma GR_{ij}(T_i^4 - T_j^4)\right] \tag{4}$$

where GR is the radiative conductor used by ESATAN to model the heat flow path between two nodes when the heat flow is proportional to the fourth power difference in nodal temperatures.

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Nearby instruments and their corresponding dissipated powers determine the environment of the studied unit. Six interfaces have been defined in order to provide more realism to the environment conditions selected. Five of them are radiative and one is conductive through the interface with the E-Rack. That interfaces are shown in Figure 11.

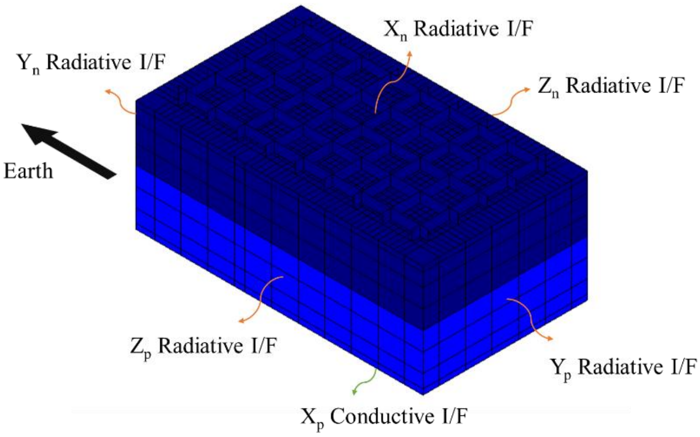

Figure 11. Interfaces defined in IMaX+ E-Unit thermal model.

7 Unit Model Analyses

In order to define inputs for the model, heat loads and radiative sink temperatures have been obtained for the E-Unit of IMaX+ with conditions exposed in Table 1 from the steady-state analysis using the SUNRISE III model. By this way values to introduce as boundary conditions in the individualized thermal model have been obtained and exposed in Table 2 and Table 3 for Hot Operational Case and Cold Operational Case respectively.

Table 2. HOC heat loads and blackbody sink temperatures.

	QA [W/m^2]	QE [W/m^2]	QS [W/m^2]	Radiative I/F [°C]	Conductive I/F [°C]
Face X_n	447.0	93.3	0.3	-81.4	-
Face Z_p	245.6	66.1	0.0	-51.1	-
Face Y_n	500.3	151.9	0.0	-56.6	-
Face Z_n	221.3	36.3	0.4	-1.4	-
Face Y_p	133.5	13.4	1.3	-18.5	-
Face X_p	-	-	-	-	19.4

Table 3. COC heat loads and blackbody sink temperatures.

	QA [W/m^2]	QE [W/m^2]	QS [W/m^2]	Radiative I/F [°C]	Conductive I/F [°C]
Face X_n	30.0	69.3	8.8	-100.5	-
Face Z_p	12.8	49.1	5.0	-77.1	-
Face Y_n	33.8	112.9	8.5	-81.3	-
Face Z_n	15.9	27.0	4.1	-29.6	-
Face Y_p	8.4	9.9	12.5	-45.1	-
Face X_p	-	-	-	-	-12.4

The radiative interface shall be modelled as a black body cavity. View factors between the top unit nodes and the lateral or bottom radiative interfaces are not considered. For that reason, every face has been covered with shell

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geometries as it is shown in Figure 12 in order to provide a full view factor of the blackbody sink temperature correspondent to that face. Blackbody optical properties and temperatures calculated for the radiative interfaces have been applied to these shells and fluxes have been applied proportionally to each face's nodes.

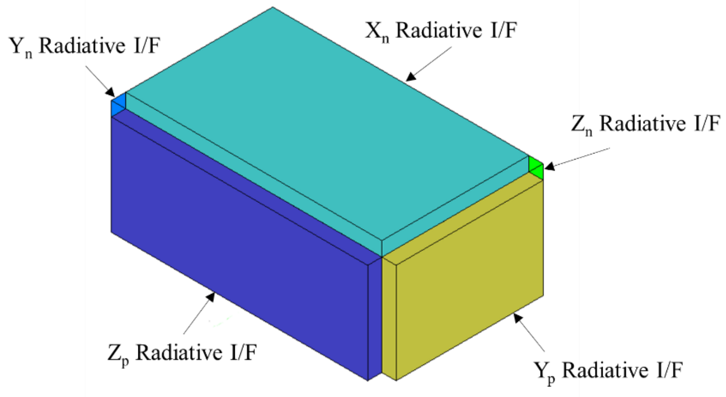

Figure 12. Radiative I/F shells implementation in ESATAN TMS.

8 Comparison

Individualized analyses have been performed with the boundary conditions presented in previous section. Results of these analyses have been compared with the ones obtained with the corresponding environmental conditions in the system thermal model. Temperatures presented correspond to maximum and minimum values to be found in both, Hot and Cold Operational Cases for the main parts of the IMaX+ E-Unit shown in Figure 13.

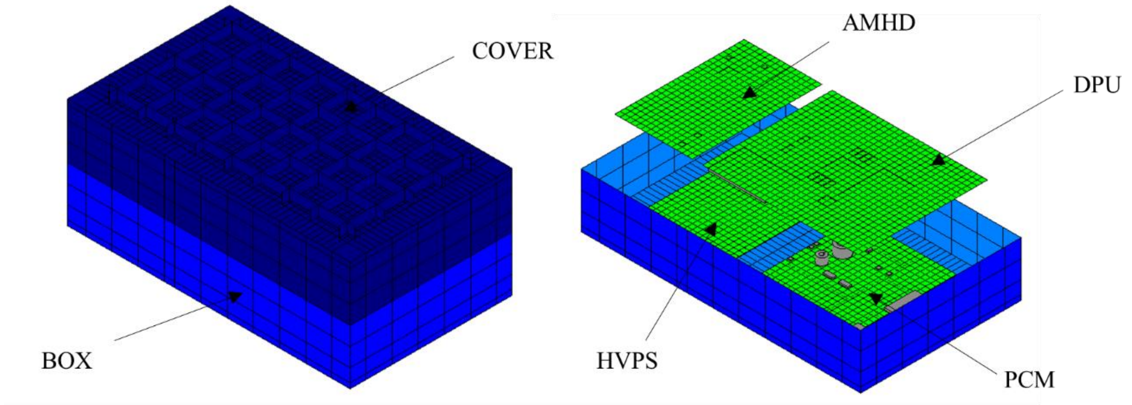

Figure 13. Main elements of the E-Unit of IMaX+.

IMaX+ E-Unit has been pressurized because of the use of COTS not resistant to quasi-vacuum conditions. It is composed by four electronic boards called Data Processing Unit (DPU), Power Converter Module (PCM), Analog Mechanisms and Heaters Drivers (AMHD) and High Voltage Power Board (HVPS). The housing follows a book concept design and it has been divided in its bottom part called Box and its top part called Cover.

Results obtained from the first analyses of the IMaX+ E-Unit are shown in Figure 14 for the Hot and Cold Operational Case respectively. These temperatures have been obtained with the system model and the environmental conditions defined in Table 1.

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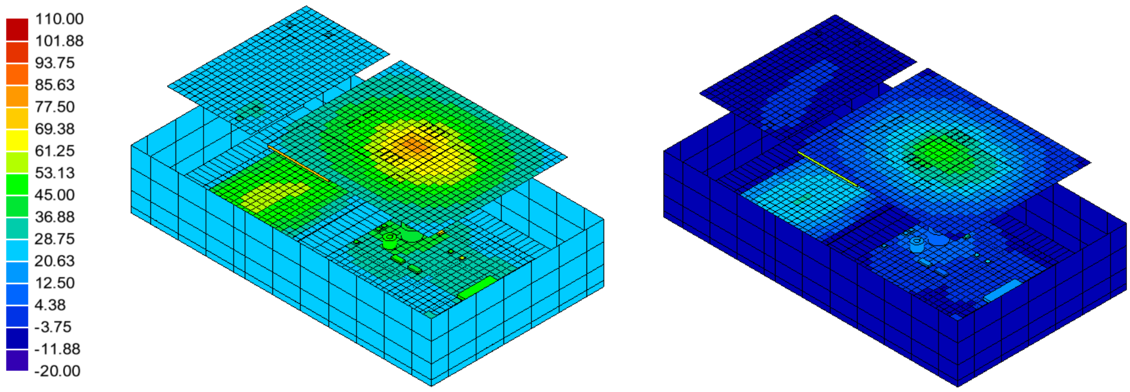

Figure 14. Temperatures of the Hot and Cold Operational Cases respectively.

Maximum and minimum temperatures obtained in both analyses, at system and unit levels, are shown in Table 4.

Table 4. Maximum and minimum temperatures of each part of the E-Unit obtained at a system and unit levels.

		Temperatures [ºC]			
		Hot Operational Case		Cold Operational Case	
		System level	Unit level	System level	Unit level
BOX	Max	24.2	23.6	-7.3	-7.0
	Min	20.9	19.8	-10.2	-10.2
COVER	Max	23.2	22.6	-7.9	-6.7
	Min	21.3	20.2	-10.2	-9.4
PCM	Max	77.8	77.3	47.0	47.3
	Min	23.7	23.3	-7.6	-7.1
DPU	Max	114.7	114.3	86.3	87.3
	Min	25.9	25.4	-4.8	-3.7
HVPS	Max	55.5	54.6	29.0	29.3
	Min	22.9	21.4	-9.0	-9.2
AMHD	Max	42.2	41.6	11.9	12.9
	Min	22.6	21.7	-8.8	-7.7

Small differences can be observed between both model analyses. Nevertheless, they are not enough significative to be taken into consideration. In this particular case, the IMaX+ E-Unit housing is made of aluminium and its external geometry is quite simple. If a more complex geometry is wanted to be studied, different interfaces can be defined to obtain more accurate results.

Conclusions

It seems there is not a clear methodology to approach the thermal control problem in stratospheric balloons. Even though space procedures are a clear reference for this kind of flights, several particularities in stratospheric balloons dynamics must be considered. The methodology proposed aims at adapting space procedures to this kind of missions, but including some updates that allow the thermal engineer to gain a better understanding of the thermal behaviour of the system under study while defining the thermal environment. Therefore, the knowledge gained and the fast parametric sweeps allow the engineer to effectively coordinate the thermal control team. Furthermore, the possibility of analysing through a simplified model allows the thermal design to start in early phases, participating actively in the design iterations. In addition, it allows to take into account variables with strong influence in the extreme thermal environmental conditions when updating the worst thermal scenarios.

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The work here presented has been carried out in the context of SUNRISE III mission. It has been applied since the early phases of the mission, and therefore its effectiveness has been demonstrated. Furthermore, the fast parametric sweeps have allowed the system level thermal engineers to provide the rest of the team with thermal environmental conditions for their subsystem analyses in the design phases. As a result, coordination and decision making have been enhanced. Additionally, the possibility of considering the main design parameters on a regular basis in the definition of the thermal design scenarios could help the engineers to reduce system's oversizing.

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