PRELIMINARY FLIGHT TEMPERATURE PREDICTIONS OF THE ITASAT SATELLITE

Douglas Felipe da Silva[1], dfsilva@ita.br
Ezio Castejon Garcia[1], ezio@mec.ita.br
[1]Instituto Tecnológico de Aeronáutica, Divisão de Engenharia Mecânica-Aeronáutica, Praça Marechal Eduardo Gomes, 50, Vila das Acácias, CEP 12.228-900, São José dos Campos-SP.

Abstract. *This work presents the preliminary temperature predictions, in which the ITASAT satellite will be submitted in an average flight case of thermal load. ITASAT will be the first satellite developed by Brazilian universities. Its payload will be one data collection transponder plus scientific experiments. Technological Institute of Aeronautics (ITA) manages this program, with participation of other Brazilian universities. The program is technically supported by the National Institute of Space Researches (INPE), in which also is sponsored by the Brazilian Space Agency (AEB). The analysis model is based on commercial software "System Improved Numerical Differencing Analyser" (SINDA). This one has the feature of calculating the orbital external heat loads (direct solar, earth and solar albedo radiations) on a given satellite. The internal heat loads are consequences of the functioning of the satellite. Some parameters (such orbit type and satellite attitude) influence directly the intensities of these thermal loads. Having these thermal loads as inputs, the flight temperature distribution can be calculated. This study is part of the thermal control design, in which has the purpose to maintain the temperature profiles within of the maximum and minimum acceptable limits.*

Keywords*: SINDA, ITASAT, Heat Loads, Thermal Control, Satellite.*

1. INTRODUCTION

The numerical thermal model is the working tool in the development of a satellite thermal control system. It is used to predict temperatures on a large scale, with most structures and others components interacting with one another and with surrounding environment. Generating the thermal model begins early in a satellite project, with additions and upgrades continuing as notions on design and performance become firmer. Final confirmation follows the thermal balance test, conducted in a vacuum chamber, when predictions from the model are correlated with test results (Karam, 1998).

The ITASAT program is a development multidisciplinary project that involves ITA, AEB, INPE and others Brazilian universities. This program has been an initiative of the ITA under-graduate students. In this stage, the staff is mainly composed with under-graduates and graduate students, but the project is normally reviewed in order to get the whole school involvement.

The ITASAT program has the purpose to design, develop, manufacture, integrate, test, launch and, operate a technological microsatellite. On-orbit, the program will validate an integrated system composed by an Attitude Control and Data Handling (ACDH), a Global Positioning System (GPS) and two others payloads: a Data Collecting Subsystem (DCS) and other scientific experiment system (to be defined).

This paper presents results of a numerical simulation of average case for prediction heat loads (between maximum and minimum) for the ITASAT. The flight critical cases, end of life (EOL) and begin of life (BOL), will be simulated accordingly with the project evolution, in the next phases.

1.1. ITASAT satellite

ITASAT satellite does not have yet a closed finished configuration (June, 2008). A preliminary definition is that the satellite will have two functions: one operational and other experimental. The operational function is to collect environmental data (manly weather data). For this purpose, ITASAT will have a Data Collection Transponder as main payload. The intention is to replace the Collect Data Satellites #1 and #2 (SCD1 and SCD2), in which were launching in 1993 and 1998, respectively. The aim of this kind of mission is to provide Brazil with environmental data collecting system supported by satellites and data collecting platforms (PCDs) distributed all over the country. Data currently collected by SCD1 and SCD2 are still used on applications such as input for weather forecast models, studies on ocean currents, tides, atmosphere composition, agricultural planning, among others. The second function is to analysis in flight, technological experiments with space applications, especially in attitude control, telecommunication, thermal control, power generation and distribution.

The ITASAT satellite will utilize low Earth orbit: circular, 750 km height, 25 degrees of inclination. This kind of orbit will remain the satellite at Earth tropical zone. Orbits whose maximum altitude are less than approximately 1800 kilometers are generally considered low Earth orbits (LEO), and have short periods, around of 100 minutes. The inclination and altitude of the ITASAT orbit will be the same of the SCD2 satellite. This inclination allows the satellite to cover Brazil's territory, region where the INPE's data collect platforms are placed. Thus, when it pass over Brazil, the data sent by the satellite’s transponder will be received by the antennas. The orbit illustration is presented in “Fig. 1”.

Figure 1. ITASAT’s orbit (Sorice, 2007).

ITASAT will be a spin-stabilized satellite, thus, it will spin around its own “Z” axis, with approximately 40 rotations per minute and will have a pointing of 0.5° relative to the Earth’s geomagnetic field. The satellite’s pictures are shown in “Fig. 2”.

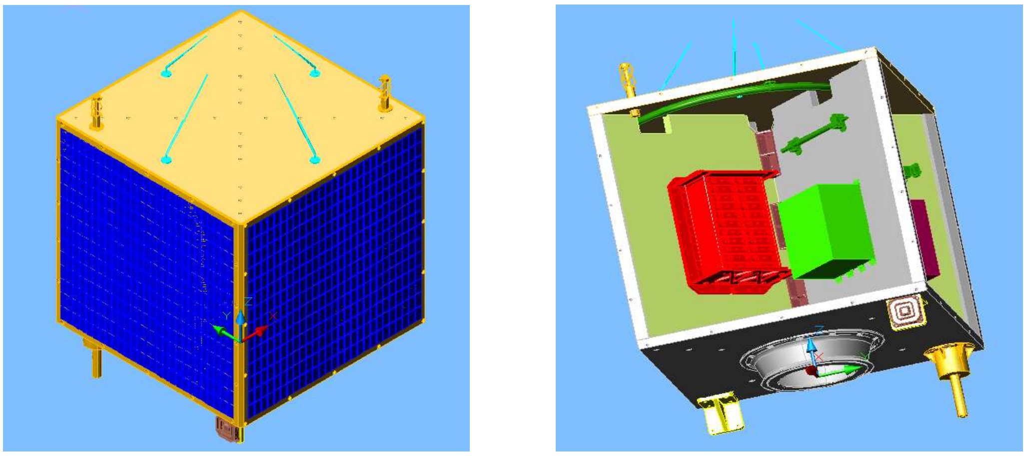

Figure 2. ITASAT’s structure (INPE, 2007). Anticlockwise rotation around “Z” axis.

The satellite’s dimension can be approximated to a parallelepiped with 0,70 m in the X direction, 0,70 m in the Y direction and 0,65 m in the Z direction. The satellite, including the antennas and others equipment, must be placed into a cylindrical shell with approximately 1 m of diameter, to ensure launch’s vehicle compatibility, and also, its mass, should not exceed 80 kg.

The solar arrays will be placed parallel to spin’s axis, to ensure the necessary illumination to generate the required power, and inside the box the internal panels are placed like a “X” shape, crossing from each corner to the opposite other.

ITASAT will be composed by the structure subsystem, electrical power/distribution subsystem (EPS or EPDS), telemetry, tracking and command subsystem (TT&C), attitude/velocity control subsystem (ACS or AVCS) and thermal control subsystem (TCS), of course.

2. THE THERMAL CONTROL SUBSYSTEM

Satellites perform better and last longer when their equipment remain within certain temperature limits, usually, but not always, close of the level whose they are designed. Satellite thermal control deals with the theory and practice by which these temperatures are produced, and the function of the thermal engineer is to determinate the influencing factors and manages them within the constraints of the satellite as one system. The process involves unique methods of analysis and test and often requires the use of some highly specialized hardware (Karam, 1998).

The thermal control subsystem (TCS) is an integral part of every spacecraft. Its purpose is to maintain all the equipment of a spacecraft within their respective temperature limits. There are several different sources of thermal energy acting on a spacecraft: solar radiation, albedo, Earth emitted infrared, and heat generated by on-board equipment. Therefore, the thermal control subsystem is different for every spacecraft. In general, there are two types of

TCS, passive and active. A passive system relies on conductive and radiative heat paths and has no moving parts or electrical power input. An active system is used in addition to the passive system when passive system is not adequate. Active systems rely on pumps, thermostats, and heaters, use moving parts, and require electrical power (Fischer, 1995).

ITASAT's features, as low power, low Earth orbit and spin-stabilized, collaborate to reach all temperatures limits employing only passive thermal control. Low Earth orbit results in less orbital period and less eclipse time, resulting on decreasing of temperature instability between the shining and the eclipse periods. In thermal point of view, the spin-stabilized is a positive factor, because it results in a temperature homogenization. The TCS concept for the ITASAT satellite should be similar to the SCD-1 satellite, where only passive thermal control material has been employed.

3. EXTERNAL HEAT LOADS

The overall thermal control of a satellite on orbit is usually achieved by balancing the energy emitted by the spacecraft as infrared radiation against the energy dissipated by internal electrical equipment plus energy absorbed from the environment. The sources of external heat loads are described bellow.

3.1. Direct Solar

Sunlight is the greatest source of environmental heating incident on most spacecraft. The emitted radiation from the sun is constant within a fraction of 1 percent at all times. However, due to the Earth's elliptical orbit, the intensity of sunlight reaching the Earth varies approximately ±3.5% depending on the Earth's distance from the sun. At summer solstice (northern hemisphere) the intensity is at a minimum (1310 W/m²) and at a maximum (1400 W/m²) at winter solstice. The solar intensity also varies as a function of wavelength (Gilmore, 1994).

3.2. Albedo

Albedo is heating from sunlight reflected off Earth. It is usually considered to be in same spectrum as solar radiation and often quoted as a fraction of the solar constant. The albedo value is given by 0.33 ± 0.13 of the solar flux.

Albedo appears more significant at the Earth's polar ice caps and can be estimated in those regions with some accuracy as a function of the sun elevation and the satellite's orbital parameters. However, predictions for overland and above oceans become distorted by the highly variable effects of cloud formations and water distribution in the atmosphere (Karam, 1998).

3.3. Earth emission

The Earth not only reflects sunlight, it also emits long-wave infrared (IR) radiation. The Earth, like a satellite, achieves thermal equilibrium by balancing the energy received (absorbed) from the sun with the energy re-emitted as long-wavelength IR radiation. This balance is maintained fairly well on a global annual average basis. The intensity of IR energy emitted at any given time from a particular point on the Earth, however, can vary considerably depending on factors such as surface and air temperatures, atmospheric moisture content, and cloud coverage. As a first approximation one can use a value around 236.5 W/m² emitted at the Earth's surface.

The IR energy emitted by the Earth, which is around 20 °C, is of approximately the same wavelength as that emitted by satellites, that is to say, it is of much longer wavelength than the IR energy emitted by the sun at 5800 K. Unlike short-wavelength solar IR, the Earth IR loads cannot be reflected away with special thermal control coatings since the same coating, would prevent the radiation of waste heat away from the spacecraft. Because of this, Earth-emitted IR energy can present a particularly heavy backload on spacecraft radiators in low-altitude orbits, which must emit energy at the same wavelength (Gilmore, 1994).

4. INTERNAL HEAT LOADS

The internal heat loads are given by satellite equipment dissipations. Equipment, its coating, operational temperature range and heat dissipation, is shown in the "Tab.1".

Table 1. Equipment characteristics.

Equipment	Face	Coating	Heat Dissipation (W)	Temperature Range (°C)
Atittude Control Wheel (ACW)	All	Black Paint	0	-50 to 75
Battery	Lateral and Superior	G407912	2	-5 to 25

Battery	Inferior	Alodine	2	-5 to 25
Codifier	Lateral and Inferior	Black Paint	0.1	-10 to 40
	Superior	G407912		
UPC Computer	All	Black Paint	2.1	-10 to 40
Converter	All	Black Paint	4.7	-10 to 50
Decoder	All	Black Paint	3.7	-10 to 40
Duplex	All	Black Paint	0	-10 to 40
Magnetometer's Electronics (ME)	Lateral and Superior	Black Paint	1	-20 to 60
	Inferior	Alodine		
PCD Transponder	All	G407912	3.4	0 to 40
Power Control Unit (PCU)	All	Black Paint	9	-10 to 50
Power Distribution Unit (PDU)	All	Black Paint	0.5	-10 to 50
Solar Sensor	Lateral and Superior	Black Paint	0.3	-30 to 50
	Inferior	Alodine		
Magnetometer' Sensor (MS)	Lateral and Superior	Black Paint	0	-20 to 60
	Inferior	Alodine		
TMTC Transponder	Lateral and Superior	Black Paint	7.6	-10 to 40
	Inferior	G407912		

5. SIMULATION CHARACTERISTICS

The actual phase of the ITASAT project (June, 2008), the design of the equipment configuration (that will compose the satellite) is not totally finished. Because of this fact, the thermal control subsystem progress is being affected, once that TCS development is based on equipment parameters such thermal properties, mass, dimension and heat dissipation, mainly. Thus, by this reason for this paper, the SCD1 equipment parameters have been used as input for the present simulation.

The satellite structure will be mainly composed of aluminum honeycomb panels. This is an anisotropic material, in which the thermal conductance is direction dependent. For this study, the thermal conductivity value adopted in transversal direction is 1.278 W/m.K, and for other two directions the value is 4.79 W/m.K. The adopted density is 315 kg/m³, and its specific heat is 936 J/kg.K. In this case, for the lateral panels, where the solar cells will be placed, the thickness is 0.01 m; for the inferior and superior panels the value is 0.025 m; for the internal panels, the thickness is 0.014 m. The adopted solar constant is 1354 W/m², the Earth infrared emission is 221.48 W/m² and the albedo value is 0.35 of the solar radiation. The external faces of the panels are coated by the following materials: a) Dupont's Kapton® film, on the inferior and superior panels; b) solar cells on the lateral panels. All internal faces have been coated with black paint. The employed material's optical thermal properties, like solar absorptivity, infrared emissivity and the relation between both, are shown in the "Tab.2":

Table 2. Material's optical thermal properties.

Coating	α_{solar}	ε_{ir}	$\alpha_{solar}/\ \varepsilon_{ir}$
Solar cells	0.85	0.85	1
Kapton®	0.34	0.55	0.618
Black paint	0.9	0.9	1
Alodine	0.3	0.1	3
Sheldahl's G407912 film	0.3	0.03	10

5.1. Thermal balance equation

The following equation, "Eq. (1)", describes the thermal balance between a node and its boundary. This balance is obtained from First Law of Thermodynamics.

$$m_i Cp_i \frac{dT_i}{dt} = \sum_{j=1}^{n+1} R_{ji}\sigma\left(T_j^4 - T_i^4\right) + \sum_{j=1}^{n} B_{ji}\left(T_j - T_i\right) + Q_i + A_i\alpha_i q_s + A_i\varepsilon_i q_{ir} \qquad i=1...n \tag{1}$$

Where:
T_i e T_j are absolute temperature from nodes *i* and *j*;
t is the time;
m_iCp_i is thermal capacitance from node *i*;
R_{ji} is the radiative-conductance between nodes *j* and *i*;
σ is the Stefan-Boltzmann's constant;
B_{ji} is the conductive-conductance between nodes *j* and *i*;
Q_i is the internal heat generation in node *i*;
A_i is node's *i* surface exposed to environment;
α_i is the solar absorptivity from node *i*;
ε_i is the infrared emissivity from node *i*;
q_s is the solar spectrum radiation's intensity that incises on *i*;
q_{ir} is the infrared spectrum radiation's intensity that incises on *i*;
n is the satellite's number of nodes which is separated;
n +1 is the node that represents the environment (or space).

The conductive couplings can be presented in various ways, depending on nodes' configuration. In case that nodes *i* and *j* represents parts on the same panel, B_{ij} can be calculated by the "Eq. (2)".

$$B_{ji} = \frac{kA}{L} \tag{2}$$

Where:
B_{ji} is the conductive-conductance between nodes *j* and *i*;
k is the material's thermal conductivity;
A is the heat exchange section's area;
L is the distance between nodes *i* and *j*.

The radiative couplings can be obtained as shown in "Eq. (3)" (Sorice, 2007).

$$R_{ij} = \varepsilon_i A_i \left[\sum_{k=1}^{n} F_{ik}\left(\delta_{jk} - (1-\varepsilon_j)F_{jk}\right)^{-1} \right]\varepsilon_j \tag{3}$$

Where:
R_{ij} is the radiative-conductance between nodes *j* and *i*;
ε is the surface's emissivity;
F is the shape factor between surface *i* and adjacent surfaces;
A is the surface's area;
δ is the Kronecker's delta.

The commercial software SINDA works on "Eq. (1)" manipulation. The "Eq's (1)" system solution results on *n* model node temperatures, in which evolutes as time-function. The coefficients m_iCp_i , R_{ji} , B_j , A_i , α_i e ε_i are inherent to satellite's physical configuration, while Q_i depends on on-board equipment's functional condition, q_s and q_{ir} depends on environmental conditions that the satellite will be exposed (Sorice, 2007).

5.2. Calculation methods

The commercial software employed (in the ITASAT thermal project) is called SINDA. This is a software pack (*Thermal Desktop, Radcad, Sinaps Plus* and *SINDA/FLUINT)* commercialized by C&R Technologies (www.crtech.com) that has a good interface with AutoCAD, and makes easy the heat load's calculation, resulting on temperature's distribution, making the orbit sketch and allowing the satellite's geometry assembly utilizing AutoCAD's environment.

Thermal Desktop™ is a program that allows the user to quickly build, analyze, and postprocess sophisticated thermal models. Thermal Desktop takes advantage of abstract network, finite difference and finite element modeling methods. RadCAD is the radiation analyzer module for Thermal Desktop. An ultra-fast, oct-tree accelerated Monte-Carlo raytracing algorithm is used by RadCAD to compute radiation exchange factors and view factors. The output of Thermal Desktop and RadCAD is automatically combined for input into SINDA/FLUINT, thermal analyzer. SINDA/FLUINT does not use nor enforce the use of geometry. Rather, it is an equation solver based not on a geometric description of a system but on an abstract mathematical (circuit or network) description. Radiation exchange, however, normally requires geometry to produce infrared radiation conductances ("RADKs") and absorbed solar fluxes. Also, manual generation of nodal capacitances and linear conductances using finite difference approximations is both tiring and error-prone, and nullifies integration with the design database. SINDA/FLUINT can solve finite element equations if they have been transformed into a network-style formulation.

6. SIMULATION'S RESULTS

The simulation results are presented below. The equipment temperatures (°C) are plotted as function of the time (s).

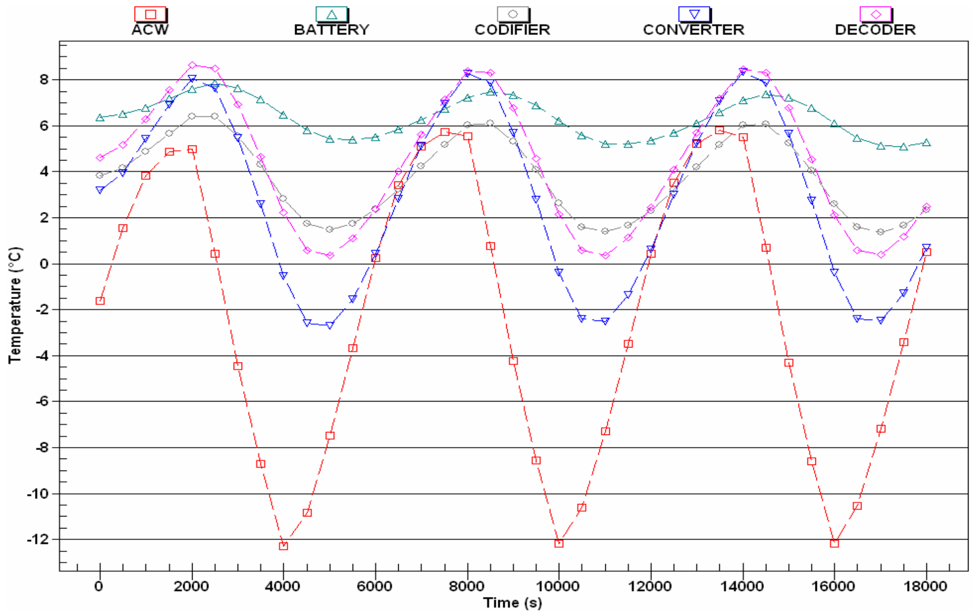

Figure 3. Temperature variation in some equipment.

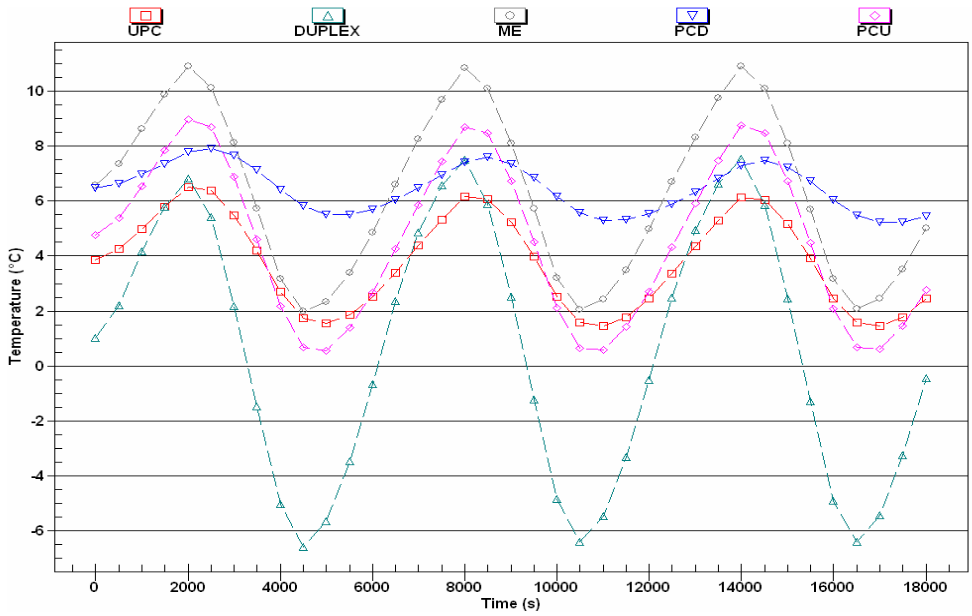

Figure 4. Temperature variation in some equipment.

"Figure 3" presents the time-dependent temperatures for the equipment: attitude control wheel (ACW), battery, codifier, converter and decoder. The temperature's variation for UPC computer, duplex, magnetometer's electronics (ME), PCD transponder and power control unit (PCU), are shown in the "Fig. 4".

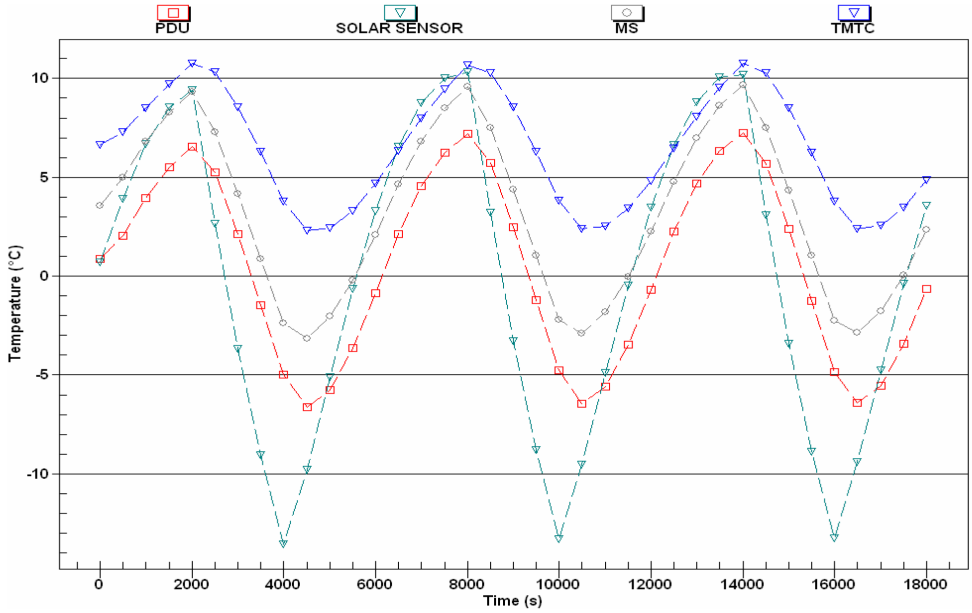

Figure 5. Temperature variation in some equipment.

"Figure 5" presents the time-dependent temperature for the power distribution unit (PDU), solar sensor, magnetometer's sensor (MS) and TMTC transponder. The time average absorbed heat fluxes are shown in "Fig. 6". These are a satellite SW isometric view.

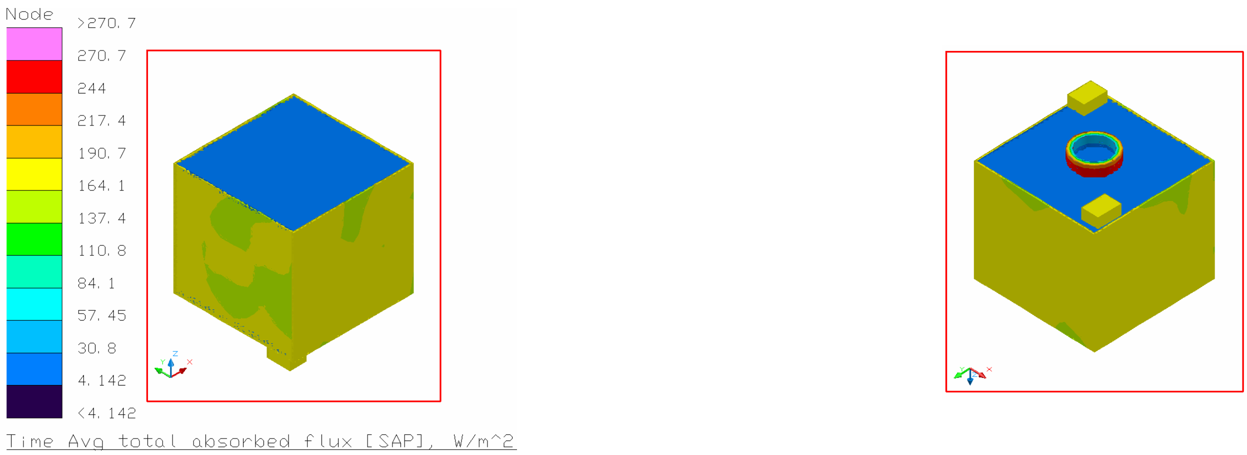

Figure 6. Time average total absorbed heat flux (W/m²).

"Figure 6" presents the time average absorbed heat fluxes, in which are situated between 4 W/m² and 270 W/m².

"Figure 7" and "Figure 8" show the steady-state temperature profiles for the external and internal faces. "Figure 7" presents the thermal profile on the external panel surfaces with the satellite in a SW isometric view. "Figure 8" presents the internal surfaces. Also, this figure shows the temperatures in the equipment, in which is located inside of the satellite.

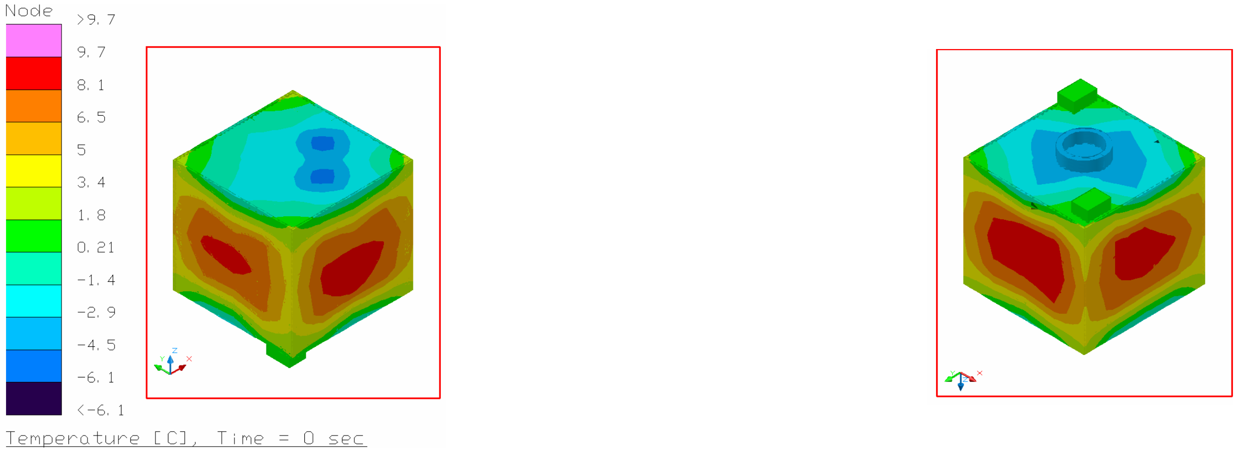

Figure 7. External face temperature profile (°C).

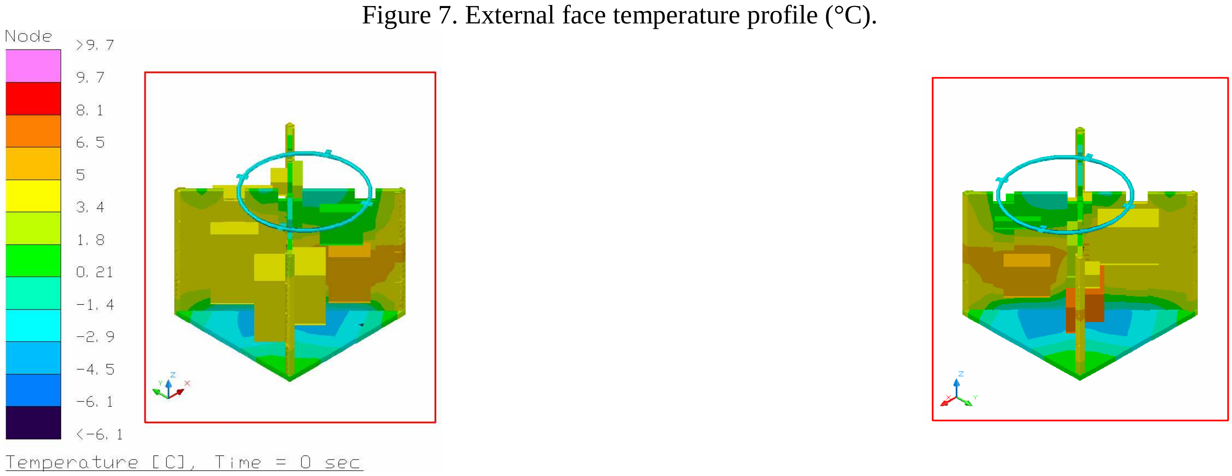

Figure 8. Internal face and equipment temperature profile (°C).

7. CONCLUSIONS

The values obtained in the absorbed heat flux are normally expected for a spin-stabilized satellite, with low Earth orbit. Based in these values, can be said that the model results have converged for confidence range.

Analyzing the time-dependent temperature results in the “Fig. 3”, “Fig. 4” and “Fig. 5”, and making a comparing with the acceptable equipment temperature ranges, in the Tab. (1), can be verified that the temperatures do not exceed the maximum and the minimum acceptable limits. This is a main important conclusion of this paper. The results obtained in this numerical simulation, provide a good preliminary reference for the ITASAT thermal control design. With this preliminary information, a coating selection can be fulfilled. The selected coatings will be employed in the simulation of the critical cases in the next phase of the project. If the results not be satisfactory, the TCS concept will be reevaluated. This simulation has the purpose of provide initial information for final thermal design and for the thermal-vacuum test (TVT) specification.. In resume, it can said, that all obtained results of this paper showed themselves, physical coherent and suitable for the low Earth orbit satellites.

8. REFERENCES

Fischer, M., Editor, 2007 File Extracted from Internet: <www.tsgc.utexas.edu/archive/subsystems/thermal.pdf>.

Gilmore, D. G., Editor, 1994, “Satellite Thermal Control Handbook”, The Aerospace Corporation Press, El Segundo, California.

Karam, R. D., 1998, “Satellite Thermal Control for System Engineers”, Progress in Astronautics and Aeronautics, Vol. 181, AIAA, Cambridge, 274p.

Sorice, A. F., 2007, “Análise da Evolução de Longo Prazo das Temperaturas do Satélite SCD-1”, Dissertação de Mestrado, Instituto Tecnológico de Aeronáutica, São José dos Campos, SP, Brasil.

9. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.