ORBITAL HEATING RATES ANALYZING ON G2-SAT MATERIAL

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ABSTRACT

Analyzing has been carried out on G2Sat body material, one of Mechatronics Division Aerospace Electronics Technology Center-LAPAN Rancabungur projects satellite. The analyzing intends to study whether the G2Sat body material is needed to control or not if it has orbital heating rates, such as using MLI (Multilayer Insulation) and white paint on solar array, based on preliminary thermal design and radiations on G2sat. Its process uses software Thermal Desktop 5.0 using Monte Carlo approach, where a ray is emitted from a surface and the task is to find which surface the ray hits, considering material properties, power, and orbit. The analyzing result such as graphic of absorbed flux distribution during G2Sat experience heating rates shows that G2Sat material is needed to control.

Key words: *Thermal, Orbital Heating rates, Monte Carlo Approach*

ABSTRAK

Telah dianalisa *orbital heating rates* pada material *body* G2-SAT, salah satu program pengembangan satelit di bidang Mekatronika LAPAN Rancabungur. Analisa ini dilakukan untuk mengetahui apakah *material body* pada G2-SAT memerlukan kontrol lebih lanjut seperti pemakaian material pelindung dalam hal ini MLI (*Multy Layer Insulation* dan penggunaan *whitepaint* pada *solar array*) jika G2-SAT mengalami pemanasan di orbitnya. Peralatan yang dipakai untuk menganalisa *orbital heating rates* ini adalah perangkat lunak *Thermal Desktop* 5.0 dengan menggunakan pendekatan Monte Carlo yang terdapat di dalamnya serta dengan mempertimbangkan semua data yang berhubungan dengan *properties* material, *power* dan orbit. Dalam pendekatan Monte Carlo ini berkas cahaya (*array*) dipancarkan dari permukaan sedangkan hal yang harus dilakukan adalah mencari permukaan mana yang terkena berkas cahaya. Selain itu, analisis tersebut dilakukan dengan berpijak dari konsep awal sistem *thermal* satelit yang telah ditentukan serta sumber radiasi panas yang terjadi pada G2-SAT. Hasil yang diperoleh berupa grafik yang menggambarkan besaran distribusi total *absorbed flux* yang terjadi pada G2-SAT *body* selama mengalami *heating rates* di orbitnya. Dari hasil analisa diketahui, sampai di orbit material tersebut memerlukan kontrol *thermal* lebih lanjut.

Kata kunci: *Thermal, Orbital Heating rates, Pendekatan Monte Carlo*

1 INTRODUCTION

G2-SAT is one of Mechatronics Division Aerospace Electronics Technology Center (PUSTEKELEGAN) - LAPAN projects satellite since January 2007. The last status of G2-SAT program has been indicated by the document of Conceptual Design Review (CoDR) of all subsystems satellite including Thermal subsystem. Thermal, one of important subsystems in the G2-SAT intends to maintain all the items of G2-SAT within their allowed temperature limits during all mission phases, subject to a given range of environmental conditions and operating modes including the extreme cold in space and the brutal, unfiltered illumination of the sun.

Strong interaction either directly or not exist between the thermal sub-system and the other G2-SAT sub-systems such as structure, orbit, power, ADCS (Attitude Determination Control System), payload, launcher, Telemetry Tracking and Command (TT & C), and On board Data Handling (OBDH) implying that the thermal engineers need to work very closely and interactively with others in order to develop the most convenient G2-SAT concept. This is applicable from the early definition stage through the end of G2-SAT life time, so that it is needed a long time. In other word, the thermal design drivers include the other subsystems. What is more, the analyzing has to develop and extensively include all subsystem on CoDR document as the basic concept. Although the CoDR document has been published, the review of it is still needed. Reviewing of CoDR document must be including the subsystem itself and the correlation to others. For that reason, a material of G2-SAT suggested by structure subsystem should re-checked if it has orbital heating rates, among athers to further decide whether the material body of G2-SAT needs as thermal control such as insulation material and paint requirement.

Generally the thermal analyzing requires ties to the aero-heating analyzing, the material response analyzing, the orbital analyzing, the structural analyzing, and of course, three-dimensional geometry. This paper will be restricted to calculate and analyzing the orbital heating rates effect of material body G2-SAT considering both the material response and properties, where G2-SAT three-dimensional geometry is not involved all components throughout G2-SAT because the concept layout of G2-SAT has not finished yet (Amundssen Ruth M. Dec, John Lindel MC.). The material body of G2-SAT means it is not only material base on G2-SAT (Al 6061 T6) but also all solar panels (GaAs) that are mounting to four sides of G2-SAT body (G2-SAT teams, 2007). Furthermore, this analyzing is only for maximum beta angle. In addition the G2-SAT model is also trying to view in orbit. Only in analyzing this case will we be computing orbital heating rates using Monte Carlo ray tracing on software Thermal desktop 5.0 (C&R Technologies, 2006).

The analyzing result of this paper is going to make the accurate prediction of G2-SAT temperature as it places in orbit, happened heating. It will be assured us whether material body on G2-SAT is suitable or not if it has orbital heating rates, thermal environment. In other words, the goal of this paper is to describe how the effect of the orbital heating rates, using Monte Carlo approach on Thermal Desktop 5.0, on material body G2-SAT either using both MLI (multi layer insulation) on the outside structure body and paint on solar panels or using base material is; therefore, we can decide to choose the best suitable control of material body G2-SAT, using them or not.

2 THEORY

The important characteristic of space environment is its high vacuum. Satellite is generally launched into orbits where the residual atmospheric pressure, and also drag is very small, but it implies the absence of any significant aerodynamic heating. In the orbit condition, its presence and indeed any convective interaction can be ignored. A satellite in space can interact with its environment only by radiation that consist of direct solar radiation, solar radiation reflected from nearby planets (Albedo), thermal energy radiated from nearby planets (planetary radiation), and radiation from satellite to deep space. The balance condition (thermal equilibrium) will be happened if the sum of the radiant energy received from the first three sources listed above, together with any thermal dissipation within satellite, is equal to the energy radiated to deep space, showing by equation:

$$q\ absorbed + q\ dissipated - q\ emitted = 0 \quad (2\text{-}1)$$

Figure 2-1 shows Thermal radiation Environment for a typical spacecraft.

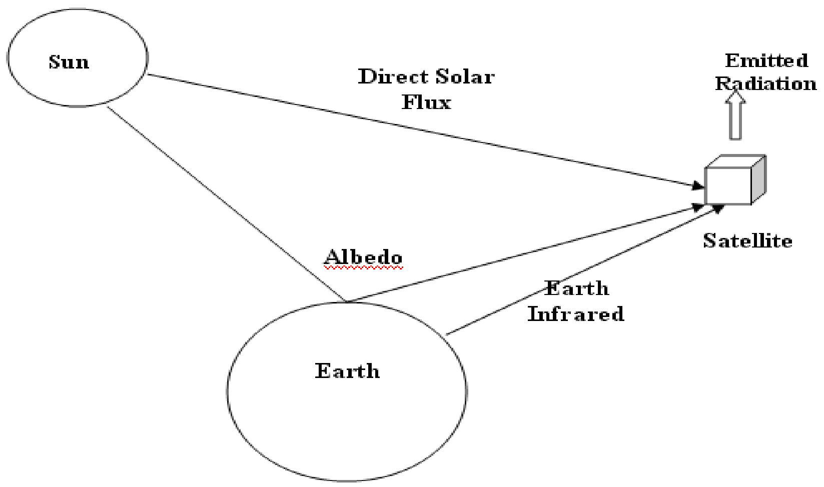

Figure 2-1: Thermal radiation environment for a typical spacecraft

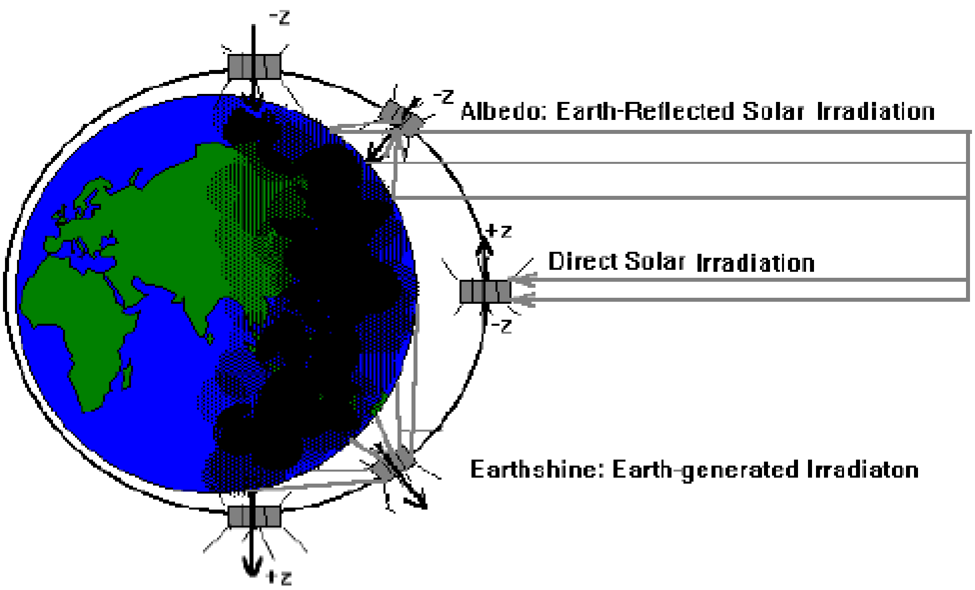

Figure 2-2: Three primary terms of the heat loads for calculating G2-SAT orbital heating rates

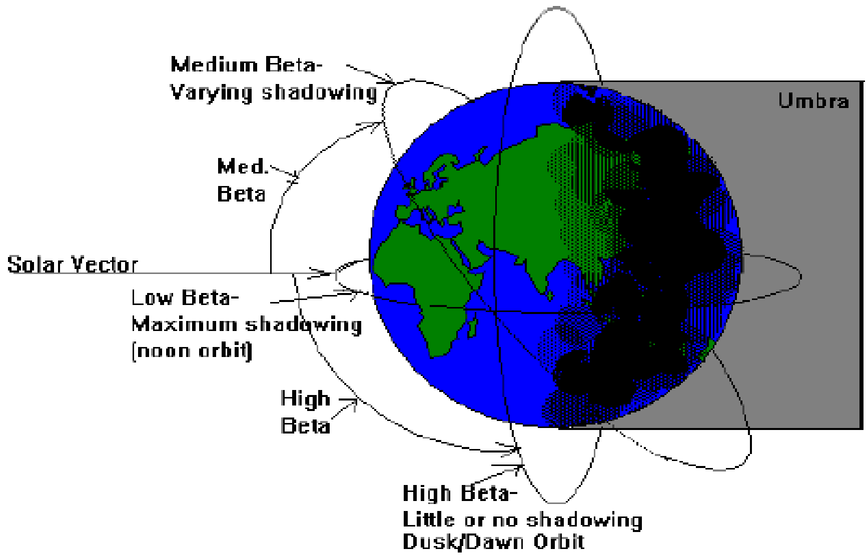

Figure 2-3: Beta angle in orbit duration

The thermal design of G2-SAT has considered five categories of design drivers (G2-SAT teams, 2007). Design drivers include temperature constraints (temperature limits) on components, data acquisition requirement, orbital environ-ments, launch and ascent requirements, and operational conditions. In orbital environments, the driver may change depends on which launch vehicle is chosen. For each orbit condition, G2-SAT must operate within the above specified condition temperature ranges. Spacecraft heat loads must be calculated for each orbit (Transfer orbit, Drift orbit, on orbit (BOL), and on orbit (EOL)). Primary terms of the heat load that shown on figure 2-2 will include solar radiation; albedo and earth generated thermal radiation. Figure 2-2 shows Three Primary terms of the heat loads for calculating G2-SAT Orbital Heating rates. Solar The G2-SAT thermal design must ensure mission integrity in pre-orbital environments including assembly, integration & testing, thermo vacuum qualification, and launch pad – cooling/ heating.

Solar flux radiation happens in four levels. They are Summer solstice (1326 W/m^2), Autumn equinox (1360 W/m^2), Winter solstice (1418 W/m^2), and Vernal equinox (1381 W/m^2). For calculating steady state temperature on a satellite, the average value (1350 W/m^2) is usually been used. Albedo radiation takes from 0.33 of solar flux. Mean while Earth Infrared radiation is set to 258 W/m^2.

One of the main factors for calculating G2-SAT heating rates is Beta angle. Beta angle is the angle between the surface normal and the solar vector. Figure 2-3 shows beta angle in orbit duration.

If Low beta orbit → cold orbit → lowest average solar heating

If high beta orbit → hot orbit → highest average solar heating

Critical beta angle refers to the beta angle at which orbit just grazes the umbra.

Generally orbital heating rates temperature has correlation to steady state temperatures of G2-SAT. It can be used either as input to calculate G2-SAT steady state temperatures or as compa-rator to G2-SAT temperatures that we calculate from other subsystems data. The steady state temperatures equation is shown below (R. Wertz. James. J. Larson. Wiley):

Worst case hot temperature

$$T_{max} = \left[\frac{(A_c.G_s.\alpha) + (A.F.q_{Imax}.\varepsilon) + (A.F.G_s.a.\alpha.K_a) + Q_{dis\text{-}max}}{A\sigma\varepsilon} \right]^{1/4} \quad (2\text{-}2)$$

Worst case cold temperature

$$T_{min} = \left[\frac{(A.F.q_{Imin}.\varepsilon) + (Q_{dis\text{-}min}}{A.\sigma.\varepsilon} \right]^{1/4} \quad (2\text{-}3)$$

Noticed that:

A_c = $\pi.D^2/4$, cross section area of the spherical satellite (m^2)

F = $(1-\cos\rho)/2$, view factor of an infinitesimal sphere viewing a finite Sphere

G_s = Solar flux radiation constant

α = solar absorbtivity of the satellite

A = surface area of satellite

$q1_{max}$ = Maximum Earth IR emission = 258 W/m^2

$q1_{min}$ = Minimum Earth IR emission = 216 W/m^2

ε = IR emissivity of the satellite

a = albedo = 0.33 of solar flux radiation

K_a = a factor which accounts for the reflection of collimated incoming solar energy off a Spherical Earth = $0.664 + 0.521\,\rho - 0.203\,\rho^2$

ρ = the angular radius of the Earth = $\sin^{-1}(R_E\,(H + R_E))$

H = the altitude of a satellite

R_E = The radius of the Earth = 6,378 km

$Q_{dis\text{-}max}$ = Max power dissipation

$Q_{dis\text{-}min}$ = Min power dissipation

σ = Stefan-Boltzmann's constant = $5.67 \times 10^{-8}\ W/m^2.K^4$

2.1 Monte Carlo Approach in Thermal desktop 5.0[2]

Monte Carlo approach is one of techniques in software Thermal desktop 5.0 for computing radiating, dialog box factors, and heating rates. Principally in this approach, rays are emitted from each node and "traced" around the geometry. The rays simulate the effect of a "bundle" of photons. When a ray strikes another surface, energy is decremented from the ray and absorbed by the struck surface. The ray is then reflected or transmitted, according to the optical properties on the surface. Time to solve models grows exponentially with model size (geometry).

Generally process can be shown: First of all, we should build G2-SAT three-dimensional geometry using Auto cad program. For this time the G2-SAT three-dimensional geometry is not including all components because the lay out of structure has not finished yet. Then, its geometry we give pre-input, either both body material base (Al) and solar panels material (GaAs) or together with optical materials, MLI and paint. Next step, we manage orbit, using all data (beta angle, orientation, altitude), then we set three primary terms of the heat loads. Finally, software thermal desktop 5.0 is ready to be running to calculate orbital heating rates what will happen on G2-SAT body.

3 ANALYZING METHODOLOGY

The overall orbital heating rates analyzing process is shown in figure 3-1. G2-SAT trajectory, material and thermo physical properties, geometry, radiation heating, and orbit data are all incorporated in G2-SAT Thermal modelling. G2-SAT thermal analyzing is done with thermal desktop 5.0, and temperatures are passed to orbital heating rates analyzing of G2-SAT using Monte Carlo approach in thermal desktop 5.0.

The three dimensional G2-SAT geometry modelling is not showing all components throughout G2-SAT body. It has been only shown general layout of G2-SAT. At this moment a cubic shape is the best shape for G2-SAT structure (G2-SAT teams, 2007). In fact, a cubic shape is easier to be manufactured, easier to manage space for satellite component, better to give good stabilization. Lay out the structure concept of G2-SAT is shown in figure 3-2.

The material G2-SAT and optical material can be used as pre-input in geometry G2-SAT as it will be processing orbital heating rates using thermal desktop 5.0. Material G2-SAT, base body material and solar panels material, can be using together (all incorporation) or not with optical material, Kapton Alumized and paint, to get comparation result. What is more, G2-SAT trajectory, orbit data (beta angle and altitude), and G2-SAT radiation are all incorporated as input as we are going to run software thermal desktop 5.0 to get final calculation orbital heating rates.

Based on CoDR document (G2-SAT teams, 2007), the beta angle is choosen for maximum condition, 34° with altitude 778 km. Notice that we use maximum beta angle to get highest average solar (sun). Base body material of G2-SAT is using Al 6061 T6 (thickness = 10 mm), and Solar panel material is using GaAs. We set attitude of G2-SAT to Sun oriented (viewing from sun). In addition thermal control system of G2-SAT body is set to both using white paint material in solar panel and using kapton, Alumized, 2mm with ITO (Indium Tin oxide) coating as MLI material heating.

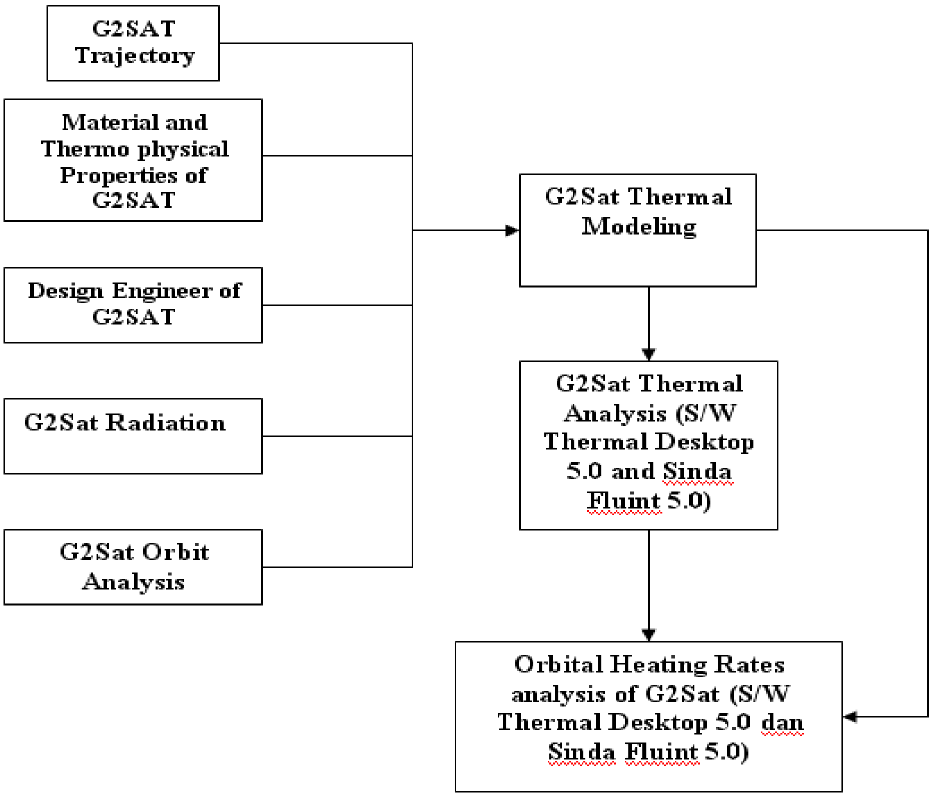

Figure 3-1: Orbital heating rates analyzing process of G2-SAT

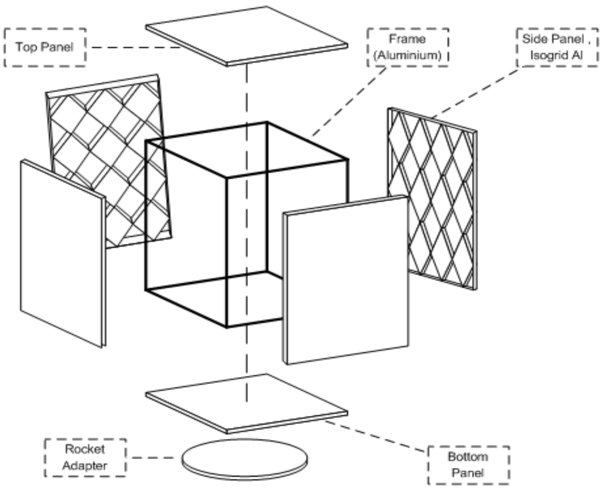

Figure 3-2: Lay out the structure concept of G2-SAT[1]

Mean while we use some assumptions as input as running software thermal desktop 5.0. First of all G2-SAT is set in steady state and isothermal condition. MLI thickness is set 2mm, and GaAs sets 2 mm. Orbit position scale input is 3, and Solar shadow field is 1. What is more, heating rate position input is 0 (real position), and we set solar panels using 4x7 array.

Unfortunately in Monte Carlo approach we will have some errors if many parameters are being computed. This happens because arrays in direct components are not reflected since the reflected components are derived from the view factor matrix.

4 RESULT AND DISCUSSION

After running using thermal desktop 5.0 we get prediction of orbital heating rates on G2-SAT body. In this case the G2-SAT model is running in steady state condition in order to quickly evaluate the effect of the orbital heating rates on G2-SAT material body, both base material (Al 6061 T6) and Solar panels material (GaAs). Once condition we set G2-SAT body is only using Al 6061 T6 and GaAs (**case 1**), another we set using them plus MLI material (for all G2-SAT body) and paint for solar panels material (**case 2**). For getting the result we use software thermal desktop 5.0 using Monte Carlo approach. Because so many parameters are being computed, the result for four sides of G2-SAT body consists of many colors for (figure 4-2 A and B). According reference 2 the result is still acceptable because the total values for all node, shown by all colors in all G2-SAT body, is above 95% of the total sum for listed each node.

In figure 4-2 A the total values for all node = 190.9 + 199.2 + 207.5 + 215.9 + 224.1 + 232.4 + 240.7 + 249.1 + 257.4 + 265.7 + 274 = 2158.5 W/m^2 (Pink and Dark red color are not in the listed because they are not are shown by the color result).

The total sum for listed each node = the total values for all node + < 190.9 + > 274

% the total values for all node of the total sum for listed each node = ~ more than 95 %.

Therefore, the result is still acceptable.

In figure 4-2 B the total values for all node = < 4.164 + 4.164 + 19.44 + 34.71 + 49.99 + 65.26 + 80.54 + 95.81 + 111.1 + 126.4 + 141.6 + 156.9 = 885. 914 W/m^2 ((Pink is not in the listed because it is not shown by the color result).

The total sum for listed each node = the total values for all node in figure 4-2 B + > 156.9

= ~ more than 95 %

Therefore, the result is still acceptable.

First of all, the result starts to show orbit orientation. Both conditions (cases) have the same result. Figure 4-1 shows this result with orbit positions 180°.

Next step, we start to calculate orbital heating rates of G2-SAT body. This result is shown by both figure 4-2A and 4-2B where Figure 4-2A shows orbital heating rates of viewing for all G2-SAT body, and figure 4-3A and 4-3B shows its calculation from back-right.

From figure 4-2 and 4-3, we know that total absorbed flux (SAP) for case 2 is lower than case 1 is. Range total absorbed flux for case 1 starts (> 190.9) to (>274); indeed, range in case 2 starts (< 4.164) to (>156.9).

Figure 4-2 A and 4-3 A (case 1) show that the total values for all node is 190.9 + 199.2 + 207.5 + 215.9 + 224.1 + 232.4 + 240.7 + 249.1 + 257.4 + 265.7 + 274 = 2158.5 W/m^2 (Pink and Dark red color are not in the listed because they are not are shown by the color result).

Figure 4-2 B and 4-3 B (case 2) show that the total values for all node is < 4.164 + 4.164 + 19.44 + 34.71 + 49.99 + 65.26 + 80.54 + 95.81 + 111.1 + 126.4 + 141.6 + 156.9 = 885. 914 W/m^2 ((Pink is not in the listed because it is not shown by the color result).

This result absolutely shows that total absorbed flux (SAP) for case 2 is lower than case 1 is.

Lower absorbed flux has been received, lower orbital heating rates will happen; therefore, material will be safer in brutal condition in space (hottest condition). If we link the result above to Eq. (2), the lower total absorbed flux (SAP) will decrease the hottest temperature: that is, component is saver in brutal condition (q_1 decrease ➔ T max decrease). For that reason, the material body of G2-SAT needs as thermal control as insulation material and paint.

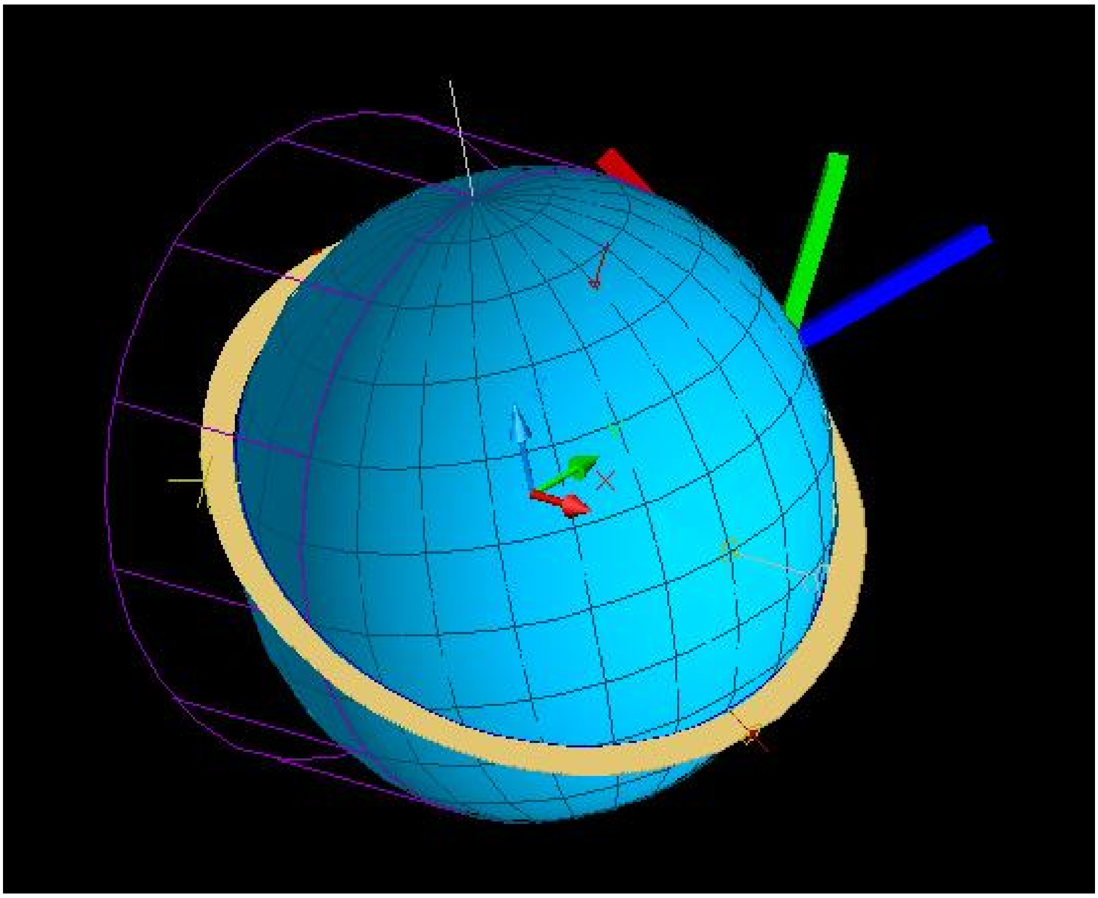

Figure 4-1: Orbit positions 180° of both cases

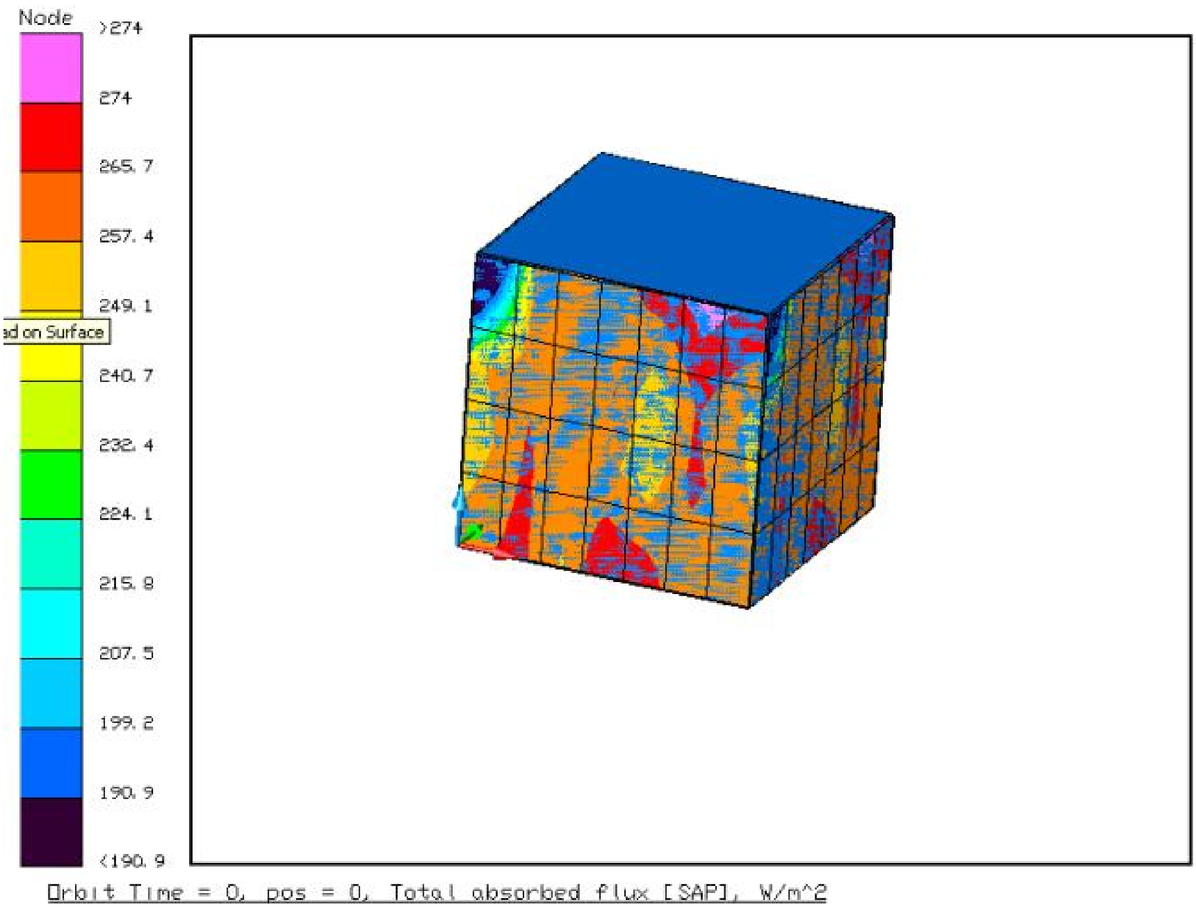

Figure 4-2A: Orbital heating rates case 1 for all G2-SAT body

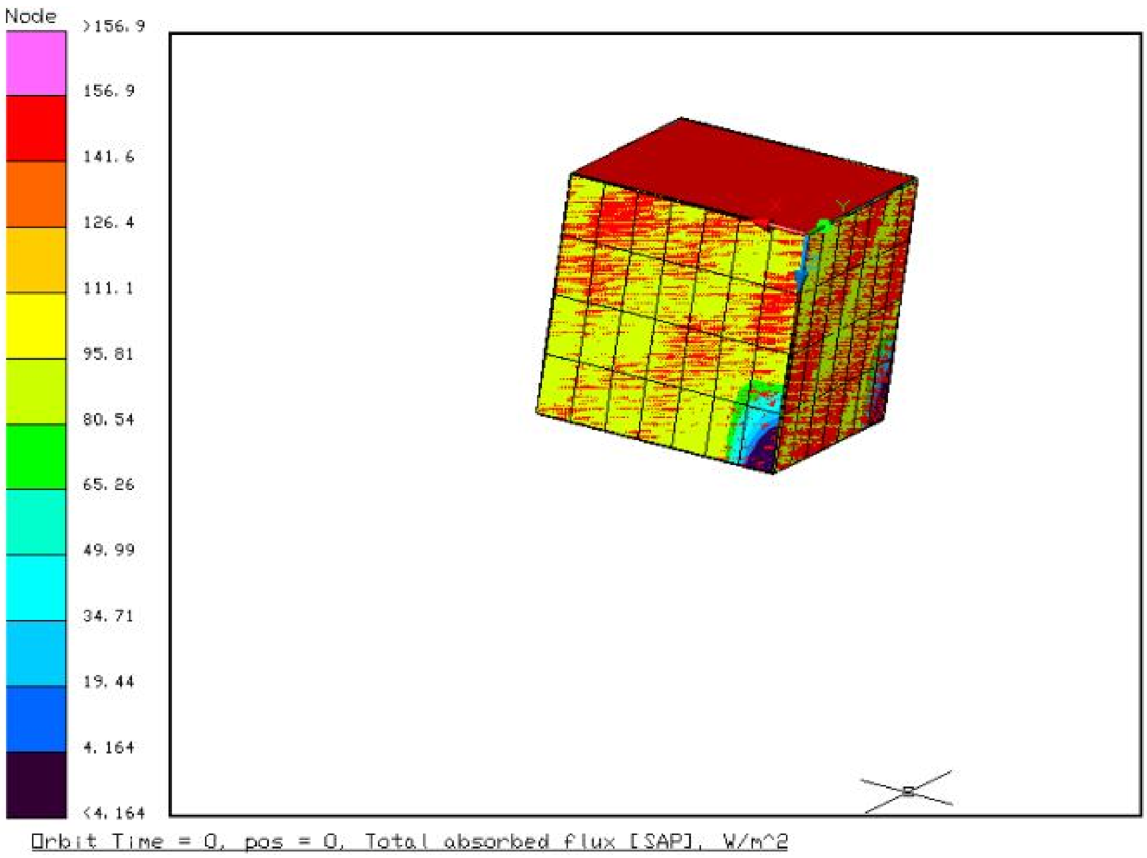

Figure 4-2B:Orbital heating rates case 2 for all G2-SAT body

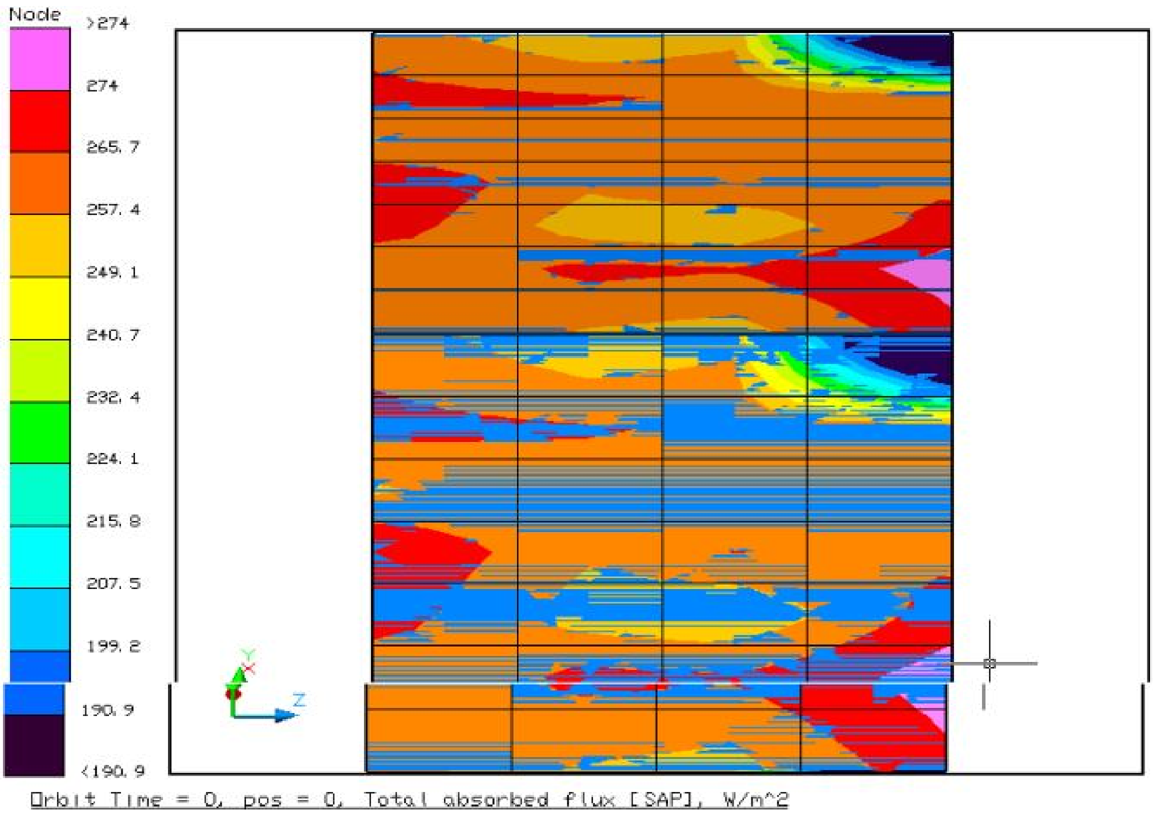

Figure 4-3A:Orbital heating rates case 1 from back-right view

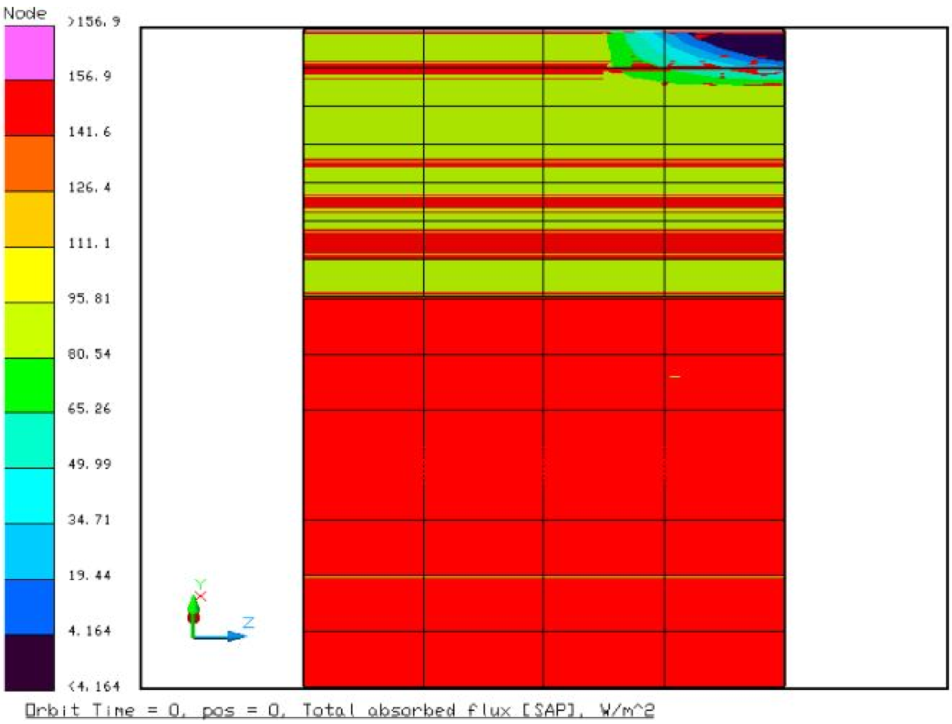

Figure 4-3B:Orbital heating rates case 2 from back-right view

5 CONCLUSIONS

The analyzing had been done for case 2, using MLI and paint, showing that it gave lower total absorbed flux. It means that lower temperature will be happened in brutal condition. Figure 4-1 and 4-2 state it clearly. Therefore, we suggest all G2-SAT body should be insulated using MLI material, Kapton Alumized, 2mm with ITO (Indium tin oxide) coating to prevent electrostatic discharge and associated EMI problems. Furthermore, the rears sides of solar panels should be paint with low α/ε to keep the solar cells cool for maximum efficiency. In other words, the material body of G2-SAT is needed to control, both using MLI and paint; that is, the hottest temperature of G2-SAT body will be lower. It makes all components through out G2-SAT body will operate within their allowed temperature limits during all mission phases.

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