# HEAT TRANSFER MODEL OF A SMALL SIZE SATELLITE ON GEOSTATIONARY ORBIT

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**Abstract:**
*The purpose of the study is to compute an approached satellite thermal model to be able to estimate the heat transfer and the maximum temperature through the harmonic gear for small size geostationary satellite. We use finite element method using known data with Nastran In-CAD FEM software. The presented results show temperature gradients compatible with experimental information. Though the results are not correlated with dedicated tests, they seems to be in line with what can be found in literature. The paper use these information in dedicated analysis related to impact of temperature gradient in precision mechanism. The second purpose of the study is to show that simplified tools and methods allows to reach results sufficient for preliminary analysis. The space business is changing fast with growing private companies that are challenging conservative space standards. A simplified analysis allowing to reduce cost and increase competitiveness is presented.*

**Keywords:**
*Simplified thermal model, FEM modelling, Nastran In-CAD, Harmonic gear, Heat transfer*

## 1. Introduction

Mechanisms in the space environment are usually more robust to extreme temperatures than electronics. The components driving the thermal design and thermal control of satellites are the most sensitive ones. For this reason, mechanism are susceptible to be submitted more constraining temperatures. These temperatures would not disturb the proper basic functioning of the mechanism, but still, some aspects of mechanism are impacted by temperature gradients. For example, the positioning accuracy. Literature [1–11] present relevant information to perform accurately thermal analysis of satellite. Thermal behavior of small satellite were studied in [12] and simplified model of temperature evolution in [13,14]. Many different cases and configuration were analyzed as in [15-18]. This study present estimated temperature evolution analysis for a small-size satellite. The development of this type of satellite is growing fast and opportunities to find application of such developments seems more favorable.

Finally this article present the worst case temperature distribution in position mechanism for the defined type of satellite. The paper presents innovative simplified way to determine approximately temperature gradient in satellite, hoping to initiate new possibilities for decreasing engineering costs at early stages of satellite architecture development. On the base of presented simulations, the temperature distribution on the mechanical joints may be estimated. Basing on this estimation, the temperature correction factors for mechanical elements, such as harmonic gear, can be calculated.

## 2. Materials and Methods

To perform the study we use simplified methods with conservative approach. The program used is Nastran In-CAD (Inventor®). The Nastran module of Inventor® is limited in terms of radiation module analysis [19]. We compare the results obtained with data available in literature but also cross check with simplified analytical calculation.

The purpose of this work being to estimate approximately the extreme temperature in positioning mechanism, the mesh will not be refined nor manual but automatic through Inventor – Nastran In-CAD.

The considered satellite is on geostationary orbit. We estimate the worst case temperature that is seen by positioning mechanism. When the satellite is on dark side of Earth, its temperature can be regulated by heaters and thus it is not expected to be very low. We then concentrate on the hot case, when the satellite goes out of the shadow of Earth and enters the sunlight, as it is presented in figure 1.

We consider two parts in our study. The first part consists in the steady state analysis. We present the temperature gradient in mechanism for the same condition. We then consider the transient case at the moment the satellite enter the sun beam to verify the thermal behavior at mechanism level and check if temperature in mechanism exceed steady state temperature.

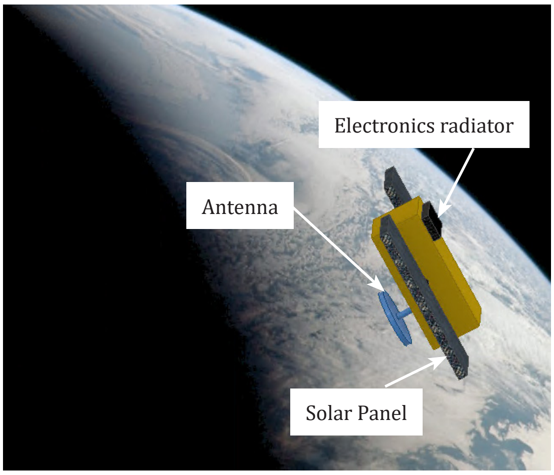

**Fig. 1.** Geostationary satellite entering the sunlight from the Earth shadow

The satellite analyzed in this paper is of small size – 200 x 300 x 500 mm. The material selected for the model is Aluminum 7075, which is commonly used in space applications. We will not consider here MLI [20].

The Satellite is modelled as a plain structure to consider mass of electronics and instruments. Following assumptions were made:

- The mass of the satellite is approximately 40 kg.
- The mesh element size is ~10 mm and the number of elements is more than 134 000.
- The initial temperature of the satellite coming from dark side of Earth is set to 200 K [3]. It is the approximate mean temperature of a geostationary satellite in dark side of Earth.

The model contains important simplification. The satellite emissivity will not be considered but the temperature of main components will be fixed. This is considered as a conservative case.

The constrains placed on the model are the temperatures of satellite electronics radiator, the antenna and solar panel. The electronics radiator temperature is fixed to maximum temperature allowed for electronics, 313 K. The solar panel and the antenna temperature are also fixed temperature set to typical operating maximum temperature allowed, respectively 373 K and 333 K. Boundary conditions are presented in the table 1, whereas heat fluxes from the environment are summarized in the table 2.

**Tab. 1.** Boundary condition - Typical temperature ranges of satellite components [1,2]

| Component | Typical Operating Temperature Range [K] |
|---|---|
| Electronics | 253 to 313 |
| Solar Panels | 173 to 373 |
| Antenna Dish | 193 to 333 |

**Tab. 2.** Used fluxes from environment [1]

| From | Typical Flux value used [W/m2] |
|---|---|
| Sun | 1368 |
| Earth | 236 |
| Albedo | 456 |

Figure 2 presents the simplified model of the small-size satellite used in presented modelling. The modules of the satellite are connected by the aluminum shafts, as it is commonly done in the real structures. For the proposed modelling, the assumption was made, that the Sun flux angle on the satellite side equals 30°.

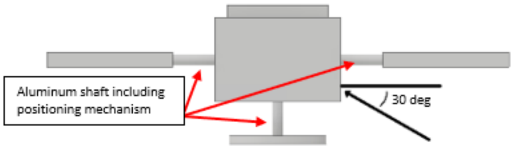

**Fig. 2.** Satellite top view – sunbeam angle of incidence

Considering the angle of incidence of sun flux on satellite side is about 30° and using values presented in the Table 2, the flux from sun seen by satellite side is considered to be:

$$S_{Side} = 1368\ W/m^2 \times \sin 60° = 1185\ W/m^2, \qquad (1)$$

in a similar way, we obtain the solar flux on front surface of the satellite (facing to Earth):

$$S_{Front} = 1368\ W/m^2 \times \sin 30° = 684\ W/m^2, \qquad (2)$$

Moreover, the solar panels are considered to be oriented orthogonally to the sun beams, so that they see the maximum flux from Sun.

We consider in this preliminary analysis that the flux is constant in the first hour when the satellite enters the sunlight.

## 3. Results

### 3.1. Steady-State Case

Considering the mentioned boundary conditions and thermal loads, the steady state model shows that maximum temperature reached at mechanism location is approximately 369 K. The distribution of the temperature on the satellite is presented in figure 3, whereas the distribution of temperature on the joint of modules is presented in figure 4.

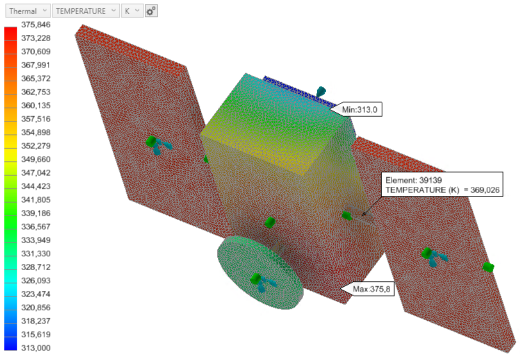

**Fig. 3.** Satellite temperature in steady state condition

(a)

(b)

**Fig. 4.** Satellite temperature in steady state condition: (a) Temperature gradient in antenna positioning mechanism; (b) Temperature gradient in solar panel positioning mechanism

As a point of comparison, in steady state, temperature was obtained on the base of formula [2]:

$$T(K)=\left(S\left(\frac{\alpha}{\varepsilon}\right)\left(\frac{A_{shaft\_inc}}{A_{shaft\_rad}}\right)/\sigma\right)^{0,25} \tag{3}$$

Where, for the aluminum shaft of radius and length r = 12,5 mm and l=100 mm, the area of surface of Sun incidence normal to Sun, $A_{shaft\_inc}$, is:

$$A_{(shaft\_inc)}=2\times r\times l=2500\ mm^2 \tag{4}$$

the area of surface radiating to space, $A_{shaft\_rad}$, is:

$$A_{shaft\_rad}=2\pi\times r\times l=7850\ mm^2 \tag{5}$$

with the total radiance, S, seen by the shaft (considering the data presented in the table 2):

$$S=1368\ \mathrm{W}/m^2+456\ \mathrm{W}/m^2+236\ \mathrm{W}/m^2=$$

$$=2060\ \mathrm{W}/m^2 \tag{6}$$

and with the Boltzmann Constant, $\sigma$:

$$\sigma=5{,}67\times10^{-8}\mathrm{W}K^4/m^2 \tag{7}$$

Considering that the emissivity and absorptivity of the shaft surfaces, is for aluminium $\varepsilon$ = 0,11 and $\alpha$ = 0,14 [2] respectively, we obtain a steady state temperature of T = 348 K.

The second point of comparison, we can find in literature [1], presenting typical maximal test temperature of solar array mechanism equal 353 K.

### 3.2. Transient Case

Due to the fact that it is necessary to confirm the most critical temperature on the mechanism, the main analyses will concentrate on the transient case. As mentioned in [3], transient event may be the most important design driver. For this reason, the heat transfers in the satellite structure was modelled, while cold steady state is perturbed by Sun radiation.

In the transient case, we verify how temperature of the satellite is changing with time and especially at positioning mechanism location. The figure 5 presents the mechanism temperature variation with regard to time.

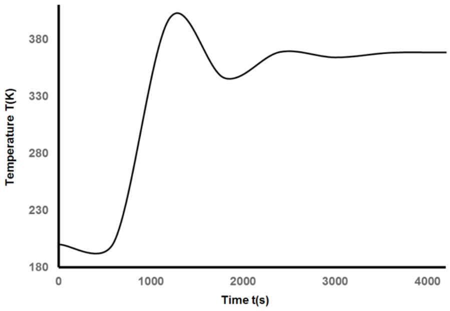

**Fig. 5.** Satellite maximum temperature variation with time

The figure 6 presents the location of the maximum temperature of 390 K on shaft/mechanism location. This temperature appears also after a time of about 20 minutes. Significant temperature differences are observed. It should be highlighted, that these temperature gradients may significantly influence on the accuracy of precision of the positioning systems, such as harmonic gear boxes.

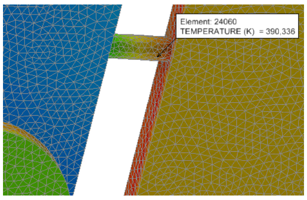

**Fig. 6.** Satellite shaft positioning mechanism temperature gradient

## 4. Conclusion

Presented results confirm the usability of proposed simplified method of estimation of temperature gradients in satellite shafts. Such temperature gradients are critical from the point of view of accuracy of positioning mechanism, especially mechanisms utilizing harmonic gear boxes. This is mainly due to the fact that temperature gradients are the source of non-symmetrical geometrical modification of gear components.

Proposed method is in good agreement with analytical calculations presented previously in literature considering the temperature of mechanisms in steady state. Using proposed method utilizing FEM, we obtained central value of temperature 369 K compared to 348 K by rough analytical calculation and 353 K for similar application [1]. This difference is due to the fact that we wanted to stay conservative in our analysis and didn't consider radiation in our model.

The presented transient thermal analysis shows that mechanism could be subjected to higher temperature than the maximum steady state temperature as well as for additional temperature gradients. Considering presented worst case scenarios for temperature and gradients, it is possible to obtain input data for detailed mechanical analysis of harmonic gear boxes.

As a result, the new method of correction of temperature drifts of such mechanism may be proposed. It should be highlighted, that proposed method presents an alternative solution for preliminary analysis, leading to the decrease of design cost at early stage of very demanding elaboration process of satellite project.

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