DETERMINING THE PROFILE OF TEMPERATURE IN THE INTERNAL ENVIRONMENT OF SARA SUB-ORBITAL PLATFORM

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Abstract. *Sub-Orbital spacecraft are submitted to simultaneous processes of heat transfer such as generation of heat dissipated by internal equipment, internal convection between the air in the capsule and the electronic equipment and heat transfer by radiation between the capsule and space. This work describes the methodology used to calculate the temperature distribution in the capsule and internal environment of (Entry Atmospheric Satellyte) SARA sub-orbital platform during its flight, using the commercial software Ansys, available in the Space Systems Division (ASE) of the Institute of Aeronautics and Space (IAE). The heat transfer in SARA was simulated considering the heat generation by electronic equipment, heat transfer by convection between electronic equipment and the air inside and radiation from the capsule to the space, to determine the effect of thermal heating of the internal environment in the internal structure and payloads of SARA sub-orbital plataform. Due to the lack of detailed information about the electronics, the physical properties considered were those of aluminum and the power dissipated by each component was considered as the total power of operation. A transiente three-dimensional analysis was performed. The results were satisfactory in most of the domain, where the temperature remained below the limit of 60ºC. Few devices inside the capsule surpassed that limit, what occurred because of the high power concentration in their small volume and proximity to other heat sources.*

***Keywords**: Internal convection, Heat dissipated, Sub-orbital platform SARA*

1. INTRODUCTION

Experiments aimed to determining the profile of temperature of internal environment of space vehicles have a high cost and have limited results, since it is not possible to determine the temperature in all points of the internal environment. Since the application of sensors is limited due to weight gain and their influence on the system, hence the importance of prior analysis of the system using finite element. The objective of this work is to estimate the profile of temperature at all points of the internal environment of SARA Sub-Orbital Platform (Da Costa et all, 2007), providing a better use of experimental methods. This technique also has advantages after the experiment, since the experimental determination of the temperature occurs in a limited number of points (Dórea, 2008).

In this work the thermal behavior of the internal environment of SARA sub-orbital platform is analyzed, in order to determine possible critical points where the temperature exceeds the maximum limit of 60°C. The geometry of the micro-satellite was implemented in the ANSYS software (ANSYS Tutorial, 2008), available at the Institute of Aeronautics and Space - IAE, considering the power dissipation of all electronic equipment inside the capsule (Dórea, 2008).

All data relative to the electronic equipment and systems that are grouped have been obtained from the manufacturer of SARA electronic equipment (Carvalho, 2006). Due to the lack of detailed information about the components, the physical properties were considered those of commercial aluminum, except the average density, obtained from the mass distribution divided by volume, both extracted from the basic configuration (Da Costa et all, 2007). The power dissipated by each component is considered as the total power of operation, given by the product of current and voltage. This approach was used because the efficiency of each component was ignored. The power generated by each component is distributed in its volumes.

The calculation was performed considering the electronic equipment, internal plates and structure closing. All internal surfaces are assumed to be exposed to convection heat transfer, with the internal air that is initially at 27º C (Lavrado Filho e Machado, 2007).

2. PHYSICAL MODEL

2.1. Heat Transfer in the Sub-orbital platform SARA

It was considered the heat generation from internal equipment, the internal convection of air in the capsule and the heat transfer by radiation between the outer surface and the space of the sub-orbital platform SARA.

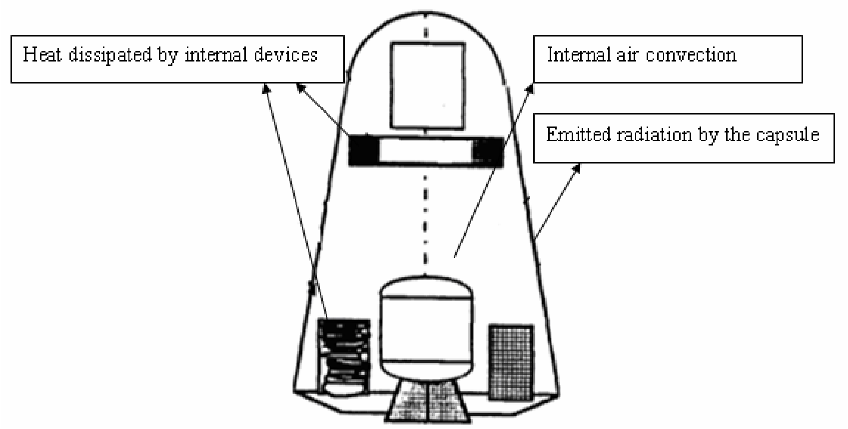


Figure 1. Heat Transfer in Sub-orbital Platform SARA

Radiation: It is the radiation emitted by the equipment surface, given by:

$$q_{em} = \varepsilon\sigma(T_w{}^4 - T_\infty{}^4) \tag{1}$$

where ε is the emissivity of the inner surface, T_w is the temperature of equipments T_∞ is the temperature of the capsule σ is the constant of Stefan - Boltzman, equal to $5{,}67x10^{-8}\ \frac{W}{m^2K^4}$

Internal heat dissipated by equipments: It is the heat produced by internal dissipation of electronic equipment in the SARA. It is considered the total power of the equipment is dissipated, given by:

$$\dot{W} = \sum U_i \bullet A_i \tag{2}$$

where $\dot{W}$ is the total power dissipated, U_i is the voltage and A_i electrical current at each equipment.

Convection: Heat transfer by the heated equipment and the internal air, given by:

$$q_{convc} = h_\infty(T_w - T_\infty) \tag{3}$$

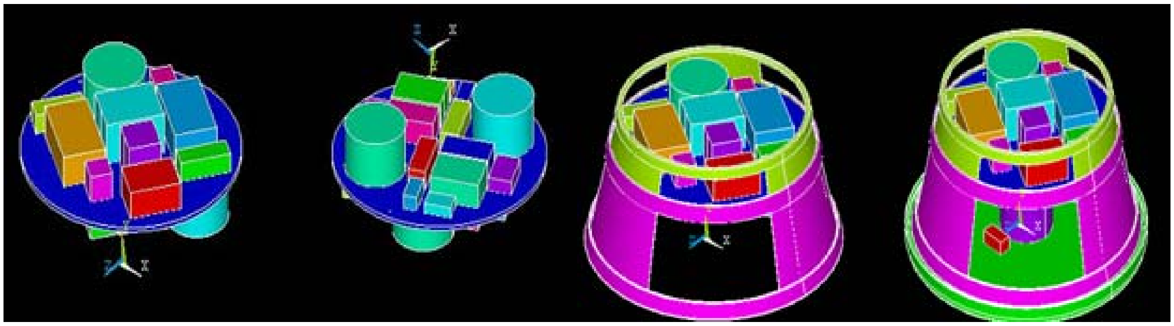
where h_∞ is the coefficient of film assumed for the condition described, equal to $6\ \frac{W}{m^2 \bullet K}$ (Lavrado filho e Machado), T_∞ is the initial temperature of the air, considered 300K or 27°C (Lavrado filho e Machado) and T_w is the temperature of the internal devices

2.2. Construction of geometrical model

The first step was to implement the geometry of the SARA (Da Costa et all, 2007) in the ANSYS software. The geometry was constructed in the software Pro/ENGINEER (Pro/ENGINEER Tutorial, 2008), available at the Institute of Aeronautics and Space - IAE, and was converted to the IGES format and imported into the ANSYS environment (ANSYS Tutorial, 2008). The geometry was divided into 34 volumes, Figures. 2,3.

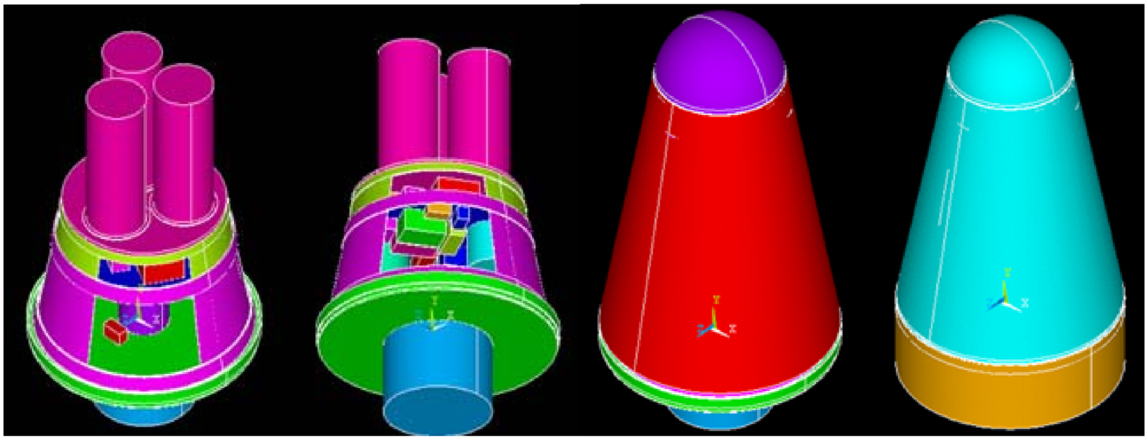
Figure 2 shows the internal environment of the complete SARA Sub-orbital Platform. Figures 2.a,b shows the circular plate and electronic devices assembled. Figures 2.c includes the conical wall and Fig. 2.d shows the second circular plate, with the rest of electronic devices.

Figures 3.a,b show the intermediate plate with the equipment, including the experimental module. Figure 3.c,d show the external wall without and with the protective skirt in the platform's back, respectively.



(a) (b) (c) (d)

Figure 2. Internal volumes of the SARA Sub-Orbital Platform.



(a) (b) (c) (d)

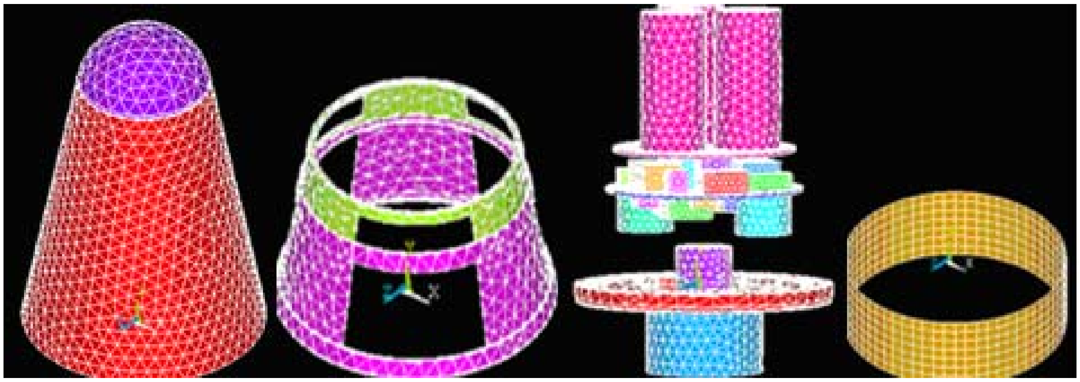
Figure 3. Internal and external volumes of SARA Sub-Orbital Platform.

2.2. Mesh generation:

The discretized model was generated using solid type elements specified as “Thermall Mass”, “Solid70”and shell type elements “Thermall Mass” “Shell57” in the Ansys software. The mesh is shown in Fig. 4. Table 1 shows the characteristics of the mesh used.

Table 1. Characteristics of the mesh used to evaluate the heat transfer in SARA

Volumes modeled as shell elements "Shell57"	4a	4b	-	4d
Volumes modeled as solid elements "Solid70"	-	-	4c	-
Number of nodes of the models	21564	2066	20156	511
Number of Degrees of Freedom of the models	21564	2066	20156	511
Initial conditions of the nodes of prescribed temperature	27°C	27°C	27°C	27°C

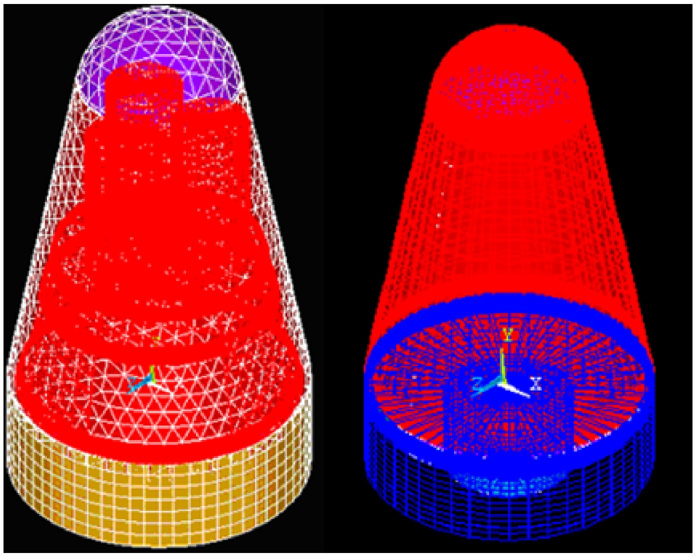


(a) (b) (c) (d)

Figure 4.Configuration of the mesh used to evaluate the heat transfer in SARA

2.3. Boundary conditions:

In the present problem, were considered the heat generation of the internal electronic devices, internal convection with the air inside and the heat transfer by radiation between the outer surface and space, considering a external temperature of 10 K. Figure 5 illustrates these boundary conditions implemented in the model of SARA. Figure 5.a shows the boundary conditions for internal convection applied to the model and Fig. 5.b represents the boundary conditions of heat transfer by radiation between SARA external surface and space.

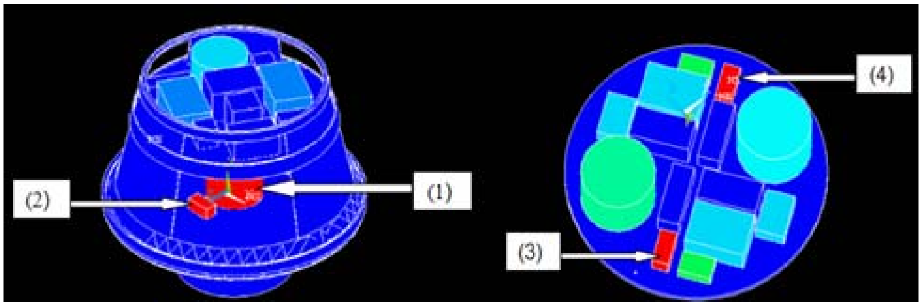


(a) (b)

Figure 5. Boundary conditions applied to model.

3. RESULTS

Figures 6.a.b show the critical points found in the internal environment of SARA Sub-orbital Platform, where the temperature exceeds the maximum limit of 60° C. Tables 2-4 shows the results for three stages of simulation analysis.



(a) (b)

Figure 6. Critical points of SARA internal environment.

Table 2. Results for the initial instant of simulation.

Number of nodes in the model	44297
Number of degrees of freedom in the model	44297
Temperature in the critical point (1)	27°C
Temperature in the critical point (2)	27°C
Temperature in the critical point (3)	27°C
Temperature in the critical point (4)	27°C

Table 3. Results for 2 hours and 14 minutes of simulation.

Number of nodes in the model	44297
Number of degrees of freedom in the model	44297
Temperature in the critical point (1)	76°C
Temperature in the critical point (2)	74°C
Temperature in the critical point (3)	52°C
Temperature in the critical point (4)	52°C

Table 4. Results for 4 hours of simulation.

Number of nodes in the model	44297
Number of degrees of freedom in the model	44297
Temperature in the critical point (1)	119°C
Temperature in the critical point (2)	116°C
Temperature in the critical point (3)	74°C
Temperature in the critical point (4)	74°C

4. CRITICAL ANALYSIS OF HYPOTHESIS

In this work a convection heat transfer coefficient of 6 $W/m^2.K$ (Lavrado Filho e Machado, 2007), what corresponds to the minimum value for natural convection in air. In order to examine whether it is a realistic consideration, the heat exchange by conduction, convection and radiation in two points of the internal environment were analyzed, one of them a point that reached 116°C (one of the critical points) and the other that has reached a temperature of 35 °C. These points were the highest and that lowest temperatures were reached, respectively, excluding the extreme points of higher and lower temperature. Since the convection is most intense heat transfer mode, h_{medium} was calculated for the two points considered. The result confirmed that the film coefficient used is a good approximation.

Initially, gravity was calculated for 300 km from earth's surface:

$$G_r = \frac{R^2}{gr^2} = 91{,}2\% \tag{4}$$

where:

R - Radius of the Earth, 6378.2 km
Gr - Gravitational attraction of the 300 km altitude
r - Distance from the center of mass of the earth to the center of mass of the SARA
g - Gravitational attraction on the Earth's surface

According to the result, gravity at 300 kilometers of the Earth's surface is 91.2% of the gravity of the earth's surface. Considering the gravity of the earth 9.81 m/s^2, the gravity of 300 kilometers of the Earth's surface is 0.912 x 9.81 m/s^2.

At the highest temperature point, temperature is 116° C and air temperature is 27° C, and the average temperature is:

$$t_f = \frac{t_w + t_\infty}{2} = 71\ .5\ °C \tag{5}$$

where:
t_w - Temperature on the point of analysis, ^{o}C.
t_{oo}- Fluid Temperature, ^{o}C.

Table 5. Properties of Air (Incropera and Dewitt 2003).

α (m^2/s)	K (W/m.K)	β (1/K)	Pr	ν (m^2/s)
29.9 x 10^{-6}	0.03	0.0029	0.71	20.92 x 10^{-6}

The number of Grashof is given as:

$$Gr_L = \frac{g\beta(T_s - T_\infty)}{\nu^2} \tag{6}$$

where:
g = Gravity Acceleration at 300Km from earth's surface, m/s^2
β = Volumetric coefficient of expansion, 1/K
ν = Kinematic viscosity, m^2/s
T_s = Temperature of the critical point, ^{o}C
T_{oo} = Air Temperature inside the capsule, ^{o}C

The number of Rayleigh is given as:

$$Ra_L = \frac{g\beta(T_s - T_\infty)L^3}{\nu\alpha} = 3.69x10^9\, L^3 \tag{7}$$

where:
α = Dynamic Viscosity, Pa.s

The number of Nusselt is given as:

$$\overline{Nu_L} = 0.68 + \frac{0.670 Ra_L^{0.25}}{\left[1+\left(\frac{0.492}{P_r}\right)^{\frac{9}{16}}\right]^{\frac{4}{9}}} \tag{8}$$

The heat convection coefficient with the side of the volume is:

$$\overline{h_s} = \frac{k}{L}\overline{Nu_L} \tag{9}$$

$$\overline{h_s} = 8.44\frac{W}{m^2K} \tag{10}$$

The heat loss by convection is:

$$q = \overline{h_s}A(T_s - T_\infty) = 3.76W \tag{11}$$

The heat loss by conduction is:

$$q = \frac{k}{l}A(T_s - T_\infty) = 0.0392W \tag{12}$$

From the results, the heat transfer by conduction is 1.04% of the heat transfer by convection. The heat loss by radiation is:

$$q = \varepsilon\sigma A({T_s}^4 - {T_\infty}^4) = 0.2521W \tag{13}$$

The heat transfer by radiation is 6.67% of heat transfer by convection. Therefore, the heat transfer by convection is more relevant, and the estimated value for the heat convection coefficient is considered valid for this case. Repeating the procedure for the less critical point:

$$\overline{h_s} = 5\frac{W}{m^2K} \tag{14}$$

The heat loss by convection is:

$$q = \overline{h_s}A(T_s - T_\infty) = 0.16512W \tag{15}$$

The heat loss by conduction is:

$$q = \frac{k}{l}A(T_s - T_\infty) = 0.0024768W \tag{16}$$

The heat transfer by conduction is 1,5% of heat transfer by convection. The heat loss by radiation is:

$$q = \varepsilon\sigma A(T_s^4 - T_\infty^4) = 0.01265W \tag{17}$$

The heat transfer by radiation is 7,6% of heat transfer by convection. Therefore, the heat transfer by convection is more relevant, and the estimated value for the heat convection coefficient is considered valid for the internal environment. Considering the film coefficient as the average of film coefficients for the most and the least critical point, the value should be 6.72 W/m^{2}K, what is close to the assumed value, 6 W/m^{2}K (Lavrado Filho e Machado, 2007).

5. CONCLUSION

In this work the commercial software ANSYS was used to simulate the distribution of temperatures in the thermal environment within the SARA Sub-Orbital Platform. Was implemented the inner and outer geometry of the SARA (Entry Atmospheric Satellite) already available in the Space Systems Division (ASE) of Institute of Aeronautics and Space of the General Command of Aerospace Technology IAE / CTA. It was possible to determine the distribution of internal temperatures in the thermal environment of Sub-orbital platform SARA, to determine the effect of heat generation in the structure of electronic equipment and payloads.

The simulation shown that the temperatures kept lower than the limit of 60ºC during most of the time. It was simulated a total time of 4 hours, and after 1 hour and 40 minutes, critical points that exceed the limit of 60 ºC appear. The maximum temperatures reached were 119°C, 116°C, 74°C, 74°C. Such temperatures occurred due to the high power concentration in small volumes and the proximity to other heat sources as well. However, it should be emphasized that all electric power was considered being dissipated. It is a very conservative hypothesis, since due to the high responsibility of electronic equipment they should provide a high efficiency and a small percentage of the energy used is dissipated in the form of heat. Therefore, the temperatures would be less affected in a real situation.

To perform the simulations, a film coefficient of 6 W/m^2K was used (Lavrado Filho e Machado, 2007). The consistency of this approach was demonstrated comparing the fraction of each heat transfer mode for two critical points. It was considered a good approximation, since this value is in the range between the highest and lowest film coefficients within SARA sub-orbital environment.

For future works, is expected to improve the geometric model, generating the geometry of SARA in ANSYS environment, in order to produce a finite element cleaner model and with less number of degrees of freedom. It is also desirable to conduct a review of meshes in order to evaluate the effect of the number of nodes in the time processing and the representativeness of the results.

In the physical aspect of the problem, the phase of the mission in which SARA evaluated, it is the stage is less critical in terms of temperatures reached in the thermal environment of SARA. Therefore it is important to analyze the temperature profile in the thermal environment during kinetic heating, which is the phase that goes from the launching until the entry into the flight. Reentry is the most critical phase of the mission, since it yields a strong heating in the external surface of SARA, and the heating of the internal environment due to the heat generation caused by the dissipation of energy of internal devices.

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