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# Technical Specifications of GT2 Thermal Module v3.1

NANOST-REQ-045

Xavier LAURAND
CSUM

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## SCOPE AND CONTENT

This document defines the programmatic and technical requirements for the Thermal module, hereafter " the tool" that shall be developed for the UM in the frame of the GT 2 of the NANOSTAR Project.
This document contains the set of requirements to be verified for the acceptance of the Thermal module.

**Important note. "*Words in Italic*" have the same definition than in IDM-CIC or Simu-CIC.**

UM and all NANOSTAR partners shall be able to use the tool for free for their own needs and for the NANOSTAR projects tasks.

## PROGRAMMATIC SPECIFICATIONS

This GT 2 Task is divided into 3 sub-tasks:

| Sub-Task | Description | Responsible | Deliverable |
|---|---|---|---|
| **1** | Write the specification of the Thermal module to be developed – validation by the GT2 leader | CSUM (Xavier LAURAND) and the GT2 Leader: ISAE-SupAero (Thibault GATEAU) | This document |
| **2** | Subcontracting the Thermal Module to be developed to a software developer that is familiar with IDM-CIC code | Subcontracor of the UM-CSUM in the frame of a public procurement process | The Thermal Module code (object and source code) including communication interface with NSS (Nanostar Software Suite) |
| **3** | Validation of the Thermal Module consisting in comparing a simplified analysis with the Thermal Module and a detailed analysis using THERMICA and discussion of the comparison. | CSUM (Xavier LAURAND) | A report to be issued on the NANOSTAR website, and on NSS source diffusion mean. |

## TECHNICAL SPECIFICATIONS

# 1- Format and Open Source Specifications

| Number | Specification | Verification Method |
|---|---|---|
| FOS-1 | **OpenSource** : The tool shall be open source LGPL v3 license. | R |
| FOS-2 | **Platform** : The tool code should be cross platform (windows 10, Unix) | R, T |
| FOS-3 | **Stand Alone** : The tool should be available as a standalone software | R, T |
| FOS-4 | **Plug-In from IDM** : The tool shall be able to act as a plug-in from IDM-CIC, in which case it shall automatically import data from the IDM-CIC model (in .idm format) | R, T |
| FOS-5 | **Import from CCSDS** : The tool shall be able to import data from a ".txt" saved in CCSDS format, protocol CIC | R, T |
| FOS-6 | **Export to CCSDS** : The tool shall be able to export data to a ".txt" in CCSDS format, protocol CIC. | R, T |
| FOS-7 | Deleted | R, T |
| FOS-8 | A well-documented API shall be provided, alongside with a quickstart guide, working standalone example and a REAMDE.md (markdown) file describing dependencies, compilation process, running example, running tests and limitations. | R, T |
| FOS-9 | A well-documented and working REST-API shall be provided. | R, T |
| FOS-10 | An Angular Front-end shall be available for interacting with the tool and all its functionalities. | R, T |

# 2- General Function Specifications

| Number | Specification | Verification Method |
|---|---|---|
| GFS-1 | **Function N°1**: Compute the required radiator area and required heater power, for each *Thermal Module (see description below)* based on the *Dissipation Budget* and thermal properties of *Equipment* (area, eps, …).<br>The results about area and heater should be able to be presented for each *Thermal Module*. | R |

| | | |
|---|---|---|
| GFS-2 | **Function N°2**: Compute temperature profile of *Thermal Modules* based on the on the *Thermal Modules Dissipation Budget* and *Equipments'* thermal properties (area, eps, …).<br>The temperature results shall be presented and exported to CCSDS format. | R |
| GFS 3 | **Function N°3 :** Compute the required heater power needed in each *Thermal Modules* to maintain the minimum *Equipments'* temperatures based on the *Thermal Modules Dissipation Budget* and *Equipments'* thermal properties (area, eps, …).<br>The temperature results shall be presented and exported to CCSDS format. | |

# 3- Operational Specifications

| Number | Specification | Verification Method |
|---|---|---|
| OS1-1 | **"Project":** The tool shall allow to create a "project". It shall contain:<br>• *Thermal Module*<br>• *Dissipation budget*<br>• A thermal data set<br>• The three functions defined above | R, T |
| OS-1-2 | ***Thermal Module*:** The tool shall allow for the creation of Thermal Modules. A Thermal Module shall contain *Equipments (Eq).*<br>For each Equipment it shall be possible to identify with a check box if it is a *Radiating Surface (RS).* | R, T |
| OS-1-3 | ***Equipment* Properties:** The thermal module shall display and allow definition of the properties given in Table 1 : *Equipment* properties. | |
| OS-1-4 | **Dissipation Budget :** The dissipation shall contain "*Satellite Modes*" and the thermal dissipation associated to each *Equipment* in each *Satellite Mode.* | R, T |
| OS-1-5 | **Thermal Data Set :**<br>The Thermal Data Set shall allow definition of thermal properties given in the Table 2. | RT |

TABLE 1 : *EQUIPMENT* PROPERTIES.

| | Description | Applicable to | Default value | Units |
|---|---|---|---|---|
| $\varepsilon$ | Surface emissivity in the Infrared Wavelength. May be comprised between 0 and 1. | RS | 1 | No unit |
| $A$ | Surface Area. | RS | 1 | $m^2$ |
| $T_M$ | Lowest maximum operating temperature of the equipment present in the thermal module. This value may be imported from IDM-CIC. | Eq | 303 | K |
| $\alpha$ | Surface Absorptivity in the visible wave length. May be comprised between 0 and 1. | RS | 1 | No unit |
| $\theta$ | Angle between the plane of the surface and the impinging solar flux $F_s$ . May be comprised between 0° and 90°. | RS | 90 | degree |
| VF | View factor between the Surface and the Earth. May be comprised between 0 and 1. | RS | 1 | No unit |
| $m$ | Masse of the equipment<br>This value may be imported from IDM-CIC. | Eq / RS | 1 | kg |

| | | | | |
|---|---|---|---|---|
| $C_p$ | Specific heat capacity per mass basis of the *Equipment*'s material | Eq / RS | 897 | $J.K^{-1}.kg^{-1}$ |
| $\gamma$ | Angle between the plane of the surface and the impinging Earth flux $F_E$ . May be comprised between 0° and 90°. | RS | 90 | degree |
| $P_n$ | Power dissipated by each of the *Equipment* for each *Satellite Mode*<br>This value may be imported from IDM-CIC. | Eq | 0 | W |

TABLE 2 : THERMAL DATA SET PROPERTIES

| Value | Description | Default value | Units |
|---|---|---|---|
| $\sigma$ | Stefan-Boltzmann constant: $5.670374 . 10^{-8}$. | constant | $W.m^{-2}.K^{-4}$ |
| $F_s$ | Solar Flux. | 1370 | $W.m^2$ |
| $F_E$ | Earth Flux. | 350 | $W.m^{-2}$ |
| a | Earth Albedo. May be comprised between 0 and 1. | 0.3 | No unit |

| Number | Specification | Verification Method |
|---|---|---|
| OS-2-1 | **Inputs from IDM-CIC :** When launched as a plug-in, the tool shall automatically import the following data from IDM-CIC :<br>• List of *Thermal Module* and *Satellite Mode*<br>• List of *Equipment* in each *Thermal Module*<br>• List of *Equipment Dissipation* for each *Satellite Mode*<br>• List of NOP min for each *Equipment* | R, T |
| OS-2-2 | **Update from IDM-CIC :** If launched as an IDM-CIC plugin, the tool shall perform automatic update when new commit is made to the IDM-CIC Project. | |
| OS-2-3 | **Saving:** The tool shall allow to save a project (format TBD) in a single independent file. In such case link to existing IDM-CIC project and Simu-CIC Files shall be kept. | R, T |

# 4- Function n°1 Detailed Specification

**Key hypothesis:** the Thermal Modules will be considered isothermal, with a set of dissipating *Equipment* assigned to the *Thermal Modules* in the gui. One radiating surface is considered and the properties is given in the gui. A predefined and fixed Sun angle and Earth Angle with respect to the radiating surface may be defined manually, it does not need to be physically realistic. Furthermore the user may set parameters such as SunFlux, albedo, Earth Flux and view factor with respect to Earth in the Thermal Data Set Tab.

The module will compute the required area considering this inputs and the lowest maximum operating temperature of the equipment present in the thermal module.

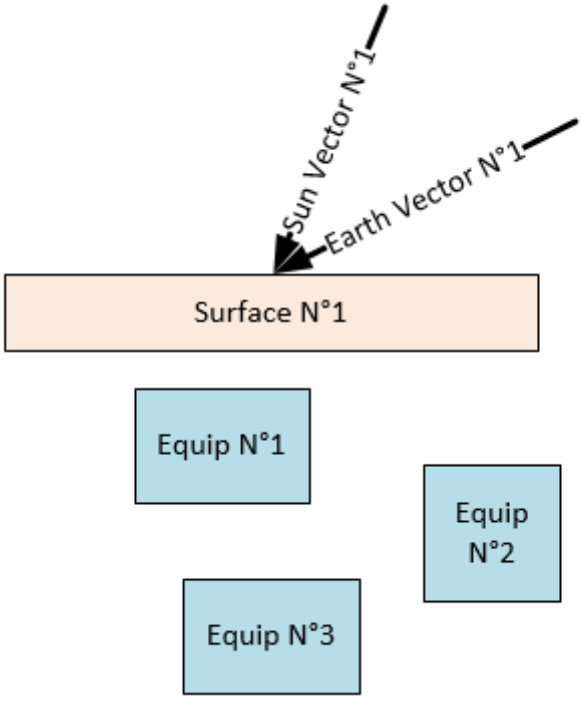


FIGURE 1 : SCHEMATIC OF FUNCTION N°1.

| Number | Specification | Verification Method |
|---|---|---|
| F1-1 | **Equation N°1** : The function shall solve the following equation to find "A" for each *Satellite Mode* and each *Thermal Module* | R, T |

EQUATION 1 : FUNCTION N°1 THERMAL EQUILIBRIUM EQUATION.

$$\sigma\varepsilon AT_M = F_s\alpha A cos\theta + F_E VF\varepsilon A|cos\gamma| + F_s VFa\alpha A|cos\gamma| + \sum_{1}^{n} P_n$$

# 5- Function n°2 Detailed Specification

**Key hypothesis:** the thermal modules will be considered isothermal, with a set of dissipating equipment assigned to the modules in the IDM CIC-gui and a set of radiating surfaces assigned to the module in the IDM CIC-gui. A predefined and fixed Sun angle and Earth Angle with respect to the radiating surfaces may be defined manually, it may be different for each surface and does not need to be physically realistic. Furthermore the user may set parameters such as SunFlux, albedo, Earth Flux and view factor with respect to Earth.

Such function would require the addition of a Flag in IDM-CIC and a parameter to define the radiative surface area in order to be fully compatible.

The module will compute the module temperature considering these inputs of the area and the equipment present in the thermal module. It will solve a steady state condition but may also solve a time dependent results.

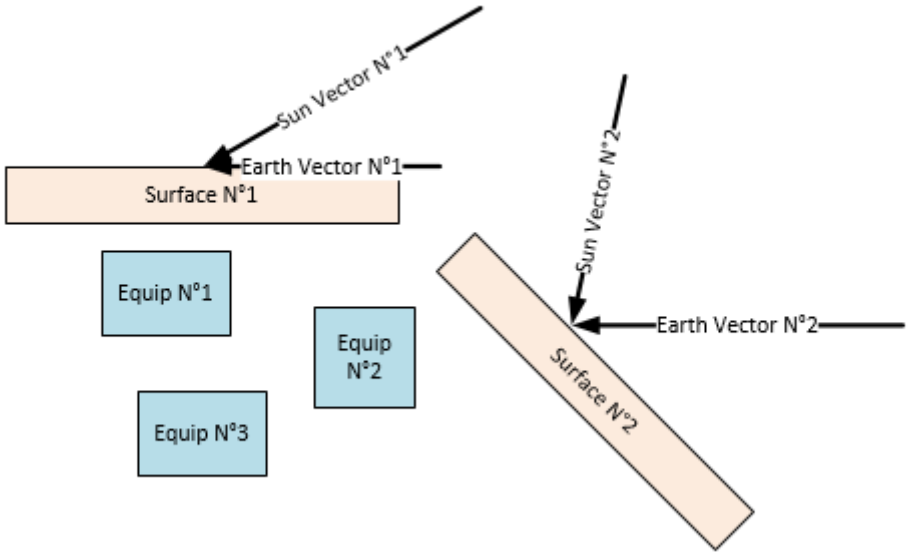


FIGURE 2 : SCHEMATIC OF FUNCTION N°2

| Number | Specification | Verification Method |
|---|---|---|
| F2-1 | **Equation N°2** : The function shall solve the following equation to find "T" for each *Satellite Mode* and each *Thermal Module* | R, T |
| F2-2 | **Equation N°3** : The function shall solve the following equation to find "T" as a function of "t" for each *Satellite Mode* and each *Thermal Module* for any given *set of* mission parameters | R, T |

| | | |
|---|---|---|
| F2-3 | **Time dependency:** For solving the Equation N°3, in case they are different time steps for the time dependent inputs, the tool may do linear interpolation to define the values at the needed time. | R, T |
| F2-4 | **Mission Parameters:**<br>The tool shall allow to upload in a CCSDS format the following information :<br>• Earth direction in satellite frame<br>• Sun Direction in satellite frame<br>• Sun Visibility<br>Maybe imported from SIMU-CIC results | |
| F2-5 | **Definition of Power dissipation profile:** The tool shall allow to define the "*Satellite Mode*" to apply as a function of the simulation time. | |

EQUATION 2 : FUNCTION N°2 THERMAL EQUILIBRIUM EQUATION

$$(\sigma\varepsilon_n A_n)T^4 = \sum_1^n F(\alpha_n A_n cos\theta_n) + \sum_1^n EVF(\varepsilon_n A_n cos\gamma_n) + \sum_1^n FVFa(\alpha_n A_n cos\theta_n) + \sum_1^n P_n$$

$$\sum_1^n$$

EQUATION 3 : FUNCTION N°2 TIME DEPENDENT THERMAL EQUATION

$$(-\sigma\varepsilon_n A_n T).dt + \sum_1^n F(\alpha_n A_n cos\theta_n).dt + \sum_1^n EVF(\varepsilon_n A_n cos\gamma_n).dt + \sum_1^n FVFa(\alpha_n A_n cos\theta_n).dt + \sum_1^n P_n.dt$$

$$\sum_1^n (mC_p)\frac{dT}{dt} = \sum_1^n$$

Where:

| Value | Description | Default value | Units |
|---|---|---|---|
| $t$ | Time | 1 | s |

| Number | Specification | Verification Method |
|---|---|---|

| | | |
|---|---|---|
| F2-7 | **F2 Results Export 1**: The temperature results shall be exportable for visualization in IDM-View in CCSDS format | I, T |
| F2-8 | **F2 Results Export 2**: The results shall be exportable for visualization in excel in CCSDS format | I, T |

# 6- Function n°3 Detailed Specification

**Key hypothesis:** the *thermal modules* will be considered isothermal, with a set of dissipating equipment assigned to the modules in the IDM CIC-gui and a set of radiating surfaces assigned to the module in the IDM CIC-gui. A predefined and fixed Sun angle and Earth Angle with respect to the radiating surfaces may be defined manually, it may be different for each surface and does not need to be physically realistic. Furthermore the user may set parameters such as SunFlux, albedo, Earth Flux and view factor with respect to Earth.

The module will compute the required heater power to maintain the *thermal module*s temperature above the higgest minimum temperature assigned in the IDM CIC-gui. It will consider the area and the equipment present in the thermal module. It will solve a steady state condition but may also solve a time dependent results.

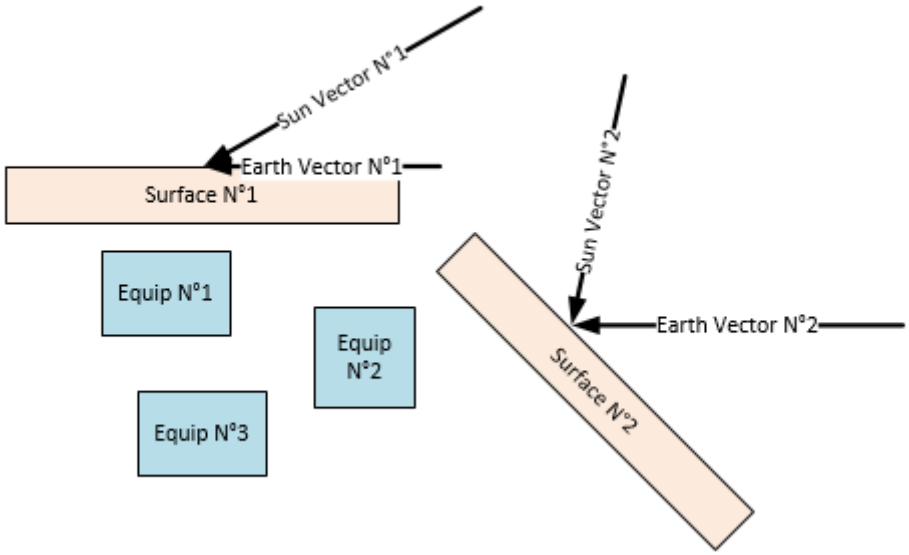


FIGURE 3 : SCHEMATIC OF FUNCTION N°3

| Number | Specification | Verification Method |
|---|---|---|
| F2-1 | **Equation N°2** : The function shall solve the following equation to find "T" for each *Satellite Mode* and each *Thermal Module* | R, T |
| F2-2 | **Equation N°3** : The function shall solve the following equation to find "T" as a function of "t" for each *Satellite Mode* and each *Thermal Module* for any given *set of* mission parameters | R, T |

| | | |
|---|---|---|
| F2-3 | **Time dependency:** For solving the Equation N°3, in case they are different time steps for the time dependent inputs, the tool may do linear interpolation to define the values at the needed time. | R, T |
| F2-4 | **Mission Parameters:**<br>The tool shall allow to upload in a CCSDS format the following information :<br>• Earth direction in satellite frame<br>• Sun Direction in satellite frame<br>• Sun Visibility<br>Maybe imported from SIMU-CIC results | |
| F2-5 | **Definition of Power dissipation profile:** The tool shall allow to define the "*Satellite Mode*" to apply as a function of the simulation time. | |

EQUATION 4 : FUNCTION N°2 THERMAL EQUILIBRIUM EQUATION

$$(\sigma\varepsilon_n A_n)T^4 = \sum_1^n F(\alpha_n A_n cos\theta_n) + \sum_1^n EVF(\varepsilon_n A_n cos\gamma_n) + \sum_1^n FVFa(\alpha_n A_n cos\theta_n) + \sum_1^n P_n$$

$$\sum_1^n$$

EQUATION 5 : FUNCTION N°2 TIME DEPENDENT THERMAL EQUATION

$$(-\sigma\varepsilon_n A_n T).dt + \sum_1^n F(\alpha_n A_n cos\theta_n).dt + \sum_1^n EVF(\varepsilon_n A_n cos\gamma_n).dt + \sum_1^n FVFa(\alpha_n A_n cos\theta_n).dt + \sum_1^n P_n.dt$$

$$\sum_1^n (mC_p)\frac{dT}{dt} = \sum_1^n$$

Where:

| Value | Description | Default value | Units |
|---|---|---|---|
| $t$ | Time | 1 | s |

| Number | Specification | Verification Method |
|---|---|---|

| | | |
|---|---|---|
| F2-7 | **F2 Results Export 1**: The temperature results shall be exportable for visualization in IDM-View in CCSDS format | I, T |
| F2-8 | **F2 Results Export 2**: The results shall be exportable for visualization in excel in CCSDS format | I, T |

# 7- Test Cases

The test validation will be performed by comparison the tool results with a Thermica simulation (V4.8.0) available at CSUM. As the tool is developed as part of small satellites projects, the validation will be done on 1U and 3U CubeSat model.

The four IDM CIC model are included as an annex to this document for reference.

## a. Case 1: 1Unit SSO 6h-18h

The case will be very simple. It will be made of 1 single unit cubesat, with attitude control so that one of the face is permanently exposed to the Sun and one of the face is permanently pointing Earth. The model will be made of a single *Thermal Module* with constant dissipation.

This results may also be validated via “hand calculation”.

## b. Case 2: 1Unit SSO 00h-12h

The same model as above may be used. However the Cubesat orientation will be defined so that different faces point Earth at different time. Sun illumination will also vary as the satellite enters and exits Eclipse.

## c. Case 3: 3Units SSO 6h-18h

The case will be more complicated. It will include a 3Units CubeSats, “each unit” will be a *Thermal Module* and include one to two units with different *Thermal Modes*. The Attitude will be constant, with Solar Array facing the Sun.

## d. Case 4: 3Units SSO 00h-12h

The case will be the most complicated. It will include the same model as above however the Attitude will be constant, with Solar Array facing the Sun part of the mission and One antenna point Earth for acquisition.

# 8- Display Preview

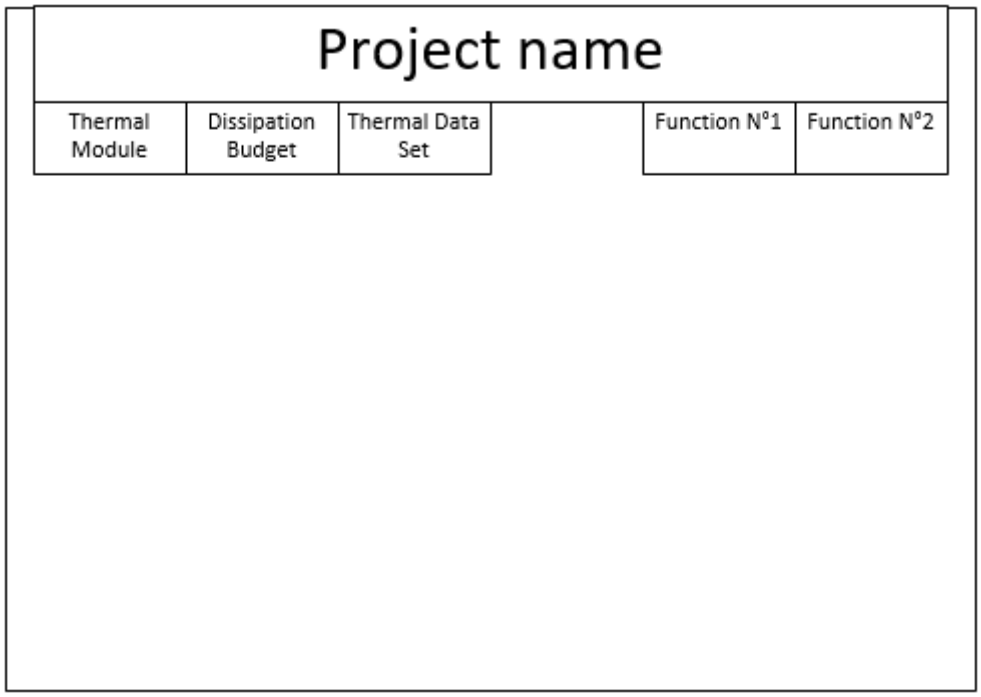


FIGURE 4: PREVIEW OF MAIN SCREEN.

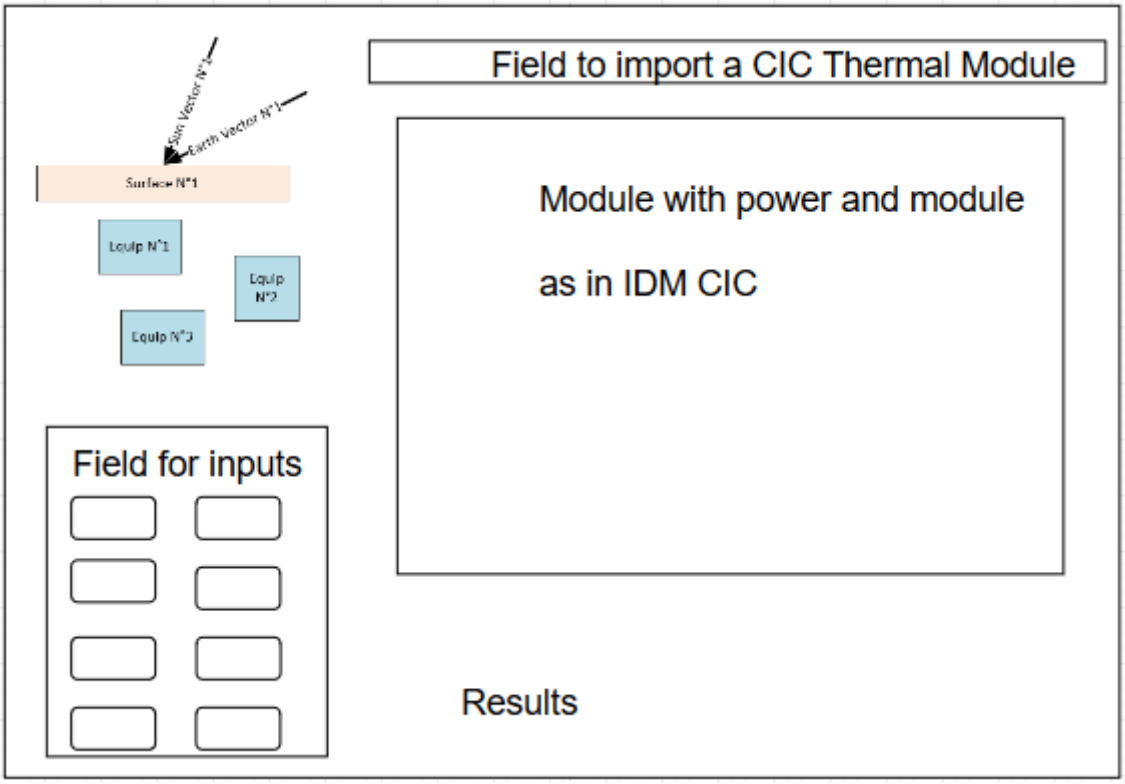


FIGURE 5 : PREVIEW OF FUNCTION N°1 VIEW ON SCREEN

| Number | Specification | Verification Method |
|---|---|---|
| F1-2-1 | **Display Function N°1** : The tool shall display function 1 elements as specified in the figures above. The function display shall fit onto a single screen. | I, T |

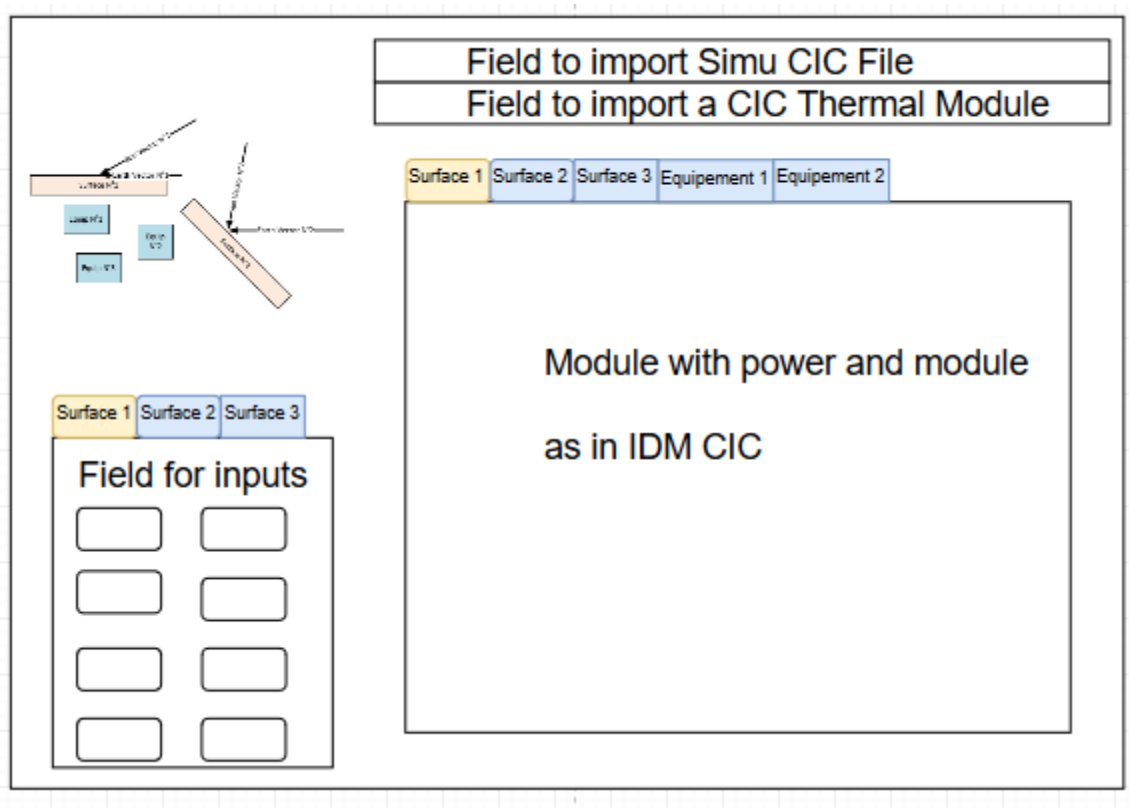


FIGURE 6 : PREVIEW OF FUNCTION N°2 INPUT SCREEN

| Number | Specification | Verification Method |
|---|---|---|
| F2-4 | **Display Function N°2** : The tool shall display function 2 elements as specified in the figures above. The function display fit onto on two screens:<br>• One screen for inputs<br>• One screen for results | I, T |

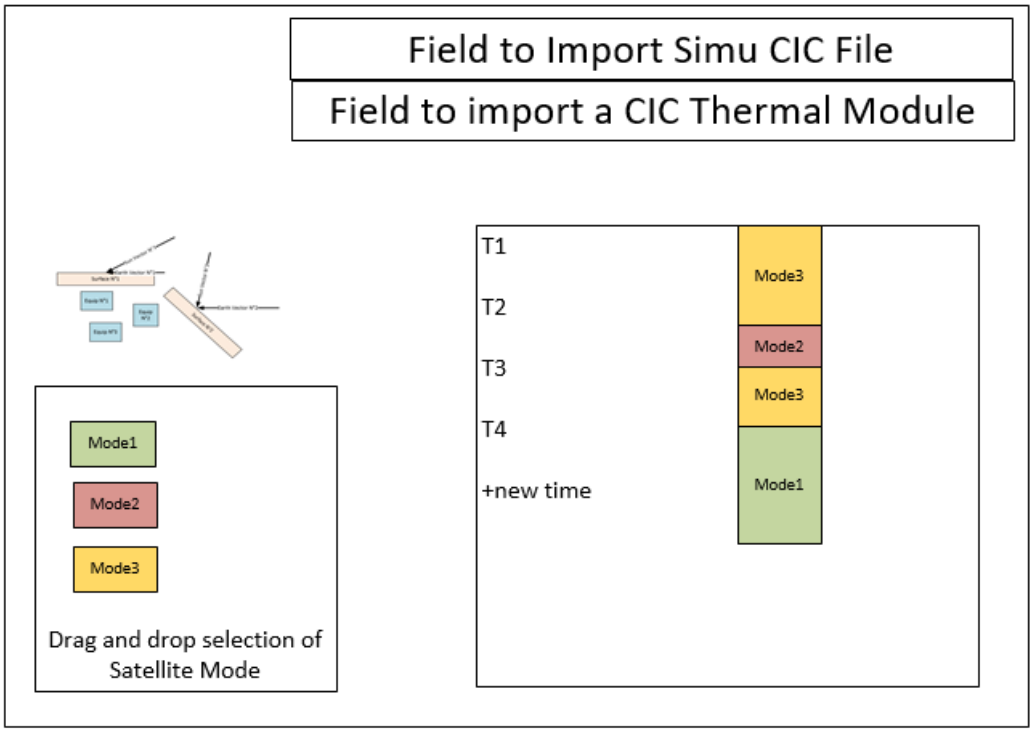


FIGURE 7 : PREVIEW OF FUNCTION N°2 INPUT SCREEN

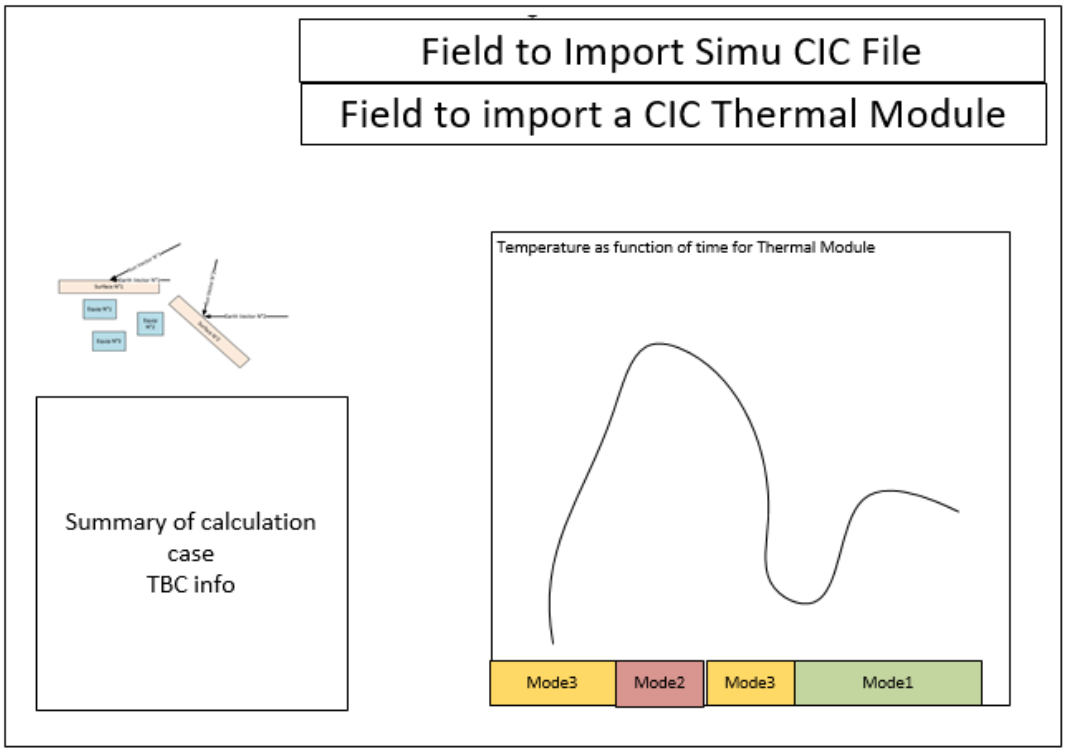


FIGURE 8 : PREVIEW OF FUNCTION N°2 RESULTS SCREEN

# DEFINITIONS AND ACRONYMS

Definitions

**Tool:** this term refers to any computer program (source code and object code), as well as the preparatory material and associated documentation and its manual, including in a general manner, all elements, including but not limited to all media, programs, manuscripts, lists and other documents, whether in written form or in any other form readable by man or machine.

**Basic Software:** This term refers to software owned by either party prior to this GT2 Task.

**Derivative software**: this term refers to software made from a Basic Software in the context of this GT2 Task. There are two categories of Derivative Software: Adaptations and Extensions.

**Adaptation:** this term refers to Derivative Software using the same algorithms as the Basic Software from which it derives and / or rewrites in another language.

**Extension:** This term refers to Derivative Software that provides access to new features or performance as compared to the Base Software from which it derives.

**New Software** : this term refers to the Tool created ex nihilo as part of the GT2 tasks.

Acronyms

| | |
|---|---|
| API | Application Programming Interface |
| CCDS | Consultative Committee for Space Data Systems |
| CIC/CDF | Centre d' Ingénierie Concourrante/Concurent Design Facility |
| CSUM | University Space Center of Montpellier |
| GT2 | Groupe de tâches 2 |
| LGPL | Lesser General Public License |
| NANOSTAR | Project selected in the frame of the SUDOE INTERREG program |
| REQ | Requirement |
| REST-API | Representational State Transfer- Application Programming Interface |
| RF | RadioFrequency |
| TBD | To be Done |
| UM | University of Montpellier |