EF2260 Lab B Hands-on Project Report

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Contents

1 Introduction

Thermal control is a crucial aspect of satellite design and operation. The main role of the thermal control subsystem (TCS) is to maintain all the spacecraft and payload components within their temperature range for each mission phase. TCS also ensures that the temperature gradients and temperature stability requirements are satisfied.
Its design process involves the identification of thermal requirements and constraints of the mission, such as the determination of the thermal environment and a series of iterations (design and analysis) in order to define the thermal strategies and hardware needed [1].

The focus of the addressed lab is to perform a preliminary design of the thermal control system of the SPOT Satellite using a simplified model and optimize the design using more complex models. The preliminary sizing of the TCS involves the definition of the main thermal cases, as well as the calculation of the absorbed flux of each face of the satellite and the radiators heat rejection capacity. Afterwards, the obtained data were used to position the satellite equipment accordingly, and a preliminary sizing of the radiators and heaters were performed.

The second part of this lab involves a simulation with a more complex thermal model and its optimization based on the thermal results obtained for the hottest and coldest case. At the end, the results have been validated for the survival attitude as well.

Figure 1: SPOT Satellite [2]

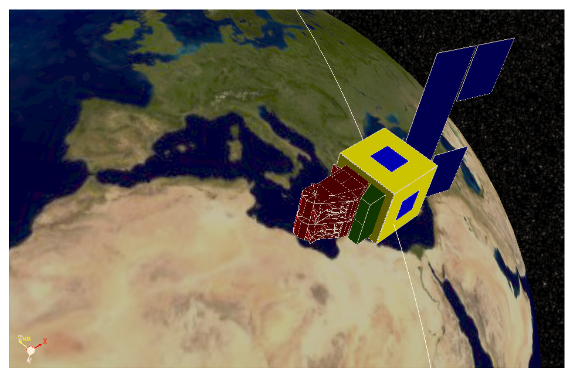

Figure 2: Systema/Thermica SPOT model

2 Simulation Set-up

2.1 SPOT Mission specifications

- SPOT has a sun-synchronous[1] orbit around the Earth at an altitude of 830 Km with a mean solar time at the ascending node of 22h30.
- Nominal attitude(pointing during nominal operations): -Z axis points towards the Earth and -Y axis towards the direction of the satellite velocity

[1]A sun-synchronous orbit (SSO) is a specific type of polar orbit in which a satellite's orbital plane precesses around the Earth at the same rate as the Earth orbits the Sun. This synchronization allows the satellite to pass over any given point on Earth's surface at the same local solar time during each orbit [3].

- Survival attitude +Z pointed towards the Sun and the satellite spins around its Z axis.
- Thermo-optical properties of the heat radiators: SSM[2] Aluminium with emissivity coefficient of 0.78 and absorptivity of 0.15 at Beginning-of-Life (BOL) and 0.19 at End-of-Life (EOL) due to material degradation.
- As stated in the project guidelines [2], the extreme Earth positions correspond to summer and winter solstices, which coincide with the furthest and closest Earth positions with regard to the Sun.

2.2 Satellite Equipment

The satellite equipment consist of Power Supply, On-board data processing, Attitude and Orbit Control System (AOCS) ad telemetry. Each of them has to fit within the nominal mode temperature range. The temperature range, the mass and the dissipated power per each component is shown in Table 1.

Table 1: Satellite equipment [2]

Function	**Nominal mode**		**Mass (kg)**	**Dissipated power (W)**	
	T_{min} **(°C)**	T_{max} **(°C)**		**Nominal mode (Operat./Standby)**	**Survival mode**
Power supply	**-10**	**40**	**40**	**150 / 50**	**20**
On-board data processing	**-10**	**40**	**5**	**15 / 10**	**10**
AOCS	**-10**	**40**	**30**	**110 / 50**	**30**
Telemetry	**-10**	**40**	**20**	**70 / 0**	**20**

2.3 Systema/Thermica software

Systema Thermica, part of Airbus/Astrium's Systema software suite, is a powerful tool for thermal analysis in spacecraft design. It includes two key components: Thermica and Thermisol.
Thermica converts imported geometric models into mathematical representations to analyze thermal exchanges like radiative and conductive processes, solar and planetary fluxes, and thermo-optical material properties. Using advanced ray-tracing algorithms, it computes radiative exchange factors, considering parameters such as absorptivity, emissivity, and surface properties.
Thermisol, the thermal solver, calculates transient and steady-state temperatures throughout a mission, crucial for optimizing spacecraft thermal control.
For instance, in the addressed satellite's preliminary thermal design, Thermica computed heat fluxes, and Thermisol iteratively analyzed temperatures and residual fluxes that allowed the team to size radiators and heaters, achieving optimized thermal configurations [4].

3 Part 1: Preliminary sizing of TCS

For the preliminary sizing of TCS, a simplified model is used, representing a cube whose faces are 1 m^2. Firstly, the cube is considered entirely covered by heat radiators, except for the ±X faces which are taken by the instrument and the solar panel. The objective of the preliminary sizing is to size the heat radiators and the heating power on the faces +Y, -Y, +Z and -Z.

[2] Semi-Solid Metal casting

3.1 Calculation of absorbed fluxes from environment

Question 1: Thermal cases definition

The first step was the definition of the thermal cases. Four extreme cases were defined, depending on the degradation of the thermo-optical properties of the radiators' coating and on the position of the Earth (therefore of the spacecraft) with respect to the Sun.
The cases are BOL - Summer , BOL - Winter, EOL - Summer, EOL - Winter, where Summer and Winter implies the trajectory input inserted in the software. Indeed, *Summer* indicates that the spacecraft accomplishes one revolution starting from the Summer Solstice position, whereas *Winter* states for one revolution from the Winter Solstice.
According to SPOT Mission specifications, the thermo-optical properties of the heat radiators degrade over time, resulting in an increase in the absorptivity, from 0.15 at BOL to 0.19 at EOL. As a consequence, the radiators performance decreases. It is expected that the hottest case is EOL-Winter, and the coldest case is BOL-Summer.

Question 2: Thermal fluxes absorbed by each face of the satellite

The thermal fluxes absorbed by each face of the satellite during one orbit around Earth have been calculated using Systema/Thermica. The addressed absorbed fluxes were the mean Sun thermal flux, the Earth Albedo and the Earth IR thermal fluxes. The total abosrbed flux for hottes and coldest case, as per question 1, are presented in Table 2.
Detailed calculation of the Earth Albedo radiation, Earth IR radiation and Solar flux, for each face and each thermal case analyzed, is presented in appendix A.

Table 2: Absorbed fluxes for BOL-Summer and EOL-Winter

BOL-Summer					**EOL-Winter**				
Face	**Albedo**	**IR**	**Solar**	**Total [W/m^2]**	**Face**	**Albedo**	**IR**	**Solar**	**Total [W/m^2]**
Z	0	0	60,46	60,46	Z	0	0	78,44	78,44
-Z	16,52	131,32	7,8	155,64	-Z	21,35	131,14	11,35	163,84
Y	4,54	36,09	44,94	85,57	Y	5,86	59,36	59,13	100,98
-Y	4,54	36,09	44,91	85,54	-Y	5,86	35,96	59,16	100,98
X	4,36	36,09	38,69	79,59	X	6,34	35,96	72,33	114,63
-X	4,21	36,09	0	40,3	-X	5,28	35,96	0	41,24
				507,1					**600,08**

The results in Table 2 and 13 confirm what expected and described in Question 1, showing that the hottest case is the EOL-Winter, with absorbed thermal fluxes equal to 600.08 W/m^2 and the coldest case is BOL-Summer, with absorbed thermal fluxes equal to 507.1 W/m^2.

3.2 Calculation of radiators rejection capacity

Question 3: Heat rejection capacity of each radiator at 20°C and 0°C for the hottest and coldest case

The rejection capacity of a surface is defined as the net thermal flux per unit surface, where the net is equal to the emitted minus the absorbed flux [2].
The components have the temperature requirements to stay within the range [-10, 40]°C. However, during the initial design phase, some margin was taken, targeting a temperature range of [0, 20]°C.
The heat rejection capacity of each face i of the spacecraft has been calculated through Eq.1:

$$[\text{Heat rejection capacity}] = \varepsilon\sigma T_i^4 - f_{\text{abs}} \tag{1}$$

where ε is the emissivity, σ is the Stefan-Boltzmann constant (5.67×10^{-8} W/m^{2}K^4), T_i is the temperature in Kelvin of the face i and f_{abs} is the absorbed flux calculated with Thermica [Table 13].
Since each face has the same area, being equal to 1 m^2, the emitted power of each face is the same, given that the temperature is the same. The values for 0°C and 20°C are shown in Table 3

Table 3: Temperature vs Emitted power values.

Temperature (°C)	**Emitted power**[W]
0	245.66
20	325.95

Knowing the emitted power, the heat rejection capacity of each face is shown in Table 4.

Table 4: Heat rejection capacity [W/m^2] of each face for hot and cold cases at different temperatures.

Face	**Hot case (0° C)**	**Hot case (20° C)**	**Cold case (0° C)**	**Cold case (20° C)**
+ Z	167.22	247.51	185.20	265.49
- Z	81.82	162.11	90.02	170.31
+ Y	144.71	225.00	160.09	240.38
- Y	144.68	224.97	160.12	240.41
+ X	131.03	211.32	166.07	246.36
- X	204.42	284.71	205.36	285.65

3.3 Equipment positioning

Question 4

The preliminary objective of the analysis is to position the equipment according to the results obtained regarding the absorbed fluxes and the heat rejection capacity of each face.
The team decided to allocate the different equipment in the different positions as shown in Table 5 taking into account that the faces available were the + Y, - Y, + Z, - Z. The adopted reasoning has been positioning the component whose dissipated power is higher in the face with the highest heat rejection capacity.

The allocation started from the power supply since is the equipment that dissipates more power overall considering both the nominal and the survival mode (Table 1), and it was decided to install

Table 5: Positioning of the instruments on the different faces of the satellite.

Instrument	**Positioning**
Telemetry	+ Y
AOCS	- Y
Power supply	+ Z
OBDP	- Z

it in the + Z face, which is the one that has the higher heat rejection capacity (look at Table 4). Then, the allocation of the AOCS was assessed, and the - Y face was assigned to it. The process continues until the instrument with the less power dissipation is coupled with the side of the satellite that has the less heat rejection capacity.

3.4 Preliminary sizing of radiators and heaters

Question 5: Radiators sizing

The sizing of the radiators' area was set by forcing the thermal equilibrum, as in Eq.2:

$$A\varepsilon\sigma T_i^4 = P_{\text{diss}} + f_{\text{abs}} \times A \tag{2}$$

The obtained area is:

$$\text{A} = \frac{P_{\text{diss}}}{\varepsilon\sigma T_i^4 - f_{\text{abs}}} \tag{3}$$

The target temperature used was 20°C, and the hypothesis used is that the fraction of each face not covered by a radiator is covered by a Multi-Layer Insulation (MLI), leading to a condition in which there is no heat exchange with the space.
Considering all the characteristics above, the radiators' area found are:

Table 6: Radiators' area for every face of the satellite.

Instrument	**Positioning**	**Radiator Area** [m^2]
Telemetry	+ Y	0.311
AOCS	- Y	0.489
Power supply	+ Z	0.606
OBDP	- Z	0.093

Question 6: Heaters power sizing

The last step of the preliminary sizing problem is to assess the study of the heating power needed by the heaters to satisfy the requirement of staying above 0 °C.
The heaters' power were calculated as:

$$P_{\text{heater}} = A_{\text{rad}}(f_{\text{emit}} - f_{\text{abs}}) - P_{\text{diss stdby}} \tag{4}$$

The dissipated power in standby mode is used since in this condition the equipment dissipates less power, meaning that more power is needed from the heaters to keep the equipment above 0 °C.

Table 7: Heater power needed to keep the instrumentation above 0 °C.

Instrument	**Positioning**	**Heater power** [W]
Telemetry	+ Y	49.81
AOCS	- Y	28.29
Power supply	+ Z	62.24
OBDP	- Z	0

Resulting in the following results:
In the case of the on-board data processing, a negative heater power was obtained, so there is no need to warm it up, therefore it was set as zero.

4 Part 2: Nodal network simulation and TCS optimisation

The aim of part 2 of the addressed project is to optimize the thermal control system with the provided model and mesh of the SPOT satellite. The new TCS design must aim to use less heater power per orbit as possible, maintaining the desired temperature range and keeping the heater duty cycle[3] between 60% and 70% .

Question 7: Nodal thermal network

A visual diagram of nodal thermal network is shown in Figure 3. Temperatures are calculated in Thermica using a nodal representation that couples radiative and conductive elements. The adopted hypothesis are that there is no mechanical contact between the different faces, the equipment is installed mechanically on the corresponding radiator, the radiator is installed mechanically on the corresponding wall and the MLI is installed on the wall as well [2].
The instrument and the solar panel are de-activated and conductive heat transfer occurs between equipment and wall and radiators. The wall is also thermally linked with the MLI.
As stated previously, according to the project instruction, it is assumed that the part of the face not covered by the radiators is covered by MLI. It is interesting to notice that the Solar flux, as well as the Earth Albedo and IR radiation affects the MLI and the radiators as they are the outermost part of the spacecraft.

As mentioned in the introduction, Part 2 involves a more complex model, mesh as well as user defined script to input the simulation specifications such as radiators' area, heaters power, thermal capacitance of the equipment and conductive couplings between the nodes.

Question 8: Hot case analysis without internal radiation

Using the sizing done in part 1 for the radiator and heater, the thermal model has been simulated for the hot case, which is EOL-Winter.

For the conductive coupling between the equipment and the radiator, the value depends on the type of mechanical contact. The three available options were:

[3] The fraction of time a heater is active within a given cycle, expressed as a percentage

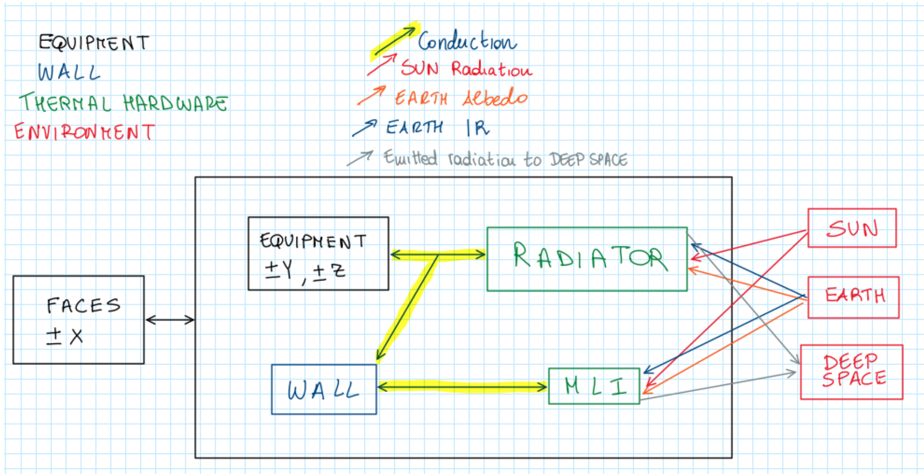

Figure 3: Nodal thermal network

1. Thermal joint: 40 W/K
2. Equipment directly screwed into the radiator: 10 W/K
3. Equipment insulated from the radiator using washers made of insulating material: 0.6 W/K

The type of contact chosen for the first iteration is the thermal joint. It was preferred since it provides a high conductivity guaranteeing good heat dissipation performances.
In addition, different materials used in the radiator and satellite structure may expand and contract differently due to temperature changes in space. Thermal joints accommodate these differences, reducing mechanical stresses that could lead to structural damage or degraded performance over time.
Furthermore, thermal joints act as a cushion that reduces mechanical stresses caused by launch vibrations, thermal cycling, or material mismatches. This increases the longevity and reliability of the thermal interface and the satellite as a whole.
Finally, thermal joints are often preferred because they allow the radiator deployment and since this is a preliminary phase, the design is not yet defined by the system engineers and mechanical experts, the thermal joints have been chosen also for their flexibility in later steps of the design. [5]

From the graph in Figure 4, it can be seen that there is a great margin in terms of temperature specifications, since the upper limit is 40 °C and in this simulation the maximum temperature is lower than 20 °C. This is due to the conductive coupling chosen, which is the most conductive option between the three proposed. This is important to be taken into account for the optimization, in order not to over-design the TCS.
Furthermore, it is observed that there is one face which is at a constant lower temperature with respect to the other faces. It is the - Z face, which needs less cooling.

Question 9: Hot case analysis with internal radiation

Concerning the hot case with internal radiation, figure 5 shows that the margin is decreasing, with a maximum temperature of less than 16 °C after 20 orbits, and it is noticed that all the components' temperature are closer.

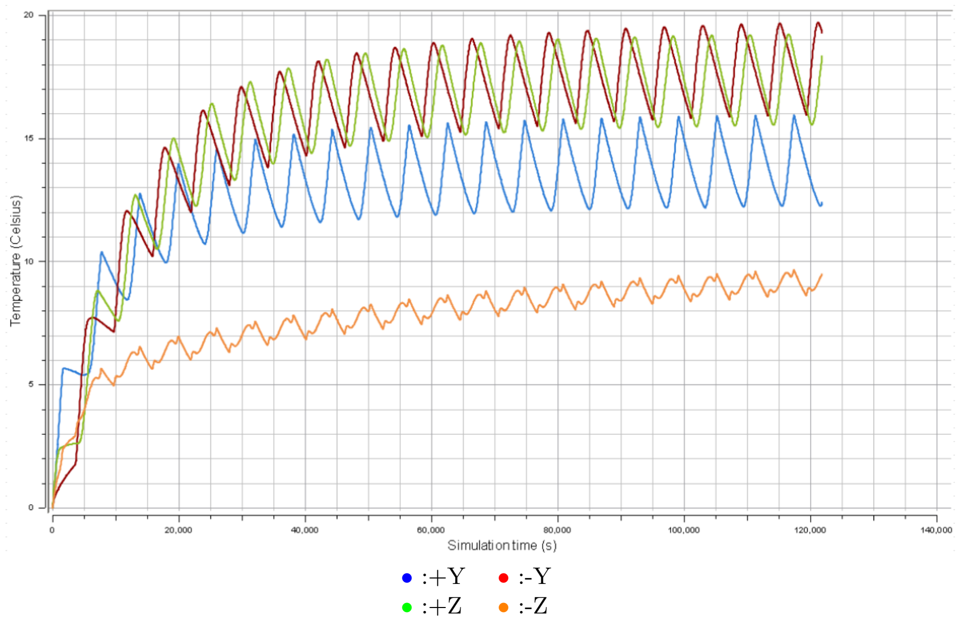

Figure 4: SPOT faces temperature results from the hot case without internal radiation, 20 orbits simulation.

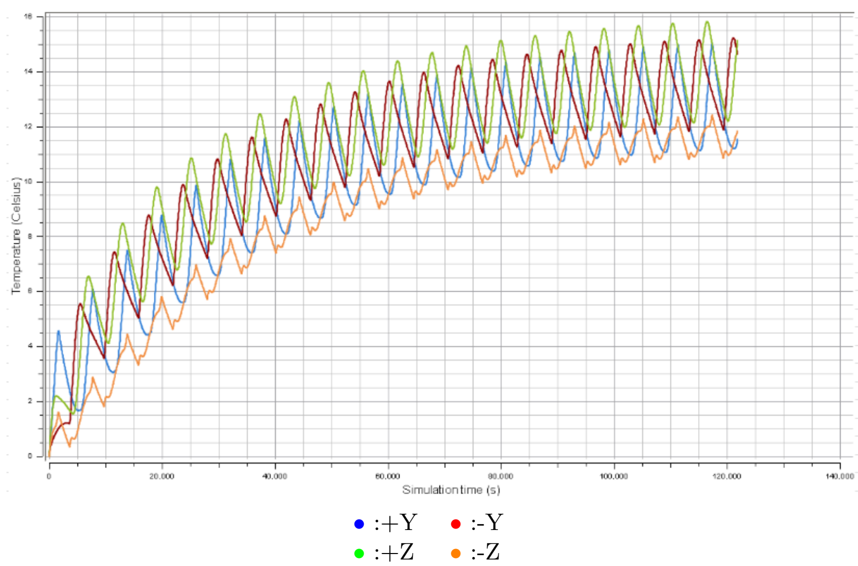

Figure 5: SPOT faces temperature results from the hot case with internal radiation, 20 orbits simulation.

Question 10: Cold case analysis with internal radiation

Analyzing the coldest case, the target is not to drop the temperature below -10 °C, as per temperature requirements in Table 1. The resulting graph is shown in Figure 6.
From Figure 6 we can observe that the temperature requirements are not satisfied since it is decreasing in time, going below -10 °C in some parts during the 20 orbits simulation.
Furthermore, it is noticeable a particular behaviour in the -Z face temperature. In the following section, all these aspects have been fixed via the TCS optimization process.

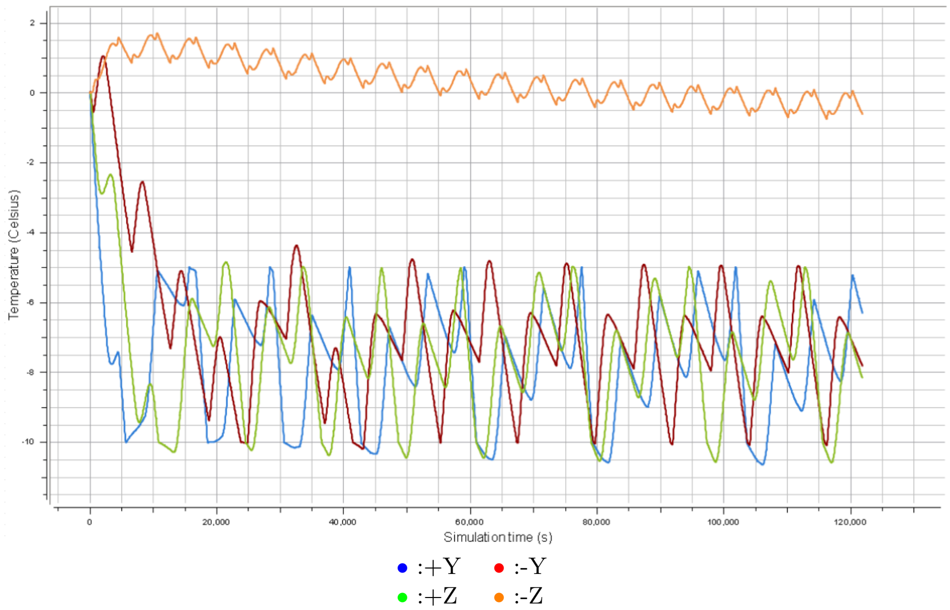

Figure 6: SPOT faces temperature results from the cold case with internal radiation, 20 orbits simulation.

Question 11: TCS optimization

At the first iteration, as seen in Figure 6, the temperature requirements were not satisfied. To this end, since the margin in the hot case was significant, it has been decided to optimise the radiators' areas for a target temperature of 30 °C instead of 20 °C.
Another constraint was added during this design phase: having the duty cycle between [60,70] %. To reach this desired range, it has been decided to modify the heaters' power individually, finding the right increasing or decreasing percentage to apply to each face, as shown below:

Table 8: New radiators' area and heaters power after TCS optimization.

Instrument	**Positioning**	**New Radiator Area** [m^2]	**New Heating Power** [W]
Telemetry	+ Y	0.250	57,27
AOCS	- Y	0.404	19,80
Power supply	+ Z	0.500	63,48
OBDP	- Z	0.070	0,00

As discussed before it is seen how the areas have been decreased in size, while for the heating power of the radiators empirical results have been obtained after several tests. The percentage change in the power is the following:

- Telemetry: +15%
- AOCS: -30%
- Power supply: +2%
- OBDP: Not modified

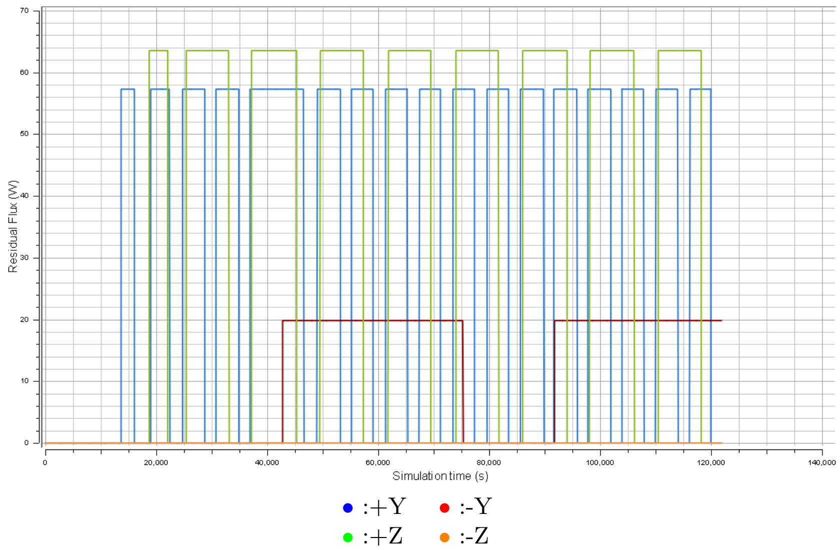

Figure 7: SPOT optimized duty cycle, 20 orbits simulation.

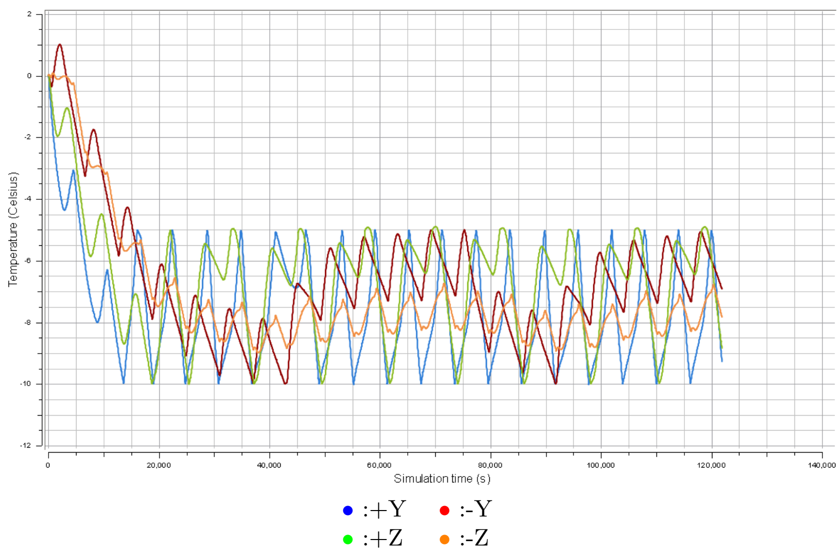

Figure 8: SPOT faces temperature results from the optimized cold case, 20 orbits simulation.

As shown in Figure 7, the duty cycle fits inside the desired range. The ducy cycle values are presented in table 9. Figure 6 shows that the equipment temperature now fits in the desired range, staying above the minimum value of -10 °C.

Table 9: Heaters' duty cycle [Question 11].

Instrument	**Positioning**	**New Duty Cycle (%)**
Telemetry	+Y	60.9
AOCS	-Y	66.0
Power Supply	+Z	63.0
OBDP	-Z	0.0

Bonus question: General optimization with survival mode

As the last part of this laboratory, it has been performed several thermal analyses iterations taking into account also the survival mode, in order to choose the most adequate position where to put the TTC antenna, either on the +Y side or on -Y side. The simulations have been conducted being sure to optimize the nominal case in both hot and cold cases, too. The goal was to validate the design for survival mode as well, with the target of avoiding heaters saturation, while keeping the nominal mode duty cycle in the desired range.
Some changes occurred from the last optimized solution, and both radiators' areas and heating powers changed in order to satisfy all the requirements concerning both nominal and survival modes.

The first and fundamental step of the optimization has been changing the conductive couplings between the equipment and the radiators. Indeed, choosing the thermal joints has its advantages but in a preliminary design phase, tailoring the coupling according to the equipment dissipation and faces heat rejection capacity can optimize the design a lot. To this end, the final conductive couplings chosen are different from the initial ones, shown previously. The updated ones are shown in Table 10.

Table 10: Final conductive couplings

Instrument	**Positioning**	**Conductive couplings**
Telemetry	+Y	0.6 (Thermal washers)
AOCS	-Y	10.0 (directly screwing the equipment into the radiator)
Power Supply	+Z	10.0 (directly screwing the equipment into the radiator)
OBDP	-Z	0.6 (thermal washers)

All the results and plots will be displayed and discussed in the next sections, but it is important to highlight that it has been decided to put the TTC antenna in +Y side. The final radiators' areas and heating power are presented in table 11.
A detailed description of the iteration performed in this phase is presented in appendix B.

Table 11: Final configuration of radiator's areas and heating powers.

Instrument	**Positioning**	**Final Radiator Area** [m^2]	**Final Heating Power** [W]
Telemetry	+ Y	0.264	37.35
AOCS	- Y	0.245	32.53
Power supply	+ Z	0.545	62.24
OBDP	- Z	0.093	0.00

5 Simulation results

After the iterative design and analysis process, the thermal constraints for all three scenarios have been fulfilled. The plots of temperatures in hot and cold case, as well as the residual fluxes in nominal cold case and the temperatures and residual fluxes during survival mode are shown respectively in Figure 9, 10, 11, 12a and 12b.

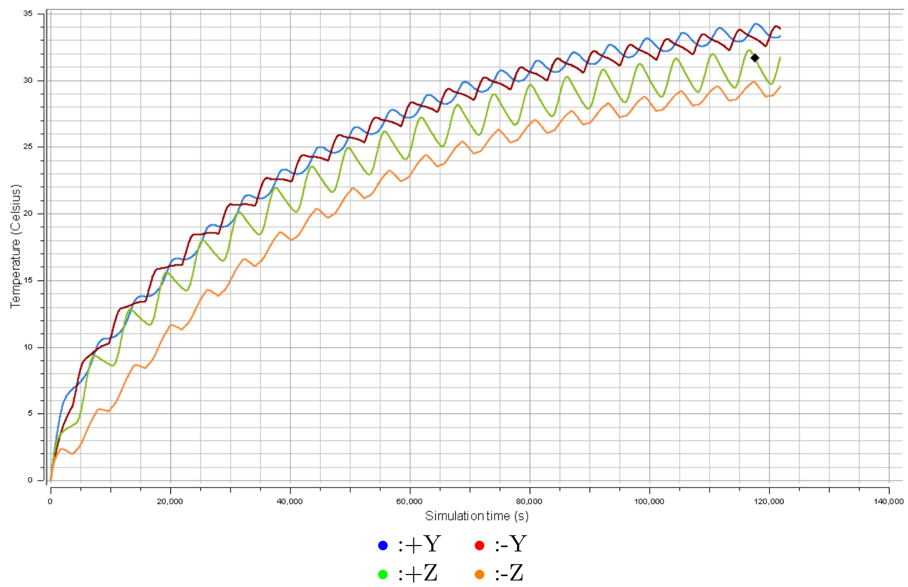

Figure 9: SPOT faces temperature results from the hot case, 20 orbits simulation.

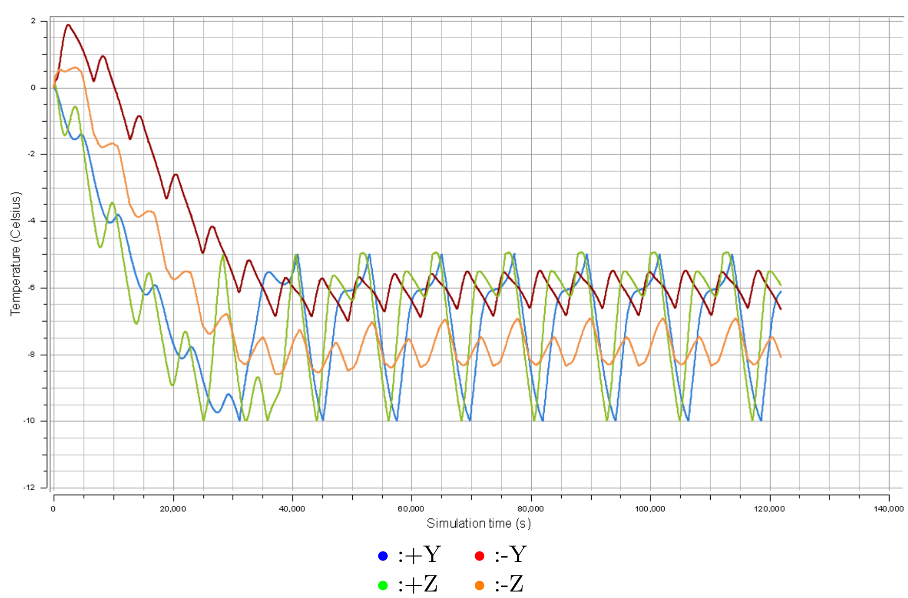

Figure 10: SPOT faces temperature results from the cold case, 20 orbits simulation.

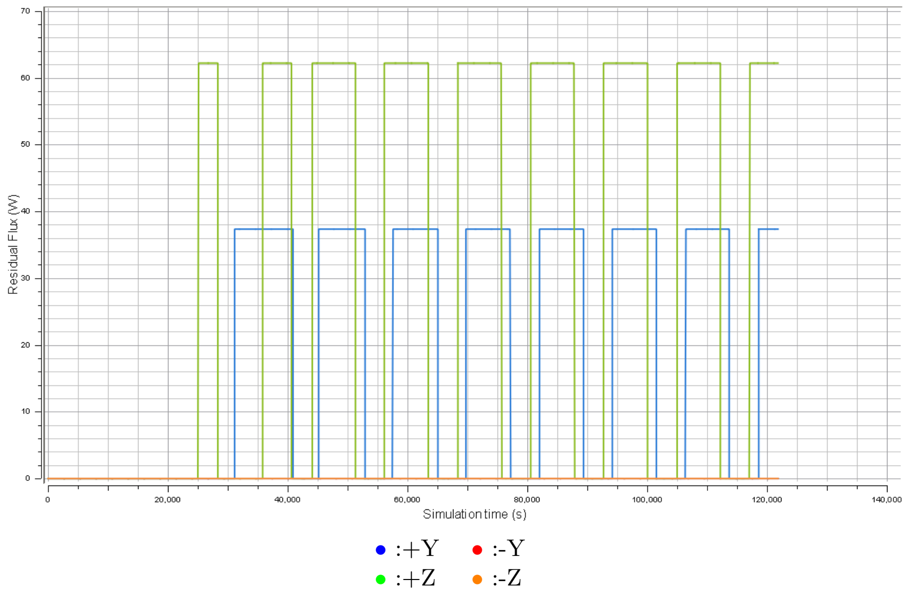

Figure 11: SPOT residual fluxes in the cold case, 20 orbits simulation.

6 Discussion

The plots displayed in the previous section show how the satellite is honed to face all the worst thermal conditions successfully.
Figure 9 shows that the temperature stays below 35 °C after 20 orbits in the hot case scenario. The same can be observed in the opposite scenario in figure 10 and 11, where in the cold case, the satellite temperature never goes below -10 °C, and by fulfilling the duty cycle constraints with the + Y face reaching 61% and + Z reaches 60.1%.
The last case to analyze is the survival mode, in which the satellite manages to maintain the temperature in the desired range by using just two of the four heaters and without saturating them Figure 12a and 12b).

In the set-ups implemented before the bonus question, there was not a large temperature margin for the cold case scenario. On the other hand, in the hot case the gap between the components' limit temperature and the one actually reached by the satellite was significant, so this last configuration is meant to reach temperatures closer to the limits, in order not to have an over-sized system.

7 Conclusion and Further improvements

The team managed to complete the thermal control system design and optimization of the SPOT satellite with proper organization and step by step processes. Optimization of key goals like sizing of radiators and heaters power to avoid saturation and reach the desired duty cycle range have been achieved with simulations of extreme thermal cases and several design iterations.
Key results showed that the thermal requirement was met for both the hot and the cold conditions of operation with all components within the temperature range. Also in the optimization part, the desired heater duty cycle was achieved to avoid over-design phenomena and to reduce power consumption while meeting the operating requirements. The TCS design was validated for normal

operations and also brought the system design into survival mode.
However, even though the assumptions are appropriate, the work addressed in the report represents just a preliminary design, done with relatively simple models therefore thermal testing and successive thermal analysis and iterations would be needed.

Future improvements might involve the use of a more complex thermal model , with more nodes and the activation of the elements not considered in the current analysis (Instrument and Solar panel).
This project was able to bring out the importance of a meticulously designed TCS for the successful operation of a satellite and it was an important experience for the team to learn the basis of an important thermal software such as Systema/Thermica, as well as the importance of team work and task prioritization in particular when the deadlines were closer and the required work was considerable.

8 Group Members Contributions

Member	**Lab**	**Presentation**	**Review**	**Report**
Kirtan Patel	Pt1 and Pt2	-	Individual	Discussion and conclusion
Matteo Ruvolo	Pt1, Pt2 and Bonus	Pt1 and Conclusion	Individual	Pt1, Pt2, Bonus, Discussion and Conclusion
Sara Sanchis Climent	-	-	Individual	Pt2, Discussion and Conclusion
Mattia Tadiotto	Pt1, Pt2 and Bonus	Pt2 and Conclusion	Individual	Pt1, Pt2, Bonus, Discussion and Conclusion

Table 12: Group members' contributions

References

[1] James Richard Wertz et al. *Space mission analysis and design*. Vol. 8. Springer, 1999.

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[3] Wikipedia contributors. *Sun-synchronous orbit — Wikipedia, The Free Encyclopedia*. `https://en.wikipedia.org/wiki/Sun-synchronous_orbit`. [Online; accessed 20-December-2024]. 2024.

[4] EF2260. *Airbus Thermica Lab Intro slides*. 2024.

[5] W. Pinter-Krainer M.N. De Parolis. *Current and Future Techniques for Spacecraft Thermal Control 1. Design drivers and current technologies*. ESA Bulletin Nr. 87, 1996.

A Absorbed flux for different thermal cases

Table 13 shows the absorbed thermal fluxes for each satellite face for eachh extreme thermal case analyzed. The total absorbed flux has been calculated a sum of Earth Albedo, Earth IR radiation and solar flux.

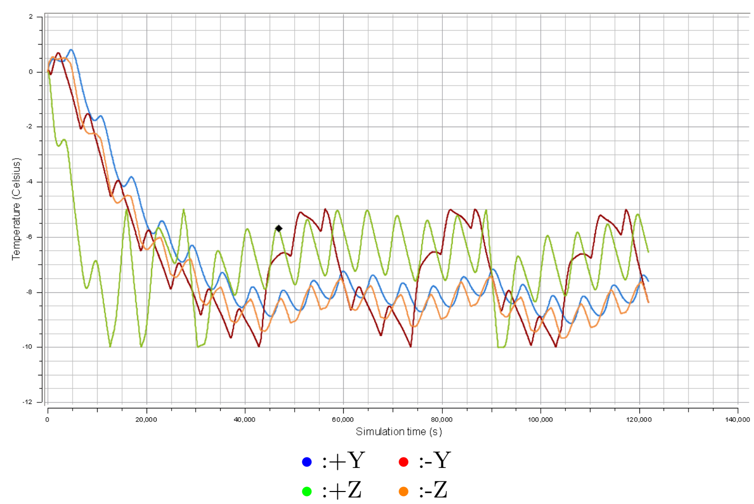
Table 13: Absorbed fluxes for different thermal cases

BOL-Winter					**EOL-Winter**				
Face	**Albedo**	**IR**	**Solar**	**Total [W/m^2]**	**Face**	**Albedo**	**IR**	**Solar**	**Total [W/m^2]**
Z	0	0	61,93	61,93	Z	0	0	78,44	78,44
-Z	16,87	141,42	8,96	167,25	-Z	21,35	131,14	11,35	163,84
Y	4,64	35,09	46,67	86,4	Y	5,86	59,36	59,13	100,98
-Y	4,63	36,09	46,7	87,42	-Y	5,86	35,96	59,16	100,98
X	5,05	36,09	57,1	98,24	X	6,34	35,96	72,33	114,63
-X	4,18	36,09	0	40,27	-X	5,28	35,96	0	41,24
				541,51					**600,08**
BOL-Summer					**EOL-Summer**				
Face	**Albedo**	**IR**	**Solar**	**Total [W/m^2]**	**Face**	**Albedo**	**IR**	**Solar**	**Total [W/m^2]**
Z	0	0	60,46	60,46	Z	6,07	35,96	49,01	91,04
-Z	16,52	131,32	7,8	155,64	-Z	20,9	131,14	9,88	161,92
Y	4,54	36,09	44,94	85,57	Y	5,73	35,96	56,93	98,62
-Y	4,54	36,09	44,91	85,54	-Y	5,86	35,96	56,93	98,75
X	4,36	36,09	38,69	79,59	X	6,07	35,96	49,01	91,04
-X	4,21	36,09	0	40,3	-X	5,32	35,96	0	41,24
				507,1					**582,47**

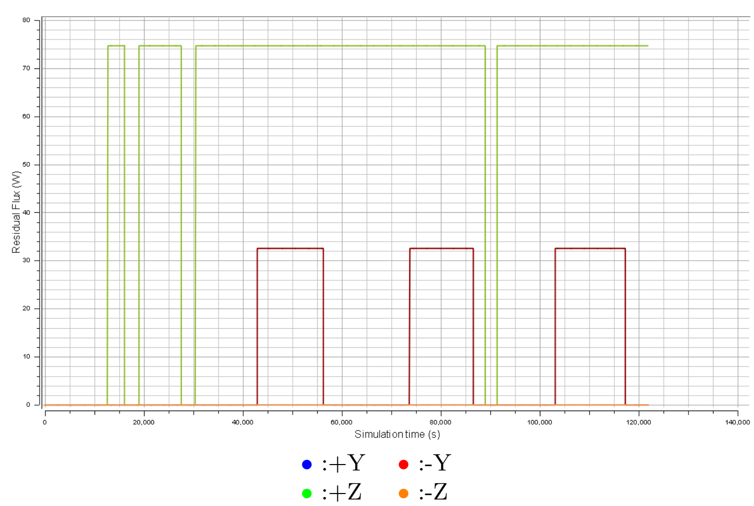
B Optimization process in survival mode and validation for nominal hot and cold cases

After the design has been optimized for hot and cold case in Question 11, the challenge in the Bonus question was the choice of the position of the TTC Antenna. Indeed, as per project instruction, the options were to put it either in +Y side or in -Y side. Moreover, the antenna needs to be pointed to Earth.
To this end, the simulation set up changes. Indeed, a new pointing is defined in the *Kinematics* block in Thermica. As stated in the project instructions [2], the survival attitude consists of the +Z axis pointed towards the Sun and the satellite spinning around its Z axis. In addition, the equipment's dissipated power in survival mode is different from the one in nominal mode, therefore the user defined script to input in Thermica has been updated to include the dissipated power during survival mode.

The first design idea was to position the TTC antenna in +Y side, pointing towards the Earth. Furthermore, as stated in subsection 4, the conductive couplings between the equipment and the radiators were modified. The first option of thermal joints was abandoned in favor of the thermal washers for +Y and -Z faces, and the direct screwing for -Y and +Z faces.
The adopted strategy was "freezing" the conductive coupling choice and modifying the radiators' area and the heaters power so to avoid heaters' saturation while keeping the spacecraft above the critical temperature of -10 °C.
The whole iterative process consisted of approximately thirty attempts. Indeed it was essential to write down every small change applied in order to understand how the design parameters (radiators areas and heaters power) affected the results in terms of temperature and duty cycle. Practically, a sensitivity analysis have been performed and the final design parameters are shown in 11, while the temperature graph and the residual fluxes in survival mode are depicted in Figure 12a and 12b.



(a) SPOT faces temperature results from the survival case, 20 orbits simulation.



(b) SPOT residual fluxes in survival mode, 20 orbits simulation.

Figure 12: SPOT analysis results in survival mode, 20 orbits simulation.