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Research Article

Thermo-orbital analysis of STUDSAT-2, A Twin Nano satellite

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Abstract

Small satellite's are now paving way for the students to explore and demonstrate cutting edge technologies, prove the same and implement it on bigger satellites. Thermal control plays a major role in satellite development due to the harsh temperature conditions it is subjected to in space. It has to be considered in order to have the smooth functioning of the satellite, this paper describes the thermal environment for a Twin Nano Satellite named STUDSAT-2.

Keywords: *Albedo, Beta angle, Declination, Eclipse angle, Inclination, Right ascension.*

1. Introduction

In our terrestrial environment or in laboratories, temperature is often regulated naturally. But Satellite environment in orbit is completely different. Good temperature control within a satellite is the most important parameter for the success of the mission. The requirements for thermal control may include a function and a survival temperature range, which, if exceeded, may have a reduced performance and/or permanent damage to the components which may result in failure of the mission. Electrical and electronic devices will not work properly or may have a shortened life span if they overheat. Battery efficiency reduces if the temperature is not within the limited range.

This means that thermal conditions are very particular and likely to cause dangerous changes in temperature if not taken care. Optimum temperature can be maintained only by applying scientific method and specific thermal control technology.

STUDSAT-2, a twin Nano satellite which will be placed at an altitude of about 700km is bound to be subjected to extreme temperatures ranging from -100° to +150°c.

Hence thermal analysis of STUDSAT-2 will pave a way to understand how the external environment can affect the satellite. Throughout the mission each component is maintained at a temperature within the operational temperature range as specified by the data sheet of each component. Thermal system is always a combination of power system, Orbital dynamics and Mechanical system.

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2. Space Environment

Space environment is very harsh and it should be monitored to help ensure satellite's health and to minimize outages. The factors to be considered for thermal control in space are vacuum, microgravity, radiation, severe temperatures etc. Hence these should be considered during the design of the satellite for a smooth operation of the mission.

3. The Atmosphere

In Low Earth Orbit, ranging 600 km-2000km, the density and the pressure are very low; the figure shows that the atmospheric pressure depends on altitude. It can be seen that at 600km altitude, the pressure is approximately $6*10^{-38}$ bar, hence vacuum can be assumed here.

The density is also dependent on the altitude; hence the density is to be determined. Below figure shows the air density as a function of altitude.

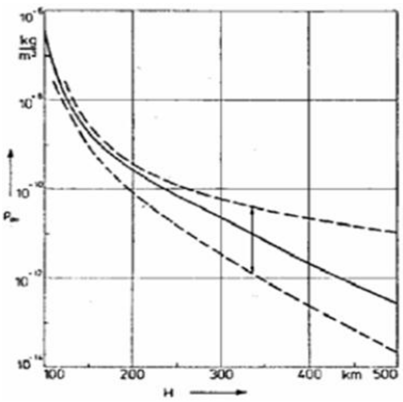


Fig. 1 Variation of pressure with altitude

To calculate the pressure as a function of altitude and temperature, the following relation is used:

$$P = p^{-gmh/RT}$$

Where,
p.-sea level standard atmospheric pressure-1.01325 bar
T.-sea level standard temperature-(288.15 K)
g-earth surface gravitational –(9.80665m/s2)
M-molar mass of dry air-(0.0289644kg/mol)
R-universal gas constant –(8.31447J/mol.k)

4. Pressure density at different altitudes

S.No	Altitude	Pressure(bar)	Density(kg/m3)
1	600	6.03219e-38	9.89e-14---8.46e-13
2	650	4.7683e-41	4.73e-14---4.77e-13
3	700	3.76937e-44	2.316e-14—2.73e-13)
4	750	2.97965e-47	1.24e-14--1.59e-13
5	800	2.35538e-50	6.95e-15—9.41e-14

5. Temperature

The temperature in space is 4K. This radiation environment causes extreme temperature variations in the satellite's outer skin. Thus the outside layers of the insulating blankets can reach temperature of 100^0C when it is facing the sun and drop to around -100^0C in the eclipse region.

For the satellite to function, the internal components need to be maintained within the optimum temperature range. Thermal balance inside the satellite is very essential for the smooth working of the satellite.

Different components have different working temperature ranges , the following factors were considered while designing thermal system.

1. Operating temperature range: considering the maximum and minimum temperature limits between which components reliably meet their specified operating requirements.
2. Turn-on temperature: The maximum and minimum temperature limits between which components can turn on without undergoing any malfunction.
3. Non-operating temperature range: The maximum and minimum temperature limits enclosed within which the components are qualified to remain functional while in a power off mode, and eventually work as required in the turn-on mode and all necessitate operating modes.

So thermal control or thermal analysis is going to play a very vital role in maintaining the temperatures in and out of the satellite for the complete successful mission.

6 .Orbital parameters of STUDSAT-2

The satellite is injected into sun- synchronous orbit with an inclination of 98^0 and at an altitude of 600-700km.As the orbit plane of a sun-synchronous orbit is at a nearly fixed angle relative to the sun, this results.STUDSAT-2 is designed for a nearly circular orbit with eccentricity of the orbit nearly equal to 0.

In LEO, there is parameter to define orbital thermal environment called orbital beta angle, in LEO it can vary from -90^0 to 90^0. It is the angle between the orbital plane and the solar vector. Hence it is clear that the beta angle can be taken into account while calculating the heat received by the satellite. Mathematically it can be defined as

$$\beta = \arcsin(\cos\delta.\sin i.\sin(\alpha - \alpha s) + \sin\delta.\cos i)$$

Where β= beta angle
α= right ascension of ascending node
δ= declination of the sun
αs= right ascension of the sun
i= orbit inclination

The STUDSAT-2 beta angle varies from +20 to -21^0. The variation of the beta angle over a year is given below. **Beta angle versus day number** over a period of one year

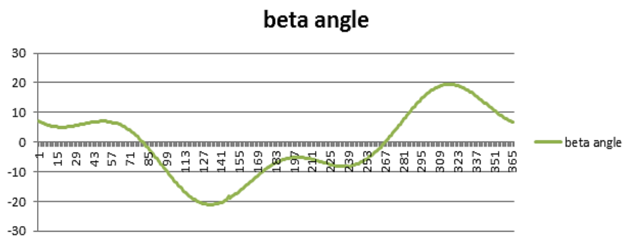


Fig. 2 The variation of beta angle for a year

7 .Orbital revolution of STUDSAT-2

The duration of a satellite is very important and it influence the thermal design of the satellite. The orbital duration will be calculated mathematically by the formula.

$$t_u = \frac{\sqrt{4\pi^2}}{\gamma.M}a^3 \quad = \quad 98.30\text{min}$$

In its total time of revolving, it will come across 2 regions namely sunlit region and eclipse region. The eclipse region is nothing but the satellite travelling in the shadow region of the earth, it is very important to study the thermal characteristics in these regions to make the satellite more reliable.

The approximate eclipse duration of the satellite in a circular orbit that passes the Earth's shadow region represented by the circular orbit (β=0) can be calculated mathematically using the relation

$$\frac{t_u}{t_e} = \frac{360}{2\propto}$$

Where

$$\alpha = \arcsin\left[\frac{\sqrt{\frac{R_e}{R}^2 - \sin^2\beta}}{\cos\beta}\right]$$

a=R=for circular orbits= R_e+H
M=mass of earth= $5.97*10^{24}$ kg
H= 700km,

For an orbit with 700km and β=0, STUDSAT-2 completes one revolution in t_u in 98.65minutes. For two-third of the orbital period, t_E=63.415min, the satellite is in sunshine and its surface gets hot, while for 35.234min it is in the earth's shadow and cools down. Depending on this continuously changing environment a very specific and carefully designed thermal control system is required.

Here is a plot **of eclipse time in min to day number over a year**, which will vary from 34.1min to the 35.3min.

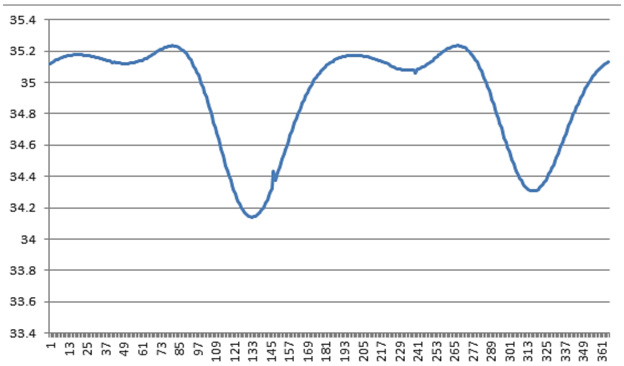


Fig. 3 Variation of eclipse region for a year

8. Heat Transfer

Fundamentally there are 3 modes of heat transfer mechanisms

1. Convection
2. Conduction
3. Radiation

Due to very low density of the atmosphere at the orbital altitude of 700 and because of the micro-gravitation, there are no mass or particles for the convection process. The temperature in space is 4K, hence there is no energy transfer between hot and cold areas due to convection. Conduction within the satellite is to be accounted as they are in contact with each other's. Radiation doesn't require any medium to transfer; hence there will be radiation effects on the satellite.

9. Heat Inputs to the Satellites

As the satellite is revolving at an altitude of 700km, there will be different types of heat inputs to the system, those are

1. Direct sun rays(sun shine)
2. Albedo
3. IR rays
4. Moon shine

The direct sun rays: It's received by the satellite from the sun rays and adds to certainly a large magnitude of heat input to the satellite depending on the side facing it.

Albedo: The view factor forms the most crucial point of the albedo heat inputs. The fraction of incident sunlight that is reflected off a planet is termed as albedo. Besides the relationship between IR absorptivity equal to its emissivity (αIR = €IR), Albedo is the reflected rays illuminated by sun side of the planet facing the respective sides of the satellite. View factor with respect to earth for 135 degree is 0.515 and for 90 degree is 0.829.

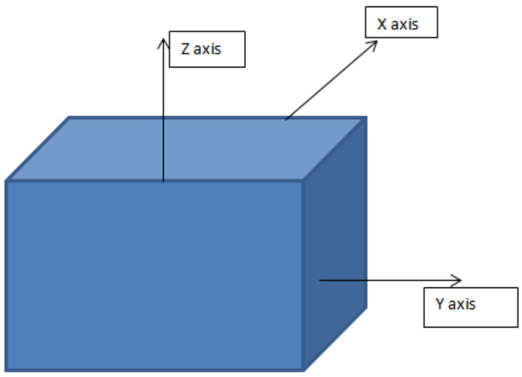
IR rays: Also known as planet flux, the origin of these rays are earth infrared radiations. The earth re-emitted thermal radiation has a spectrum of black body with properties of average temperature of 288K.The earth IR rays varies across the globe but considerably lesser than Albedo. Here assuming earth to be a completely a black body we calculate the IR.

10. Radiation

Radiation is the transfer of energy through the emission and absorption of photons or propagation of electromagnetic energy between surfaces separated by scattering media or even through vacuum, so there is no matter displacement, heat transfer takes place by reflected, absorbed or transmitted photons on surrounding bodies. Radiation doesn't require any medium to transfer; hence there will be radiation effects on the satellite for the transfer of heat.

11. Nomenclature for Thermal Analysis

1. +ve x
2. –ve x
3. +ve Y
4. –ve Y
5. +ve Z
6. –ve Z
7. Deployable panels.



12. Boundary Conditions (Matlab simulations)

In this simulation heat fluxes on each face is calculated. Simulation is done for one complete rotation of satellite around the earth using the MATLAB simulated mathematical model.

13. Worst Hot Case

By considering the following conditions worst hot case scenario is evaluated.

1. Direct sun rays is maximum (1416W/m^2)
2. Albedo is taken as 0.35
3. IR is constant
4. Sun inclination angle beta is zero.

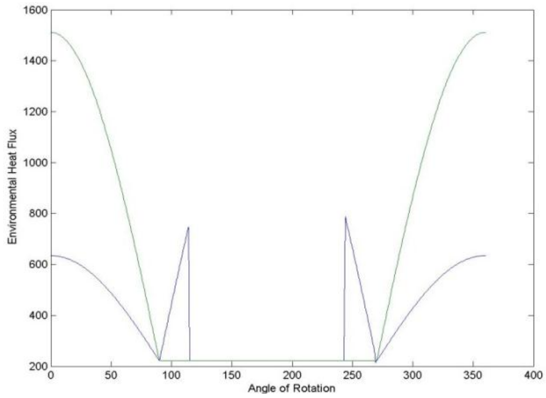


Fig. 4 Nadir and zenith faces, green curve indicates zenith and blue indicates nadir pointing.

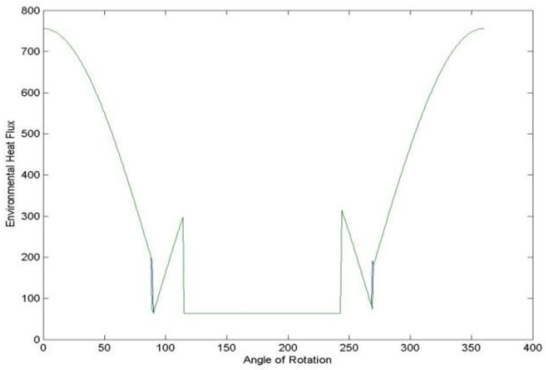


Fig.5 +ve and –ve Y face

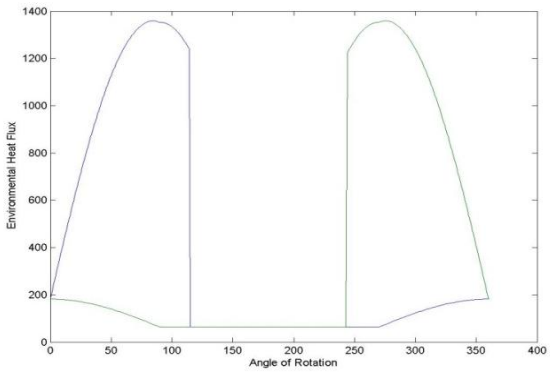


Fig. 6 Blue line indicates the +X face and green showing –X direction

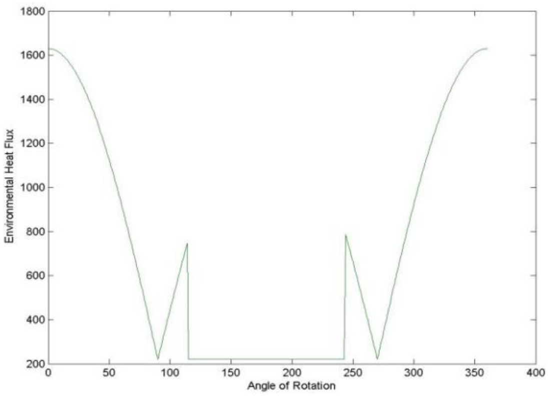


Fig .7 Deployed solar panel face

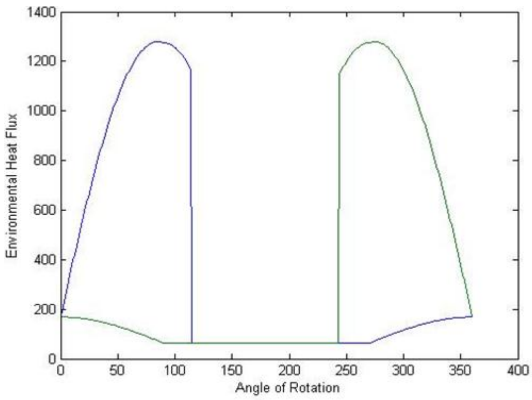


Fig. 8 Nadir and zenith faces, green curve is for zenith and blue is for nadir

14. Worst Cold Case

By considering the following conditions worst cold case scenario is evaluated. And mathematically modeled in MATLAB.

1. Direct sun rays is minimum (1316W/m^2)
2. Albedo is taken as 0.30
3. IR is constant

Sun inclination angle beta is 20^0

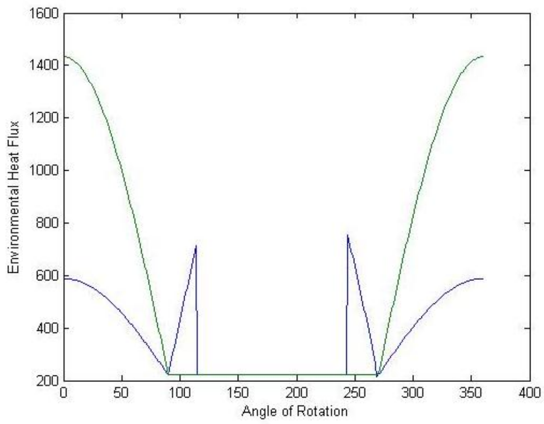


Fig. 9 +ve and –ve X face

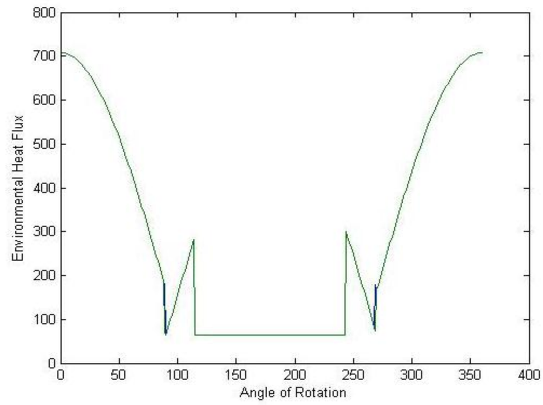


Fig. 10 +ve and –ve Y face

15. Results Observed

More heat is concentrated in the +ve X axis, -ve X axis and +ve

Z axis, Very less heat is concentrated in Y axis.
Moderate heat is concentrated in –ve Z axis.

Conclusion

Depending on the above obtained thermal environment, the thermal system has to be designed for the small satellite, By knowing the internal power dissipation, the balance of the thermal system can be done.

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