Optical Solar Reflector Degradation Analyses Defining Test Parameters for In Orbit Space Use

Marcos Galante Boato, Centro de Educação Tecnógica Paula Souza, CPS
marcos,boatto@gmail.com.
Ezio Castejon Garcia, Instituto Tecnológico de Aeronáutica, ITA, ezio@ita.br.
Francisco Carlos Cione, Instituto de Pesquisa Energéticas e Nucleares , IPEN,
fceoni@hotmail.com.
Mauro Machado de Oliveira, Instituto Federal de São Paulo, IF-SP, mauromach@gmail.com.

Abstract – Optical Solar Reflector (OSR) is a thermal control material used in almost all space satellites. An alternative material to be used in the special program was also developed by a Brazilian scientist team. The OSR is a passive radiator that could be applied as a coating outside of space environment walls to insulate the heat generated within the satellite. This type of radiator has a low absorptivity in the solar spectrum (α_s) and a high emissivity in the infrared spectrum (ε_{IR}). However, the degradation of OSR caused by the space environment increases the demand and consequently reduces the efficiency of the radiator. This design offers an experiment OSR developed by National Institute for Space Research to be tested in orbit, among other objectives, to measure their degradation when exposed to the space environment. The experiment when exposed to solar radiation will be temperature monitored. In fact, the solar radiation (α_s) variation will be found as a function of the increase of the OSR degradation over time. An analysis using the mathematical program SINDA/FLUINT was made in order to determine the relationship of increased temperature radiator with increasing the α_s. This article presents the results of this exploratory analysis and the conditions of experiment viability.

Keywords: Optical Solar Reflector, Solar Absorptivity , Infrared Emissivity, SINDA/FLUIT.

I. Introduction

A proposal for an embedded degradation experiment in a Brazilian satellite has been developing by Aeronautics Institute of Technology (ITA) with the collaboration of National Institute for Space Research (INPE).

This research from National Institute for Space Research (INPE) claim to have accomplished a new modified material for Brazilian OSR. The functionality of the passive thermal control is performed when it is added to certain parts of the external surface of the satellite. The OSR material works as a heat rejection radiator.

The OSRs are bonded in appropriate areas of external surfaces of the satellite structure with space applications silicone adhesive. The potential areas to apply the OSR are indicated on Fig. 1.

Fig.1. Example of potential areas to apply the OSR.
Photo of China-Brazil Earth Resources Satellite (CBERS).

The integration of satellites in Brazil commonly uses a special white paint as radiator. Despite the small cost it has a low rate of $\alpha_S/\varepsilon_{IR}$, which increases over time due the degradation caused by the space environment. These variations of $\alpha_S/\varepsilon_{IR}$ ratio also enhance the satellite internal temperature.

Engineers develop a larger radiator to comply with the end of life of satellites that are exposed to hot cases as a way to compensate losses by degradation in efficiency. In other hand the consequence of radiator over sizing is necessary to use electric heaters. As temperatures are lower at the beginning of an OSR's life, is mandatory their full operation to keep temperatures suitable. When satellite’s life-end the internal temperatures tends to rise what may cause problems in the functioning of its payload.

The replacement of the white paint by the OSRs is a good alternative, once this coating is a second surface mirror with high thermal optical quality and presents a negligible degradation of the $\alpha S/\varepsilon IR$ rate during the space exposition time.

Therefore, the OSR radiator should have the size reduced whether compared to the conventional white paint reflector size, reducing any necessary dissipation in case of heaters for early life. This action decreases the dissipation required and directly affects the electric energy consumption of the satellite.

II. OSR Description

The OSR is basically a second surface mirror. It is a cover layer of thin silver film with high quality glass properties deposited on the surface. High emissivity ε in the infrared spectrum is related to the cover glass coat that is transparent at the solar wavelength and opaque in the infrared spectrum below 4.5 µm (MARSHALL e BREUCH, 1968).

When compared with others passive solar reflectors this OSR presents very low thermo-optical properties degradation in the presence of atomic oxygen, protons, free electrons, and ultraviolet radiation. Unique properties degradation factor is related to volatile organics, which are generated from the outgassing of internal components and produced by propellers of the space-vehicles (GILMORE, 1994) e (MARSHALL e BREUCH, 1968).

The doped borosilicate glass with Cerium used to manufacture the OSRs has 120 µm thickness, 20mm wideness and 40mm long. To make the adherence of silver deposition more efficient three types of interfaces were deposited in the cover glass, namely, Cr or MgF_2 or Al.

The OSR is fixed on the satellite’s structure with a silicone-based adhesive, ensuring that the assembly has a large mechanical flexibility to resist differential expansion between these coatings and the satellite’s structure due to the temperature gradients found in the space environment.

III. Theoretical part of the degradation of OSR

The full temperature interaction over satellite-environment occurs only by radiation, there is a large dependence of the temperature function and thermal coating properties, and these commonly known as a radiator, is a material which has good properties of emissivity and absorptivity.

A radiator material coating is considered good thermal control if it has a high emissivity in the infrared spectrum (ε_{IR}) and low absorptivity in the solar spectrum (α_S), which is a low ratio $\alpha_S/\varepsilon_{IR}$.

In thermal control of satellites is used the following convention: the emissivity indicates the property in infrared and the absorptivity indicates property in the solar, that means, in infrared the surface radiates and absorbs proportionally to ε_{IR} and in solar, the surface absorbs proportionally to α_S.

The OSR is manufactured with thick fused silica usually it does not degrade the absorptivity and emissivity properties of the high energy particle attack, ultraviolet radiation and other elements present in the space environment. However, degradation occurs derived of contaminants stemmed by outgassing from volatile organic which are exhausted of the satellite or from rocket engine in positioning satellite stage (GILMORE, 1994) e (VILELA e GARCIA, 2014).

The degradation mechanism is not well known, but it is has guaranties that this effect causes the increase in absorbability in the mirror type radiators. What is known is that volatile organic, outgassing, are deposited on the mirror surface, and by photochemical effect, end up sticking on the surface of the mirrors and leaving blackened.

The blackening effect increases the opacity of the glass, the band of visible light, so that there is an increase in α_S (BOATO et al, 2015) e (STEWART et al, 1990).

IV. The Experiment

Degradation presented in this experiment will be studied in a space environment and the data obtained from this experiment will be quantified indirectly, because the only data to be collected are the temperatures of the sample.

The measured temperatures can be linked to degradation of the OSR. The reason relies at the material suffers degradation and its thermal-optical properties are harmed raising therefore the temperature.

IV.1. Experiment Requirements

The correlation between degradation and the increasing of temperature implies on the necessity of insulation, as much as possible the representative sample of satellite did. The showed requirements were demanded:

- Fix the sample, which must be screwed on the outside satellite's surface;
- The platform must be isolated of the external environment to not suffer any external temperature influence;
- The sample fixed on the platform must be isolated of satellite;
- The sample should be exposed to the external environment.

IV.2. Experiment Results Characteristics

The main features of this experiment were:

- The OSR was fixed on a platform made of Polytetrafluoroethylene (PTFE).
- The platform was entirely covered with Multi Layer Insulation (MLI), excluding OSR, to isolate as much as possible, the external environment and the satellite itself (GILMORE, 1994);
- The OSR was bonded on an aluminum plate which was attached to the platform;

- On the other aluminum face was fixed a thermistor and a heater skin. The thermistor reads the temperature and the skin heater maintain the temperature of sample more stable;
- A connector was used to connect the heater skin and the thermistor to the satellite wiring.
- The heater power was set at 0.7W
- The total mass of the experiment was 204 grams.
- The OSR absorptivity was 0.03 and the emissivity is 0.8 (BOATO, 2014)

The FIG. 2 shows a schematic experiment drawing.

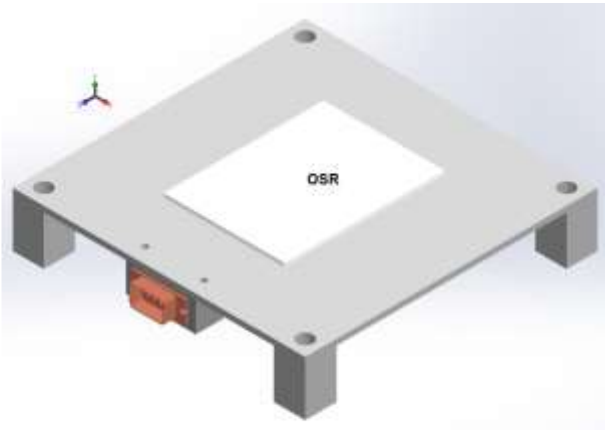

Fig. 2. Experimental design installed on the external side of the satellite.

V. Mathematical thermal design

The modeling SIND / FLUIT® program was used for the mathematical analysis of the thermal functions. The thermal design was based on a nodal calculation method and each node is assumed to be isometric.

Each node interacts with others by conduction and radiation, as occurs by space radiation. Therefore the temperatures obtained of each node were results of the interaction between nodes and the space (SILVA et al, 2014).

The equation of energy balance was used as a base of the calculations governing this system. Eq. 1 explains the exchanged energies for each node.

$$m_i Cp_i \frac{dT_i}{dt} = \sum_{j=1}^{n+1} R_{ji}\sigma(T_j^4 - T_i^4) + \sum_{j=1}^{n} B_{ji}(T_j - T_i) + Q_i$$

(1)

$$i = n+1$$

Where;

Thermal mass is $m_i Cp_i$ [J/K];

The external loads are Q_i [W], while internal heat dissipation is Q_D [W];

The conduction and radiation exchange factors are represented by Bij [W/K] and Rij [m- ²], respectively. The Stefan-Boltzmann constant is σ [W/m²/K4], and Ti and Tj [K] are the temperatures of nodes i and j, respectively;

The first term of the equation is the internal energy variation of the node;

The second term is the sum of the heat exchanged by radiation with the other nodes.

The third term is the sum of heat exchanged by conduction. Qi is the heat coming from external radiation or from an internal source. That is, the equation represents that variation rate of the internal energy (right term) is equal to the heat received by radiation and conduction added to an external or internal heat source (left term).

The balance in each node model has their 'n' equation index of his type and the unknowns are the 'n' temperatures values. The temperatures values were obtained by solving the system of equations.

V.1. Parameters used in mathematics thermal model

For this experiment were used the Amazon 1 satellite parameters developed at the National Institute for Space Research [7]. These parameters are only used to simulate the experiment in flight, it means, if the orbit parameters change, the temperatures obtained in the program will also change.

On this satellite, two cases were analyzed. The first, cold case: when the planet is at aphelion of its orbit. The second, hot case: when the planet is at perihelion of its orbit. Table 1 show the data for those two cases which were used in the program.

TABLE I

RADIATION AVERAGE VALUES ON THE SATELLITE

Parameter	Hot Case	Cold Case
Albedo (W/m²)	596	451

Earth radiation (W/m²)	233	208
Solar radiation (W/m²)	1418	1326

*Albedo: Solar radiation reflected by the Earth on the satellite.

In this analysis, the MLI used in experiment was considered as arithmetic node which the emissivity is 0.8, the absorptivity 0.45 and the effective emissivity 0.02 (GILMORE, 1994) e (SILVA et al, 2014).

VI. The correlation analysis between degradation and increased temperature.

The calculated temperatures were generated according to the OSR absorptivity variation. Was imposed an increase in the value of α, and the program generated a new temperature. Table 2 show the values of the temperatures with the respective values of α.

TABLE II

ABSORPTIVITY(α) VERSUS TEMPERATURE(T)

α	Hot Case T(°C)	Cold Case T(°C)
0.03	26.32	20,32
0.04	28.74	22,4
0.05	30.3	23,42
0.06	32.01	25,45
0.07	32.89	27,06
0.08	34.45	28,65
0.09	36.1	29,99
0.10	37.38	31,66

Analyzing these temperature values the amount of OSR degradation can be convergent quantified for a very closed space environment.

If a deterioration occurs its values probably will be intermediate the values shown in this table, so may be that the planet is in the middle position of the hot and cold cases.

I. Conclusion

The OSR is an easy to handle thermal control coating and low-cost to install in the satellite. It offers a high quality material and can be used in many satellites around the world. This results of these experiments show whether the Brazilian OSR has resistance to degradation in the satellite's life.

This study shows the feasibility of this experiment and the possibility to quantify the amount of possible degradation but also, if there is a possible an evolution of degradation regarding to lifetime in space.

A study of a thermal model demonstrates a view of a possible degradation in practicality case of space environment experiment. It offers a cover possibilities to study envision with other thermal control materials under development.

References

BOATO, M. G., Desenvolvimento e Fabricação de Uma Superfície Óptica Refletora Para Radiadores Térmicos de Satélite. 2014. 148f. Tese de mestrado – Instituto Tecnológico de Aeronáutica, São José dos Campos.

BOATO, M. G.; GARCIA, E. C.; SANTOS, M. B.; FERNANDES, G. F., Testes de degradação por foto deposição de um refletor solar óptico para controle térmico de satélites. Revista Brasileira de Aplicações de Vácuo (Impresso). , v.34, p.39, 2015.

GILMORE, D. G., *Satellite Thermal Control Handbook*. Volume I: Fundamental Technologies, Second Edition, The Aerospace Corporation Press, El Segundo, California, 1994.

MARSHALL K. N. S.; BREUCH, R. A., *Optical Solar Reflector: A highly stable, low* α_s/ε *Spacecraft Thermal Control Surface.* Journal of Spacecraft and Rocket. Vol. 5, no 9, September, 1968. Pg.1051-1056.

SILVA, D. F.; MURAOKA, I.; GARCIA, E. C., Thermal Control Design Conception of the Amazonia 1. Journal. Aerospace. Technology. Management., São José dos Campos, Vol.6, No 2, pp.169-176, Apr.-Jun., 2014.

STEWART, T. B.; ARNOLD, G. S.; HALL, D. E.; MARVIN, D. C.; HWANG, W. C.; YOUNGOWL R. C.; MARTEN, H. D., Photochemical Spacecraft Self-Contamination: Laboratory Results and Systems Impacts. Laboratory Operation, The Aerospace Corporation, El Segundo, 25, July 1990.

VILELA, R. D.; GARCIA E. C., Numerical Model for Analysis in Space Radiators for Critical Conditions Operating, (2014) International Review of Mechanical Engineering (IREME), 8 (5), pp. 845-850.