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The Emittance and Absorptance of External Surfaces Values Effect for Payload Panels on Geostationary Orbit Satellite: Thermal Analysis Studies

Yereduruğan Yörünge Uydusu Üzerindeki Görev Yükü Panelleri için Dış Yüzeylerin Yayılımı ve Emilimi Değerlerinin Etkisi: Isıl Analiz Çalışmaları

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ABSTRACT

One of the most important parameters in the dimensioning stages of communication satellites is the calculation of the areas where the heat to be released into space is located. The satellite thermal control system calculates these areas. Thermal analyses are performed for the north and south panels where the payload equipment is located in three-axis geostationary satellites. It is important to calculate these areas where the heat to be released into space is located correctly. In this study, thermal analysis calculations were performed for a three-axis geostationary satellite with an area of 1 to 10 m^2. In the calculations, the absorptance of external surfaces at the end of the satellite's life was calculated by considering 0.27. The radiator area temperature was taken as 30 ^oC in the calculations.

Keywords: Geostationary orbit, satellite, thermal analysis.

ÖZ

Haberleşme uydularının boyutlandırılması aşamalarında en önemli parametrelerinden bir tanesi uzaya atılacak olan ısının yer aldığı alanları hesaplanmasıdır. Uydu ısıl kontrol sistemi bu alanları hesaplamaktadır. Üç eksenli yereduruğan uydularda faydalı yük ekipmanların yer aldığı kuzey ve güney panelleri için ısıl analizler yapılmaktadır. Uzay ortamına atılacak ısının yer aldığı bu alanları doğru bir şekilde hesaplanması önem arz etmektedir. Bu çalışmada, 1 ile 10 m^2'lik bir alana sahip üç eksenli yere durağan bir uydu için ısıl analiz hesabı yapılmıştır. Hesaplamalarda uydunun ömrü sonundaki yüzey soğurulma katsayısı 0.27 göz önüne alınarak hesaplanmıştır. Hesaplamalarda radyatör alan sıcaklığı 30 ^oC olarak alınmıştır.

Anahtar Kelimeler: Yereduruğan yörünge, uydu, ısıl analiz.

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Introduction

Radiator areas for heat dissipation have existed since the first satellite mission. With the increasing heat generated by electronic equipment with the development of technology, the optimization of radiator areas has become an important subject of study in space technology in recent years. Especially in various planetary missions, the design of radiator areas where heat rejection occurs is carried out by thermal control workers as high efficiency, low mass and deployable as possible.

The importance of radiator areas has been realized due to the increase in radiator areas together with the increase in heat loads produced by electronic equipment in satellite. Consequently, pioneering studies were initiated in 1968 to investigate the role of radiator areas on the structural subsystem in spacecraft applications (Cockfield, 1968). In the study, studies were conducted on the optimization of mass, which is one of the most important criteria of the structural subsystem, together with the increase in the radiator area. Important studies have been conducted on the optimization of radiator areas as a thermal subsystem in recent years (Curran & Lam, 1996; Krikkis & Razelos, 2002; Hull et al. 2006; Kim et al. 2015). Chiranjeevi et. al (2023) conducted a comprehensive study that incorporated numerical simulations, experimental investigations, and optimization of hybrid space thermal radiators, resulting in a substantial reduction in mass from 6.8 kg to 4.3 kg. Liu et al. (2016) investigated the degradation characteristics of two thermal control coatings, employing a winner process to model the degradation of absorptivity. The degradation modeling method is accurate, and the results provide insight into the life prediction and thermal design optimization of LEO satellites. Shen et al. (2024) conducted thermal analysis throughout the satellite development process based on modeling and simulations. Bulut and Sözbir (2015) investigated the temperature for different solar panel combinations in a 1U CubeSat. Bulut et al. (2010) modeled CubeSat and the thermal analysis was performed by using ThermXL spreadsheet-based thermal analysis tool. Sözbir and Bulut (2009) ensure that the electronics in the payload panel remain at appropriate temperatures by calculating the radiator area. Arslantas et al. (2017) conducted a study in which they analyzed the surface temperatures for communication satellites based on thermal uncertainty values. The necessity of thermal analysis for geostationary and nanosatellites has been widely recognized, and significant research efforts have been dedicated to developing methods for maintaining internal satellite temperatures within acceptable limits (Sözbir et al. 2008; Bulut et al. 2008; Bulut et al. 2017; Bulut & Sözbir, 2021).

Geostationary satellites in geostationary orbit are approximately 36,000 km away from the Earth. Mostly, they are designed by satellite manufacturing companies with three axes. Heat rejection to space in three-axis geostationary satellites is done using radiator areas located on the north and south panels. Figure 1 shows a three-axis geostationary satellite (Coşkun et al. 2016). The north and south panels where the heat is released are covered with optical solar reflectors (OSR). OSR's are materials with high surface emission coefficients and low surface absorption coefficients.

In this study, thermal analysis of the heat rejection capacity to space from the radiator areas in the panels where the payload is located in three-axis geostationary satellites was performed analytically.

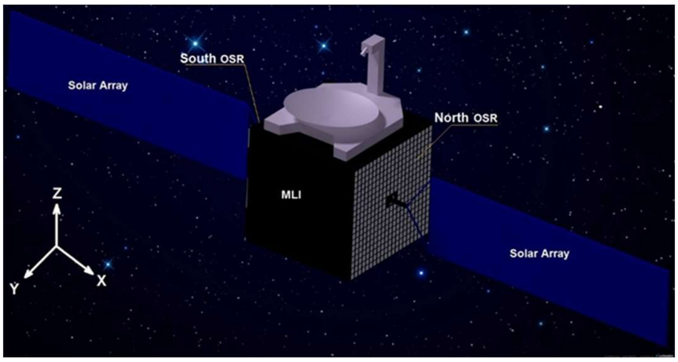

Figure 1.
Three-axis geostationary satellite (Coşkun, Bulut & Sözbir, 2016).

Material and Methods

Thermal Analysis Model

In the thermal analysis model of the satellite, OSR's and thermo-optic values are important. Radiator areas and OSR's attached to external surface of the satellite provide heat to be released into space. In the calculation of radiator areas, the worst cases such as maximum heat transfer, maximum solar radiation end-of-life (EOL) thermo-optic properties are taken into consideration (Bulut et al. 2008; Sözbir et al. 2008; Sözbir & Bulut, 2009; Sözbir et al. 2010). In the thermal analysis model of satellites, the heat absorbed by the satellite with radiation and the heat emitted by the satellite must be balanced (energy balance). The energy balance is shown in Figure 2.

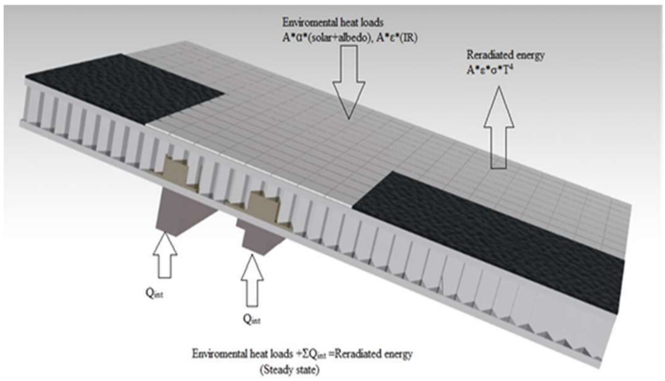

Figure 2.
Energy balance in a three-axis geostationary satellite (Bulut & Sözbir, 2023).

The energy balance in three-axis geostationary satellites is obtained by the following equation.

$$Q_S + Q_A + Q_E + Q_{int} = Q_{Surface} \quad (1)$$

The internally dissipated power is $\boldsymbol{Q_{int}}$, and the environmental heat loads associated with solar, albedo, and Earth are $\boldsymbol{Q_S}$, $\boldsymbol{Q_A}$, and Q_E. The amount of heat rejected from the satellite's radiator surface is $Q_{Surface}$.

$$(A_S q_S + A_A q_A)\alpha + A_E q_E \varepsilon + Q_{int} = A_{surface}\sigma(T_r^4 - T_s^4)\varepsilon \quad (2)$$

The left side of the equation shows the absorbed heat, the right side shows the heat emitted by the satellite. The first and second terms on the left side of the equation show the net absorbed heat, and the third term shows the operating heat load (heat produced by the elements in the satellite). A_S, A_A, and $A_E$are the surface areas related to direct solar, reflected (albedo) and directly emitted infrared radiation from the earth. q_S, q_A, and $q_E$are the heat fluxes from direct solar, reflected (albedo) and directly emitted infrared radiation from the earth. the absorptance of external surfaces is shown as α and the emittance of external surfaces as ε in equation (1). In three-axis geostationary satellites, the absorptance of external surfaces values range between 0.24 and 0.27 at EOL of the satellite. In this study, the absorptance of external surfaces (α) is taken as 0.27 in the calculations. The changes in the absorptance of external surfaces values depend on the time the satellite is in space, the location of the OSR's on the satellite, and pollution from external environments (Karam, 1998; Gilmore, 2002). Satellite manufacturers calculate the surface absorption coefficient values at the end of the satellite's life by taking into account the satellites they have previously sent into space. The emittance of external surfaces ε was calculated by taking 3 different values as 0.80, 0.85 and 0.90. In order calculate the radiative areas, 30 °C were chosen because the most of the electronic equipment in the spacecraft considered the qualification temperature of 65 °C.

Results

Table 1 shows the heat values rejected to space. For a radiator area of 1 m^2, a radiator temperature of 30 °C and a surface emission coefficient of 0.9, the amount of heat to be rejected is calculated as 431 W. For a radiator area of 10 m^2, a radiator temperature of 30 °C and the emittance of external surfaces of 0.9, the amount of heat to be rejected is calculated as 4310 W. The heat absorbed by the north and south payload panels are given in Tables 2, and 3.

Table 2 shows the total heat absorbed by the north payload panels (solar and electronic equipment) in the case that the radiator temperature is 30°C and the absorptance of external surfaces is 0.27. For the north panel radiator area of 1 m^2 and the emittance of external surfaces of 0.9, the total absorbed heat is calculated as 348 W. For the north panel radiator area of 10 m^2 and the emittance of external surfaces of 0.9, the total absorbed heat is calculated as 3480 W.

Table 1.
Heat released into space (30 °C)

Total Area (m^2)	Q (W)		
	ε=0.8	ε=0.85	ε=0.9
1	383	407	431
2	766	814	862
3	1149	1221	1293
4	1532	1628	1724
5	1915	2035	2155
6	2299	2442	2586
7	2682	2849	3017
8	3065	3256	3448
9	3448	3663	3879
10	3831	4070	4310

Table 2.
North payload panel absorbed heat value (radiator area temperature 30 °C)

North Panel Area (m^2)	North Panel @ 30 °C, α=0.27			
	QS (W)	Qint (W) @ε=0.8	Qint (W) @ε=0.85	Qint (W) @ε=0.9
1	143	293	321	348
2	286	587	641	696
3	428	880	962	1044
4	571	1174	1283	1392
5	714	1467	1603	1740
6	857	1761	1924	2088
7	999	2054	2245	2436
8	1142	2347	2566	2784
9	1285	2641	2886	3132
10	1428	2934	3207	3480

Table 3 shows the total heat absorbed by the south payload panels (solar and electronic equipment) in the case that the radiator temperature is 30°C and the absorptance of external surfaces is 0.27. For the south panel radiator area of 1 m^2 and the emittance of external surfaces of 0.9, the total absorbed heat is calculated as 338 W. For the north panel radiator area of 10 m^2 and the surface emission coefficient of 0.9, the total absorbed heat is calculated as 3381 W.

Table 3.
South payload panel absorbed heat value (radiator area temperature 30 °C)

South Panel Area (m^2)	South Panel @ 30 °C, α=0.27			
	Q_S (W)	Q_{int} (W) @ε=0.8	Q_{int} (W) @ε=0.85	Q_{int} (W) @ε=0.9
1	153	284	311	338
2	305	567	622	676
3	458	851	932	1014
4	611	1134	1243	1352
5	763	1418	1554	1690
6	916	1701	1865	2028
7	1069	1985	2176	2366
8	1221	2268	2486	2704
9	1374	2552	2797	3043
10	1527	2835	3108	3381

Conclusions

In this study, the focus was on the calculation of heat rejection capacity in three-axis geostationary satellites, with specific attention given to the consideration of radiator areas. The lowest recorded heat rejection was determined to be 293 W, a figure achieved under conditions where the radiator temperature was set at 30°C, the radiator panel area was measured at 1 m^2, and the emittance of external surfaces was set at 0.8. Conversely, the maximum heat rejection was determined to be 3480 W under conditions of a radiator temperature of 30°C, a radiator panel area of 10 m^2, and an external surface emittance of 0.9.

The analytical calculation revealed a positive correlation between the emittance of external surfaces and the increase in heat rejection. Therefore, in order to achieve effective heat rejection in satellites, it is recommended that the optical solar reflector material be selected with a high emittance of external surfaces as a priority.

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