ISAE
Institut Supérieur de l'Aéronautique et de l'Espace
SUPAERO

Satellite Thermal Control

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Systema Workshop Report

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1. Introduction

This report describes the thermal analysis and optimization of radiators on a satellite placed in a LEO orbit. The workshop has been conducted by Ahmet Burak KOÇ and Ömer Eren Can KOÇULU using SYSTEMA software.

2. Geometry generation

The first part of the workshop is generating the geometry of the CubeSat. This geometry contains the nodal breakdown as well as the thermo-optical properties.

2.1. Geometry

First, the CubeSat has been created by using "Modeler" section with dimensions of 1m x 1m x 1m. Then, two radiators represented by rectangles. First one is on the +Z side with 0.6m x 0.4m and the second one is at -Z side with 0.4m x 0.4m. Finally, a disc, which represents the payload of the satellite, has been created on the +Y face with 0.6m diameter. All shapes have been moved 0.001 mm out of the surface to remove it from the satellite. Managing the product tree is also very important for generating a geometry. We have been created different objects for Platform (MLI and radiators) and Payload (instrument). And then, we changed the colors.

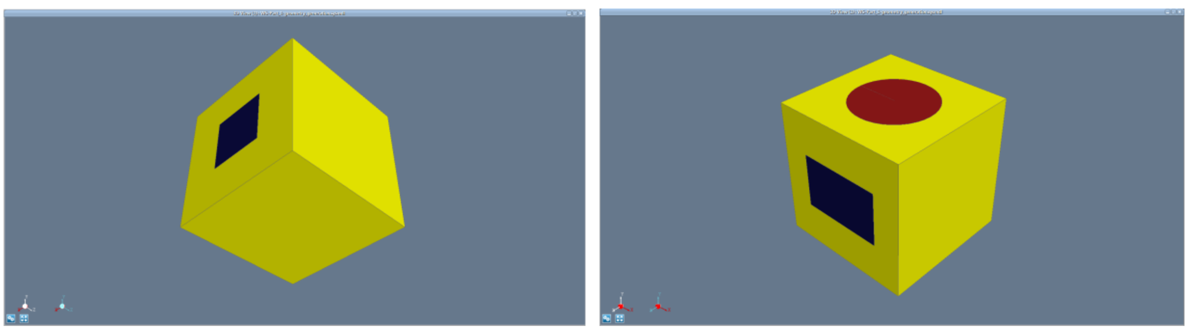


Figure 1 CubeSat Geometry

2.2. Nodal breakdown

The meshing process was carried out to the CubeSat using the values specified in the table below;

Equipment	**Range**
MLI	100 – 900
Radiators	1000 – 1900
Instrument	2000 – 2900

Table 1 Ranges for equipment

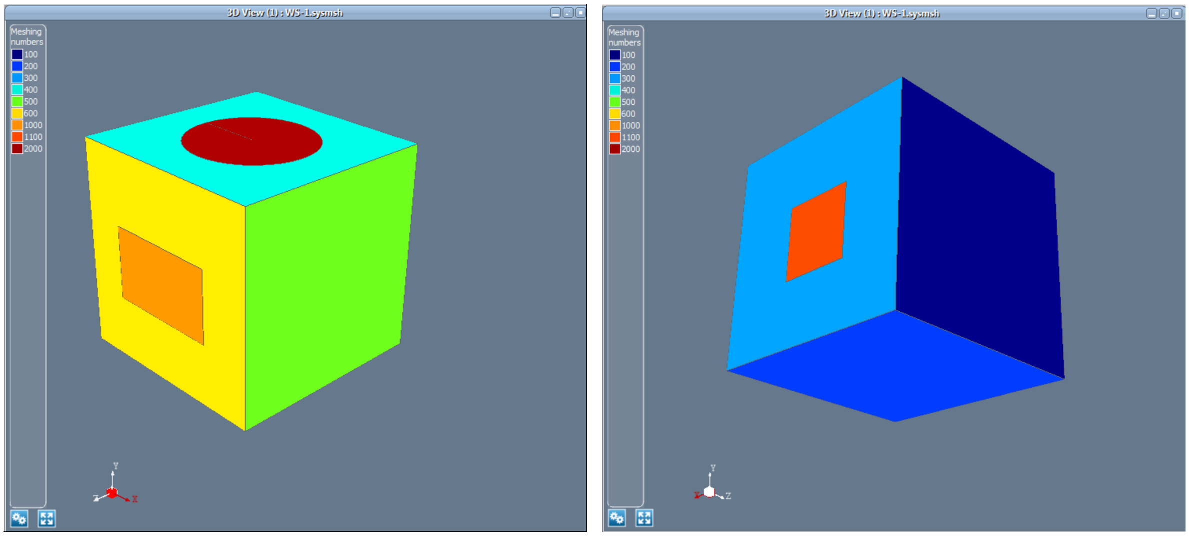


Figure 2 Payload and radiators surface meshing

2.3. Thermo-optical properties

First, a new "Material" file has been created and defined the following coating for each equipment. Because the external sides of the satellite are only active surfaces, internal sides have not been coated. To make sure the created model is appropriate; the values of absorptivity and emissivity on the geometry have been plotted and given in Figure 3 and Figure 4.

Equipment	**Material**	**Absorptivity (Alpha)**	**Emissivity (Epsilon)**
MLI	Kapton	0.52	0.75
Radiators	SSM	0.15	0.75
Instrument	Black Paint	0.93	0.9

Table 2 Material specification of each equipment

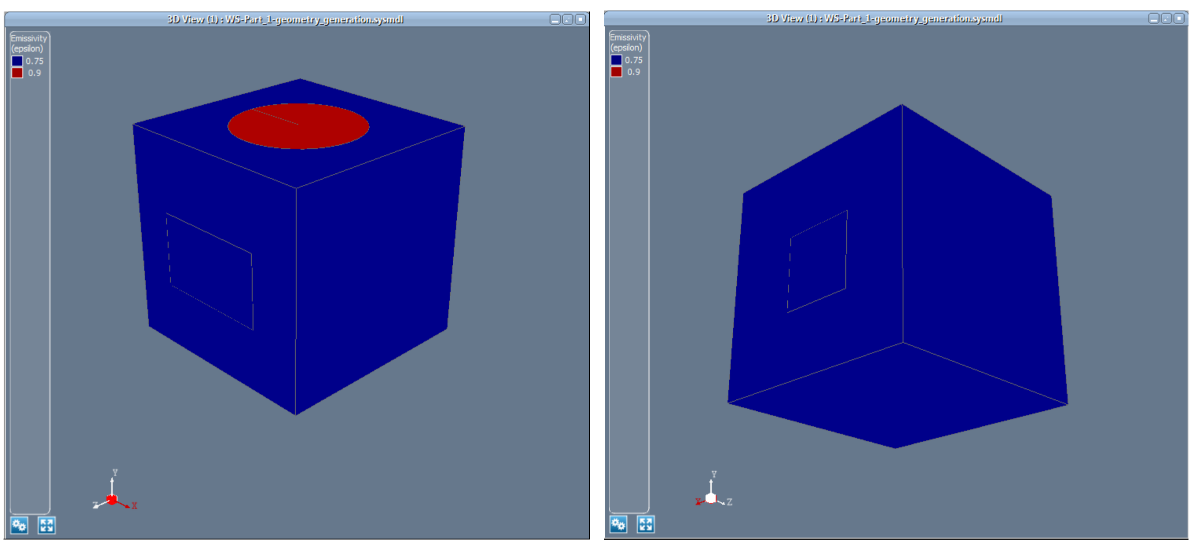


Figure 3 Emissivity (Epsilon) values of CubeSat

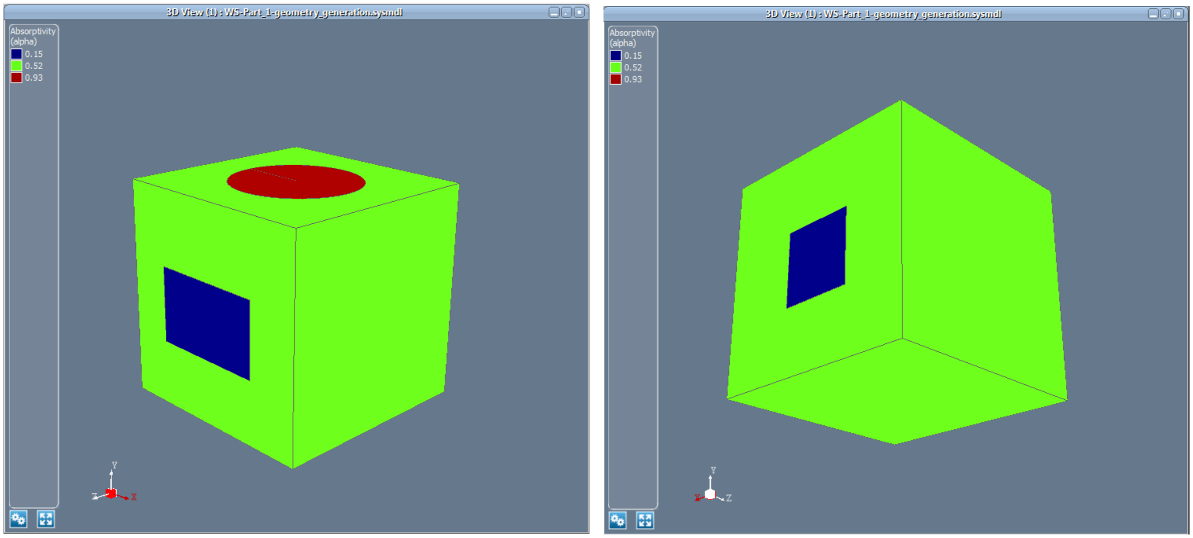


Figure 4 Absorptivity (Alpha) values of CubeSat

3. Fluxes and radiative couplings computation

The second part of the workshop includes external fluxes and radiative couplings of the spacecraft.

3.1. Trajectory

A new trajectory has been created on Trajectory tab in Systema. The CubeSat is placed on a Sun-synchronous orbit with an altitude of 800 km. The local time of Ascending Node has been calibrated as 10h30. In order to start the simulation during eclipse zone that the true anomaly angle has been chosen as 180 degree. To evaluate the worst-case scenario, the reference and start days are set at winter solstice 2015.

3.2. Kinematics

For the kinematics, our satellite instrument should look at the earth. We rotated the cube with the following vectors:

- 1st pointing vector: +Y Earth (Orbit planet reference: 0, 1, 0)
- 2nd pointing vector: +X Velocity (Orbit velocity vector: 1, 0, 0)

3.3. Mission

The mission has been defined by .sysmsh, .sysmdl, .systrj and .syskin in the mission tab. Then in the timeline, modified the computation event rule so it will compute each 5° of anomaly and at the beginning and end of the eclipse.

Satellite localization and its trajectory are shown in Figure 5.

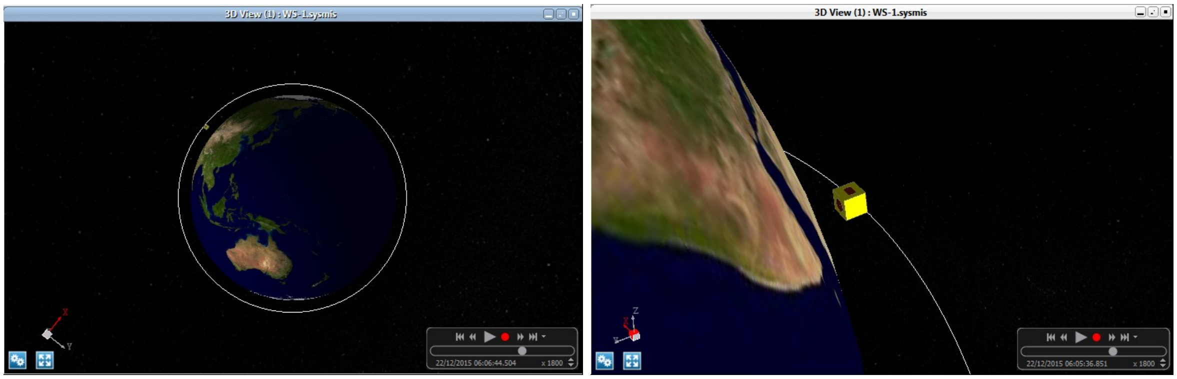


Figure 5 General orbit(left) and CubeSat on the mission (right)

3.4. Processing

In the processing tab, we have been calibrated the following boxes;

- Nodal Description
- Radiation
- Solar Flux
- Planet Fluxes

Solar flux calibrated from 2000 to 100000 and in the Planet Flux box; earth temperatures(day and night) have been calibrated -9 C, earth albedo was taken %35, moon albedo was taken %12 and moon temperature have been calibrated 123 C for day and -233 C for night.

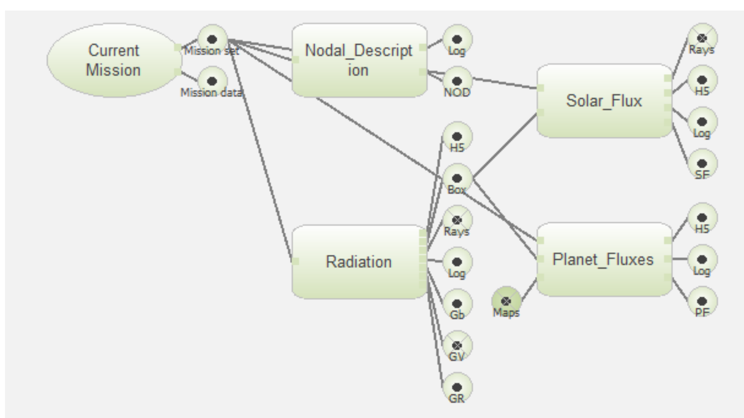
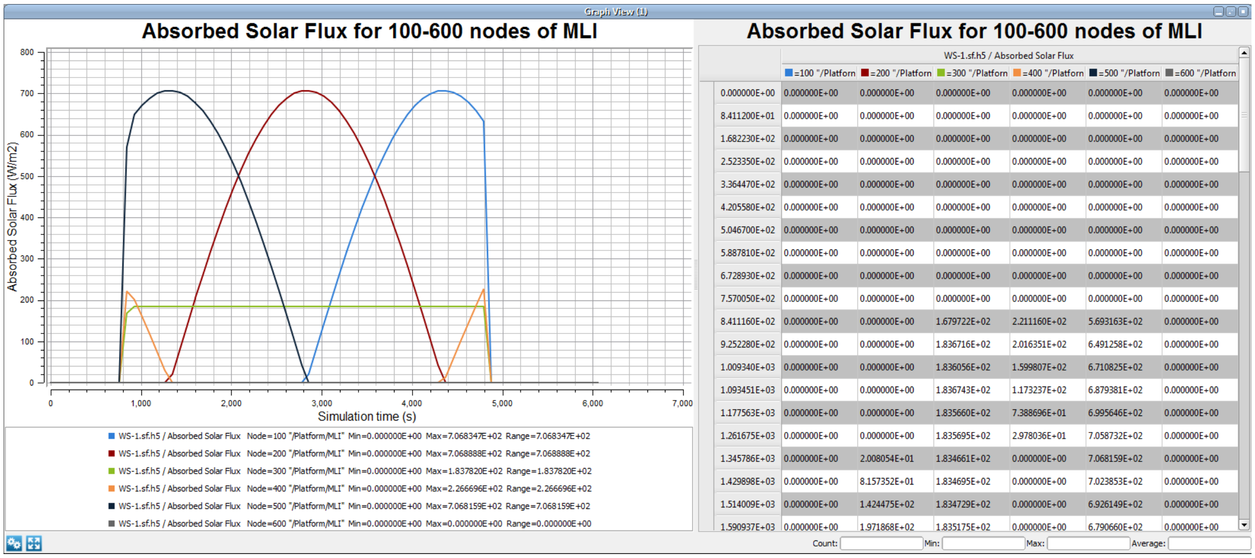


Figure 6 Process Tree

By using processing scheme shown in Figure 6, absorbed solar flux are computed for each MLI surfaces (six surfaces of CubeSat) as shown in Graphic 1. In eclipse period, absorbed solar flux values are zero. Otherwise, flux values are matched with expectations for sun-synchronous orbit.



	WS-1.sf.h5 / Absorbed Solar Flux					
	=100 "/Platforn	=200 "/Platforn	=300 "/Platforn	=400 "/Platforn	=500 "/Platforn	=600 "/Platforn
0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
8.411200E+01	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
1.682230E+02	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
2.523350E+02	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
3.364470E+02	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
4.205580E+02	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
5.046700E+02	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
5.887810E+02	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
6.728930E+02	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
7.570050E+02	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
8.411160E+02	0.000000E+00	0.000000E+00	1.679722E+02	2.211160E+02	5.693163E+02	0.000000E+00
9.252280E+02	0.000000E+00	0.000000E+00	1.836716E+02	2.016351E+02	6.491258E+02	0.000000E+00
1.009340E+03	0.000000E+00	0.000000E+00	1.836056E+02	1.599807E+02	6.710825E+02	0.000000E+00
1.093451E+03	0.000000E+00	0.000000E+00	1.836743E+02	1.173237E+02	6.879381E+02	0.000000E+00
1.177563E+03	0.000000E+00	0.000000E+00	1.835660E+02	7.388696E+01	6.995646E+02	0.000000E+00
1.261675E+03	0.000000E+00	0.000000E+00	1.835695E+02	2.978036E+01	7.058732E+02	0.000000E+00
1.345786E+03	0.000000E+00	2.008054E+01	1.834661E+02	0.000000E+00	7.068159E+02	0.000000E+00
1.429898E+03	0.000000E+00	8.157352E+01	1.834695E+02	0.000000E+00	7.023853E+02	0.000000E+00
1.514009E+03	0.000000E+00	1.424475E+02	1.834729E+02	0.000000E+00	6.926149E+02	0.000000E+00
1.590937E+03	0.000000E+00	1.971868E+02	1.835175E+02	0.000000E+00	6.790660E+02	0.000000E+00

Graphic 1 Solar Flux values of each MLI (6 surface of CubeSat)

4. Temperatures computation

4.1. Heat rejection capacities

We need to measure the external fluxes acting on the radiators and calculate heat rejection capacities (W/m^2) assuming the surface temperature of 35ºC. The Table 3 values were obtained from each graphs max value and G_R is read from the text file. When we calculate the area needed for PCDU and RIU for each radiator, the minimum resulting material assigned for each radiator. For C1000 we used **PCDU**, and for C1100 we used **RIU**.

$$C = \sum \underbrace{G_R}_{\text{from Systema}} \cdot \underbrace{\sigma}_{\text{Boltzman constant}} \cdot \left(\underbrace{T_s}_{\text{Space Temper.}}{}^4 - \underbrace{T_{rad}}_{\text{Radiator Temp.}}{}^4\right) + \underbrace{Q_S + Q_A + Q_E}_{\text{from Systema}}$$

Radiator	G_R	Q_S [W]	Q_A [W]	Q_E [W]	C [W]	Heat Rejection [W/m^2]
C1000	0.18	0	3.55	10.88	-77.4	-322.50
C1100	0.12	9.68	2.55	7.22	-41.8	-261.25

Table 3 Heat rejection calculation

4.2. First temperatures estimation

We have two different type of equipment for radiators and we need to choose one with the least area.

- PCDU: dissipation 94W; thermal capacity 2500 J/K
- RIU: dissipation 45W; thermal capacity 1400 J/K

$INITIAL

C1000 = 2500.0
QI1000 = 94.0
C1100 = 1400.0
QI1100 = 45.0

For the computation of worst-case temperatures the process tree in Figure 7 is used. In process, five orbit is simulated for Min/Max/Mean nodes.

As shown in the Graphic 2, radiators' temperatures do not exceed 50ºC. The temperature values are low because the radiator dimensions are larger than needed.

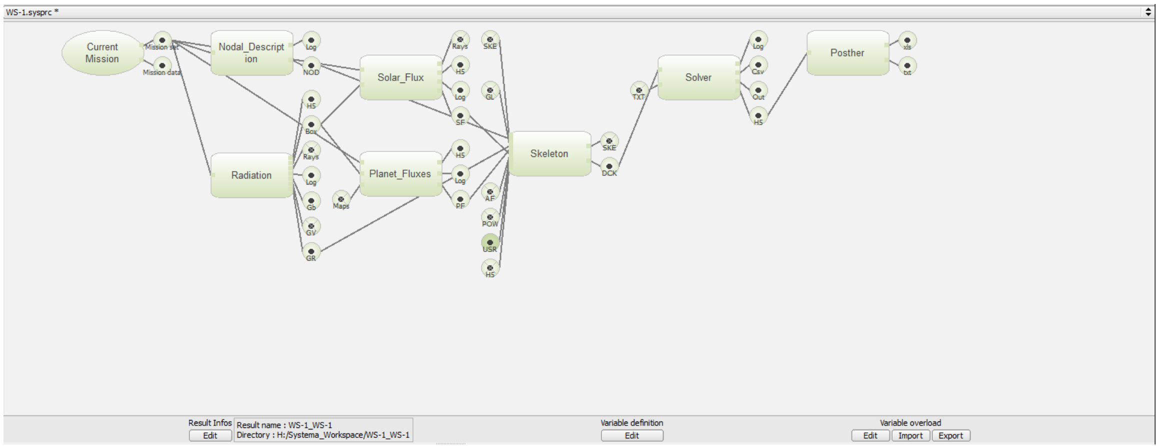
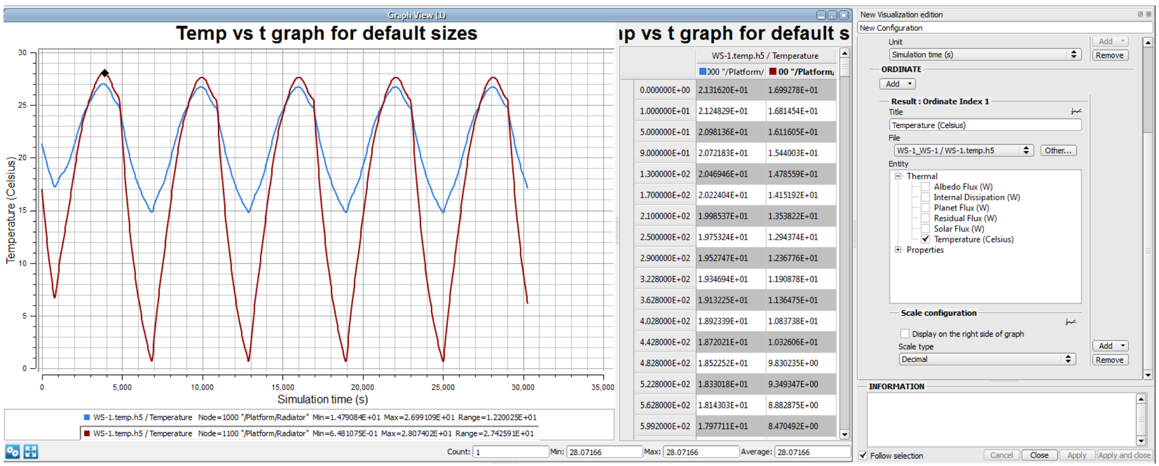


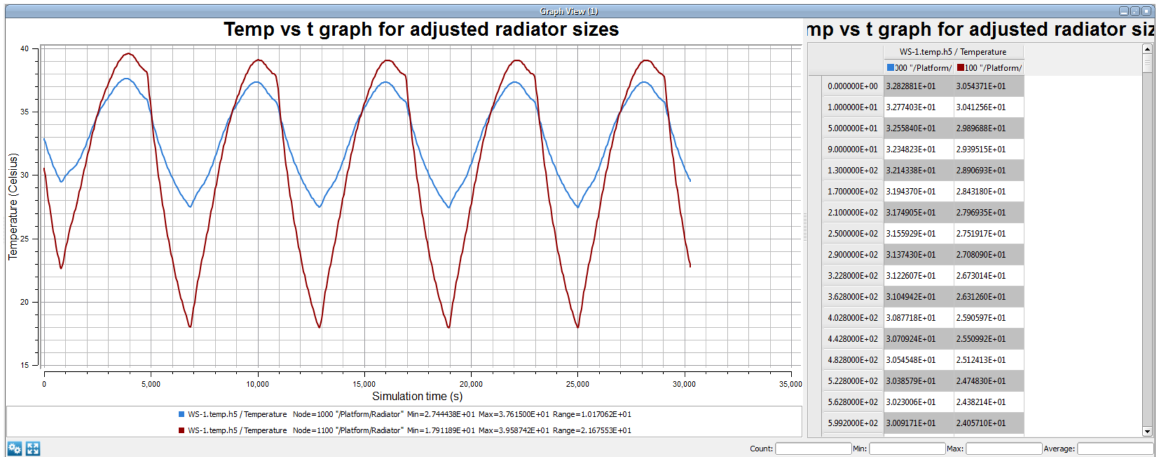
Figure 7 Process tree for temperature computation



Graphic 2 Initial temperature for C1000 and C1100

4.3. Radiators adjustment

In this part, we tried to adjust areas of the radiators so we get a better result that save the mass and cost. The PCDU and RIU have an operating temperature of 60ºC, but because of the qualification and design margins we set that limit to 40ºC (10 ºC margins qualification and 10 ºC margins acceptance). After changing the radiator dimensions from 0.6x0.4 and 0.4x0.4 to 0.55x0.35 and 0.34x0.34 respectively, the final temperature graph is obtained as in Graphic 3.



	WS-1.temp.h5 / Temperature	
	000 "/Platform/	100 "/Platform/
0.000000E+00	3.282881E+01	3.054371E+01
1.000000E+01	3.277403E+01	3.041256E+01
5.000000E+01	3.255840E+01	2.989688E+01
9.000000E+01	3.234823E+01	2.939515E+01
1.300000E+02	3.214338E+01	2.890693E+01
1.700000E+02	3.194370E+01	2.843180E+01
2.100000E+02	3.174905E+01	2.796935E+01
2.500000E+02	3.155929E+01	2.751917E+01
2.900000E+02	3.137430E+01	2.708090E+01
3.228000E+02	3.122607E+01	2.673014E+01
3.628000E+02	3.104942E+01	2.631260E+01
4.028000E+02	3.087718E+01	2.590597E+01
4.428000E+02	3.070924E+01	2.550992E+01
4.828000E+02	3.054548E+01	2.512413E+01
5.228000E+02	3.038579E+01	2.474830E+01
5.628000E+02	3.023006E+01	2.438214E+01
5.992000E+02	3.009171E+01	2.405710E+01

Graphic 3 Modified radiator temperatures for C1000 and C1100

5. Conclusion

In conclusion, thermal control design steps are experienced in the workshop from designing satellite model, generating its trajectory and mission and analyzing its thermal behavior.

In the geometry generation part, firstly, satellite model is designed as a CubeSat on which circular payload and two rectangular radiators are mounted. Secondly, active and passive surfaces are defined with node numbers. Finally, thermo-optic properties of all surfaces are defined by selection of materials.

In the fluxes and radiation couplings computation part, trajectory and kinematics of the satellite are defined. Then, mission is defined by using defined satellite model and trajectory. Finally, fluxes and radiation couplings are computed by processing the mission.

In temperatures computation part, after heat rejection capacities of radiators are calculated by hand, electrical equipment are mounted on radiators according to their power dissipation and radiators' heat capacities by using initial values. However, radiators' temperatures are computed lower than required so radiator sizes are adjusted to meet requirements. Finally, radiators' sizes are optimized by adjusting satellite model so requirements are met with lowest cost and mass.