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Investigation of external heats for cubesats at various low earth orbits

Çeşitli alçak dünya yörüngelerinde küp uydular için diş isi yüklerinin incelenmesi

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Abstract

In this paper, radiative heat loads on structural panels of small satellites are simulated for various orbital configurations. Thermal management of small satellites are challenging because of their limited available volumes. Satellites in orbits experience not only extreme temperatures but also rapid temperature changes. In order to provide safe operating conditions, the thermal environment in space must be carefully analyzed. This paper presents a numerical investigation of thermal environment influenced the panels of satellites for various orbital parameters by using Systema Thermica v4.9.0 software with Monte Carlo Ray Tracing (MCRT) method. The results of this study can be useful in the design stage of small satellites operating in similar orbits.

Keywords: Thermal analysis, Thermal modeling, Space heat flux, Low Earth orbit, CubeSat.

Öz

Bu çalışmada, küçük uyduların yapısal panellerine etki eden ışınımsal ısı yükleri çeşitli yörünge konfigürasyonları için simüle edilmiştir. Sınırlı kullanılabilir hacimlere sahip olmaları nedeniyle küçük uyduların termal yönetimleri oldukça zordur. Yörüngedeki uydular sadece ekstrem sıcaklıklara değil, aynı zamanda hızlı sıcaklık değişimlerine de maruz kalırlar. Güvenli çalışma koşullarının sağlanması için uzaydaki termal ortamın dikkatlice analiz edilmesi gerekmektedir. Bu makale, Monte Carlo Işın İzleme (MCRT) yöntemi ile Systema Thermica v4.9.0 programı kullanılarak çeşitli yörünge parametrelerinin uydu panellerine etki eden ısıl ortamın sayısal analizine yer vermektedir. Bu çalışmanın sonuçları, benzer yörüngelerde çalışan uyduların tasarım aşamasında yararlı olabilir.

Anahtar kelimeler: Termal analiz, Termal modelleme, Uzay ısı akısı, Alçak Dünya yörüngesi, Küp uydu.

1 Introduction

The number of orbiting satellites in space is increasing day by day and the majority of satellites recently launched into space are especially small satellites. Satellites, artificial objects orbiting in space, are generally classified by their weights. Small satellites having smaller sizes and lower masses are used to fulfill a wide range of missions while providing numerous benefits over larger vehicles. The technological developments allow to manufacture satellites in smaller scales, and they are classified as microsatellites, nanosatellites, picosatellites, and femto-satellites. CubeSats are nanosatellites having standard size and form and called by their volumes. The volume of 10×10×10 cm^3 is used to define 1 unit, 1U, CubeSat and other CubeSats can be called by means of this unit volume as given in Table 1 [1].

Table 1. CubeSat Classification regarding size and mass

CubeSat Designation	Size (max)	Mass (max)
1U	10 cm × 10 cm × 10 cm	1 kg
2U	10 cm × 10 cm × 20 cm	2 kg
3U	10 cm × 10 cm × 30 cm	3 kg
6U	10 cm × 20 cm × 30 cm	6 kg
12U	20 cm × 20 cm × 30 cm	12 kg

Small satellites are generally placed in low earth orbits (LEO) and operate in Sun-Synchronous (SSO) and Non-Polar Inclined orbits. Low earth orbits have altitudes between 160 and 2000 kilometers from Earth's surface. In this region, satellites encounter extreme thermal loads periodically with high frequencies depending on their positions in space. Therefore, thermal management of small-scale satellites plays a critical importance because of the limited available volumes for thermal control appliances. Passive thermal control measures are typically applied for small satellites to meet mass and power budgets and to stay within operational temperature ranges.

Studies on thermal design and analysis keep focused on small satellites. Thermal modeling for UKube-1 is performed by Reiss et al. [2] for a circular orbit with an altitude of 650 km and an inclination of 97.79 degrees while the thermal performance of the nanosatellite in LEO at 300 and 400 km altitudes is analyzed by Dihn [3]. The temperature distribution for Swayam, a 1U picosatellite operating in LEO, is analyzed by Wachche et al. [4] for the obit having semimajor axis of 7033.95 km, the eccentricity of 0.00012 and the inclination of 98.239 degrees. Das et al. [5] analyzed an earth-pointing cubic micro-satellite with deployable solar panels in SSO with the height of 500 km and the inclination of 97.4 degrees by applying two-nodal and three-nodal parametric analyses to obtain the optical properties. The thermal analysis of PiCPoT nanosatellite traveling along a circular SSO with a height of 600 km and an inclination of 98 degrees is studied by Corpino et al. [6] to improve the satellite configuration and to understand the

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requirements for thermal control system. A single-node thermal model is applied by Anh et al. [7] to small satellites in LEO to obtain linearization coefficients and to estimate temperature evolutions for the overall system by using equivalent linearization method while a two-node thermal model is applied by Chung et al. [8] to small satellites in LEO by using dual equivalent linearization technique with Newton-Raphson iteration method. In order to ensure that satellite thermal design meets the operational ranges, thermal control of TURKSAT 3U is analyzed by Bulut et al. [9]. Thermal effects on structural design are investigated by Steven et al. [10] for Surya Satellite-1. Another thermal analysis study is carried out by Kovacs and Jozsa [11] to investigate the SMOG-1 PocketQube satellite in LEO at an altitude of 550 km.

Although the thermal design and analysis of small satellites in specific orbits are available in the literature, there is only a limited number of studies investigating the thermal environmental effects. The analytical investigation conducted by Bulut and Sözbir [12] for a nanosatellite in LEO is presented to understand the thermal performance of the design for different panel combinations and panel surface temperatures for different altitudes from 500 km to 2000 km are examined in their study. Sanchez-Sanjuan et al. [13] study the behavior of solar energy and battery storage in a 3U CubeSat for three different orbit orientation scenarios that are free-orientation, sun-pointing and nadir-pointing, at SSO with the altitude of 700 km. Farrahi and Perez-Grande [14] investigate the influence of angular velocity on temperature distribution for a small satellite flying in SSO with an altitude of 800 km by considering four different beta angles. Three different satellite orientations for EIRSAT-1 that is a 2U CubeSat in LEO at an altitude of 400 km are analyzed by Wallace et al. [15] to identify the most critical component in thermal management. Heat fluxes on solar panels are simulated in the study of Almehisni and Naimat [16] for LEO conditions by using NX space thermal simulation solver to determine the most effective heat transfer path between a satellite and a solar panel. Space environmental effects are reviewed by Lu et al. [17] to discuss the neutral atmosphere, the plasma, the radiation, meteoroids/orbital debris, thermal environment and solar environment in different orbit types including LEO, medium earth orbit (MEO), geosynchronous orbit (GEO) and high earth orbit (HEO) in the study excluding the orbit-altitude perturbations assessment. Environmental effects related to the material radiative properties of satellites are estimated by Nenarokomov et al. [18] by using flight test data of Meteor-2 satellite flying in a circular orbit with an altitude of 900 km. Sundu and Döner [19] perform thermal analyses of an observation satellite in LEO by using MCRT method on Systema Thermica software. The SSO with the altitude orbit of 840 km and the local solar time of 22:30:00 is chosen in their paper to study the batteries, radiators, and heaters under extreme conditions. To the best knowledge of the authors, there is no detailed study investigating and comparing the external heat sources in sun-synchronous orbits with varying low altitudes for different orbital parameters.

This paper focuses on the effects of space thermal environment in different sun-synchronous orbits using Systema Thermica software. The external heat loads on satellite panels from sources of direct solar radiation, albedo radiation and Earth infrared radiation are investigated by means of MCRT method for different altitudes, beta angles and sizes. The altitudes are chosen as 400 km, 600 km, 800 km, 1200 km, 1600 km, and 2000 km. The degrees of 0, 15, 30, 45, 60 and 75 are selected for studying the influence of beta angles. The small satellites are modeled with the standard sizes of 1U, 2U, 3U, 5U, 6U and 12U. The motivation of the study is to provide relations between external heat loads and orbit characteristics and to present useful data for thermal modeling and analysis of satellites under space conditions.

2 Space thermal environment

Satellites experience various heat fluxes changing greatly during their lifespans in orbits. The thermal environment presented in space is greatly influential on both the operational lifetime and the performance [20]. This environment varying with respect to the orbital parameters has periodical effects on satellites [9]. Hence, space thermal environment including external heat sources are defined by considering the specific orbit, the orientation, surface properties and the size of the satellite [12].

2.1 Orbital parameters

The orbital parameters should be defined and analyzed to perform thermal analysis of a spacecraft since the external heating is highly depended on those. The position of a satellite with respect to celestial bodies influences the environmental heat fluxes [21].

Satellites traveling in LEO have altitudes ranging from 160 km to 2000 km and their orbits are mostly circular while some may be elliptical with limited eccentricities as well. The heat loads are varying depending on the altitude of a satellite.

Orbital parameters dictate the durations of penumbra (partial shadow) and umbra (total shadow), illustrated in Figure 1 that affect the magnitudes of external heat sources. The durations of illuminated and shadow passages have great effects on the thermal environment that satellites experience. The durations of shadow passages that are umbra and penumbra mainly vary depending on orbital period, altitude, and beta angle for circular LEOs. A satellite spending more time in eclipse receives eventually lower heat inputs. In other words, the lesser the period of penumbra and umbra a satellite experiences, the higher heat loads it receives. Therefore, it is very crucial to study eclipse durations to assure a functional satellite thermal control.

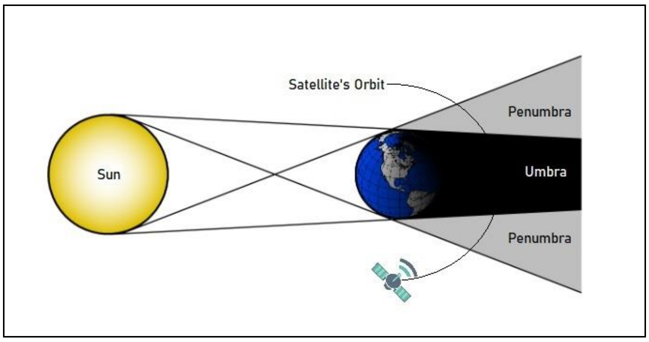

Figure 1. Shadow passages of an Earth-orbiting satellite.

On the other hand, the orbit beta angle, the minimum angle between the solar vector and the orbital plane, is an important parameter to analyze external sources and it can range from -90° to +90°. The satellite moves over the subsolar point and has the longest eclipse period when the beta angle equals to 0° while it moves near the terminator and has no eclipse when that angle equals to 90°. Therefore, lower beta angles result in higher orbit averaged solar loads for satellites [22]. The heat exchange between satellites and the outer space is occurred by means of radiation mechanism because of the existence of high vacuum condition. The main external heat sources for satellites orbiting in LEO are (1) direct solar radiation, (2) albedo radiation and (3) Earth infrared radiation [23]. Orbital parameters and material properties change these heat sources greatly [24]. A simplified scheme of the external heat sources in space for a satellite is demonstrated in Figure 2.

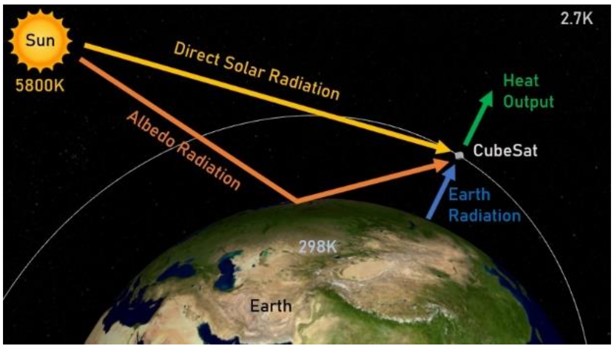

Figure 2. Space thermal environment for a CubeSat.

2.2 Direct solar radiation

The direct solar flux is by far the most intense heat input for a satellite. The spectral distribution of solar irradiation is an important parameter since it directly effects the magnitude of solar flux and the sun can be approximated as a black-body at 5762 K to simplify the thermal modeling [25].

The absorbed direct solar heat depending on the distance from the sun, the thermo-optical properties of the actual surface and the exposed area can be calculated as presented in Equation 1,

$$\dot{Q}_{solar} = \alpha_{solar}\, q_{solar}\, A_{surface}\, \cos\theta \qquad (1)$$

where α_{solar} is the absorptivity, q_{solar} is the solar constant, $A_{surface}$ is the surface area oriented toward the sun and θ is the solar ray angle [20].

2.3 Albedo radiation

Albedo is the radiation caused by the reflected solar radiation from the illuminated part of the Earth. Albedo radiation that depends on the position of a satellite and varies greatly with respect to the orbital altitude is a geometric heating property. The influence of albedo radiation is higher at orbits closer to the Earth.

The absorbed albedo radiation heat can be estimated as in Equation 2,

$$\dot{Q}_{albedo} = a\, \alpha_{solar}\, q_{solar}\, A_{surface}\, F_{s-e} \cos\theta \qquad (2)$$

where a is the albedo factor, α_{solar} is the absorptivity, q_{solar} is the solar constant, $A_{surface}$ is the surface area, F_{s-e} is the view factor of the surface and θ is the solar ray angle. The view factor varies with respect to the altitude of the satellite and the angle between the normal to the external surface and the position vector of the surface [21].

2.4 Earth infrared radiation

The Earth emits some of the received radiation back to the space as longwave infrared rays due to the temperature of the Earth and that is called as the Earth infrared radiation. The Earth infrared radiation, an important heat source for LEO satellites, changes from one point to another on the surface of planet due to the different thermo-optic characteristics [25].

The absorbed Earth infrared radiation can be calculated by Equation 3,

$$\dot{Q}_{E,IR} = \varepsilon_{IR}\, q_{E,IR}\, A_{surface}\, F_{s-e} \qquad (3)$$

where, ε_{IR} is the emissivity, $q_{E,IR}$ is the Earth radiation flux, $A_{surface}$ is the surface area, F_{s-e} is the view factor from the satellite to the Earth [12].

The Earth can be accepted as an equivalent blackbody transmitting a heat flux of 237 W/m^2 at a mean temperature of 255 K for evaluating the Earth infrared radiation. There are slight changes in spectral distribution of these infrared radiations due to daytime and nighttime, latitude, and seasons [20].

3 Thermal analysis

Thermal analysis of satellites is one of the most vital tasks to develop, design, manufacture, and operate them for successful space missions. Thermal design of a spacecraft is an integrated process combining the thermal modeling with both the available data and the analysis of the results obtained from mathematical models. As a part of the thermal analyses, external heat sources in space environment and their influence on satellite should be investigated in detail.

In order to investigate the thermal influences of space environment in various low earth orbits, on-orbit thermal simulations are dynamically performed by using Systema Thermica v4.9.0 software, developed by Airbus Defense and Space SAS. This software offers highly accurate thermal simulations of spacecraft in orbit by computing the external fluxes from the sun and the planets. The radiative heat transfer equations for nodal points are accurately solved by using MCRT method.

The small satellites having 1U, 2U, 3U, 5U, 6U and 12U sizes are modeled as illustrated in Figure 3 by using the 7075 Aluminum alloy material with the thickness of 1 mm. The Al-7075 has a density of 2800 kg $\cdot\, m^{-3}$, a conductivity of 130 W $m^{-1}K^{-1}$ and a specific heat of 915 J $kg^{-1}K^{-1}$. The values of absorptivity and emissivity are taken 1 for Al-7075 panels in the simulations.

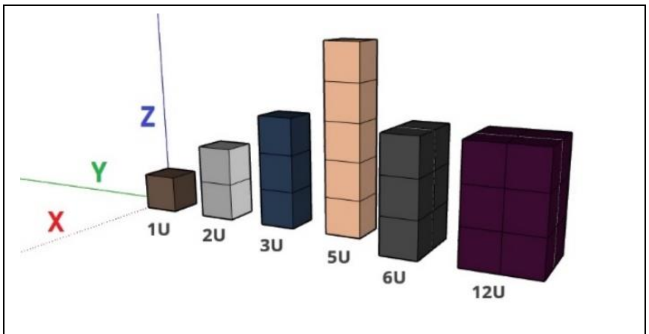

Figure 3. CubeSats models in different sizes.

Sun synchronous orbits with altitudes of 400 km, 600 km, 800 km, 1000 km, 1200 km, 1600 km, and 2000 km have been investigated by defining in Systema Thermica. For simulations, mean solar time is set to 12:30:00.000 and anomaly is taken zero while calendar date is chosen as Feb. 11, 2021. In the simulations, the -Z panel is the nadir-pointing surface, and the satellite is moving towards the +Y direction on orbits.

The heat sources of absorbed direct solar radiation, absorbed Albedo radiation, and absorbed Earth Infrared-Radiation are revealed while the effects of conduction, convection, aero-thermal fluxes, and internal heat dissipation of the satellite are excluded in this study since the aim is to provide the external heat fluxes depending on radiative mechanisms for small spacecraft in different orbits.

In addition, the illuminated and eclipse durations are examined for different altitudes and beta angles in order to provide a better understanding of thermal environmental effects in space. The beta angles of 0, 15, 30, 45, 60 and 75 degrees demonstrated in Figure 4 are used to evaluate the effect of different beta angles on external heat loads for the 1U-sized satellite at 800 km SSO.

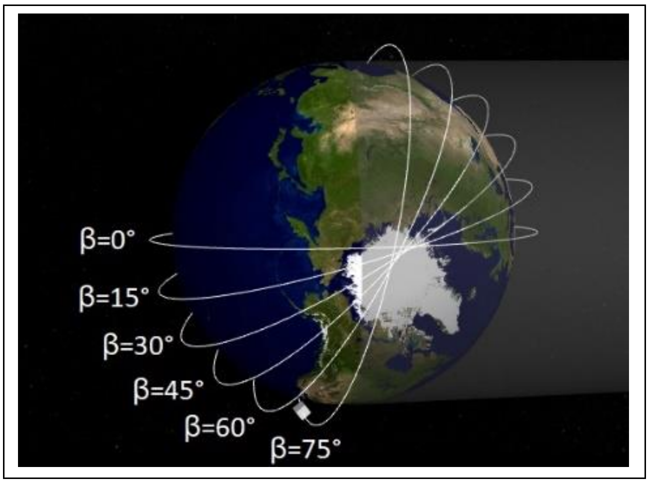

Figure 4. Different beta angles.

Last, the effects of different surface properties are analyzed in terms of the external heat fluxes that the 1U-sized small satellite received through radiation mechanism. To this end, surface properties of white paint, black paint, Kapton, Multi-Layer Insulation (MLI), Optical Solar Reflector (OSR) and solar cell are applied to all panels.

4 Results & Discussions

On-orbit thermal simulations are conducted to investigate the absorbed radiative heat on panels of a small satellite at different SSO with low altitudes. First, the thermal simulations are dynamically performed for SSOs with different altitudes to provide orbital periods together with the illuminated and shadow durations. Satellites travelling at higher altitudes have longer orbital periods, as shown in Figure 5.

As the altitudes get higher, satellites spend more time in illuminated regions. When the durations of shadow passages are compared for simulated altitudes, satellites orbiting at 1600 km spend the least amount of time in eclipse. The altitudes dictate the time in umbral and penumbral regions as well. When the ratio of the time in penumbra to the time in shadow is 0.78% at SSO 400 km, the ratio of that is 1.12% at SSO 2000 km. The satellites orbiting closer to the Earth spend less time in penumbral passage because of the shadow geometry shown in Figure 1.

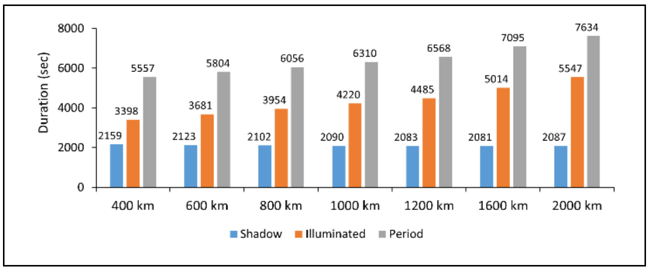

Figure 5. Shadow, illuminated and period durations at different altitudes.

In order to study the influence of different altitudes on the external heat sources, thermal simulations for a 1U CubeSat are performed for SSOs with the altitudes between 400 km and 2000 km. As shown in Figure 6, direct solar radiation has the highest contribution on total absorbed heat by the satellite for the selected orbital parameter and absorbed heat through solar radiation increases as the altitude gets higher and the satellite get closer to the Sun.

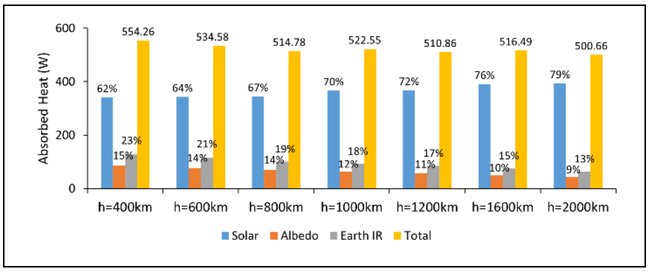

Figure 6. Absorbed heat by 1U CubeSat from external sources at different altitudes.

The contribution of Albedo and Earth IR, on the other hand, decreases when the distance between the Earth and the satellite increases. The highest total heat input is achieved at the altitude of 400 km while the lowest heat is received at the altitude of 1600 km. Satellites flying at higher altitudes are more exposed to external heat fluxes since they have longer orbital periods. That situation highly effects the total amount of heat per orbit.

The amounts of total heat received by 1U CubeSat while orbiting at different altitudes are compared as shown in Figure 7. The maximum heat input of 33.6 W is reached at 400 km altitude while the minimum heat input of 2.27 W is reached at 2000 km altitude during the eclipse.

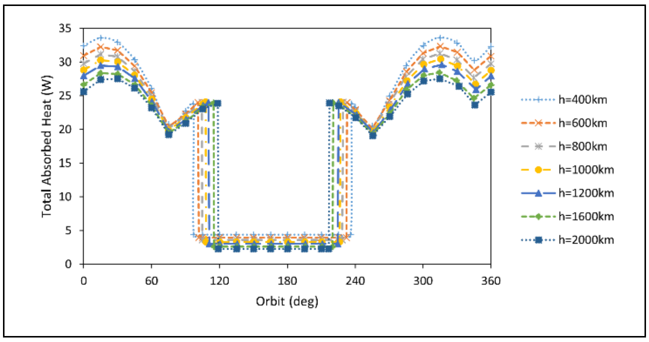

Figure 7. Total absorbed heat by 1U CubeSat at different altitudes.

The eclipse durations have influence on total absorbed heat power. The longer eclipse duration causes less heat input per orbital period. The longest eclipse duration is occurred for the altitude of 400 km.

Different panels of the satellite receive different amounts of heat fluxes because of the fact that effecting external thermal sources and their magnitudes are changing over the orbital period according to the position and the orientation of satellite panels. The total absorbed heat by different panels of 1U CubeSat is simulated at SSO 400 km as given in Figure 8.

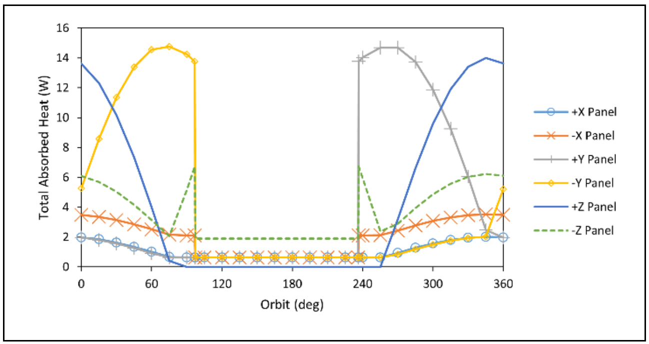

Figure 8. Total absorbed heat by different panels of 1U CubeSat at SSO 400 km.

The -Z panel is the Earth-facing side of the panel and because of that it is exposed more Albedo and Earth IR heat fluxes. The -Z panel absorbs the heat of 37.14 W from Albedo radiation and the heat of 55.11 W from Earth IR sources per orbital period while +Z panel receives no heat input from both sources since the view factor is zero between the panel and the Earth. The absorbed Albedo heat per orbit is 11.97 W for +X panel, 12.29 W for -X panel, 12.12 W for +Y panel and 12.21 W for -Y panel while the Earth IR absorbed heat on +X panel, -X panel, +Y panel and -Y panel is constant through the orbital period and the total amount is 18.05 W for each panel per orbit.

The amount of absorbed direct solar heat depends on both the orientation of the satellite with respect to celestial bodies and the material properties [12]. Total absorbed solar energy over an orbital period for different panels of 1U CubeSat orbiting at SSO with the altitude of 400 km is illustrated in Figure 9 by keeping the material properties same for all cases to exhibit the effects of panel position and orientation. Since direct solar radiation has the highest contribution to the received heat input of the satellite as discussed above, it also dictates the profiles in Figure 9 showing absorbed total heat powers from all external sources.

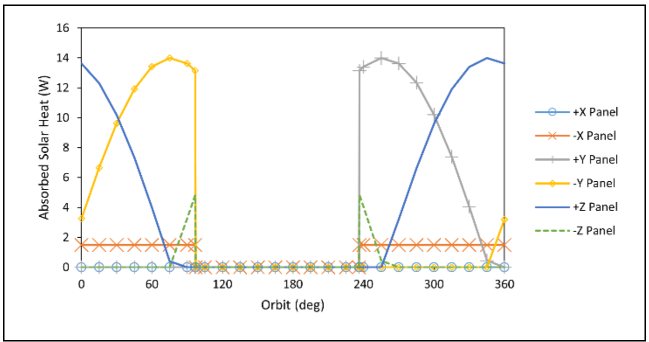

Figure 9. Total absorbed solar heat by different panels of 1U CubeSat at SSO 400 km.

It is stated by Dinh [3] that the CubeSat has at most three panels facing the sun. The findings of this study confirm that statement as shown in Figure 9. Only three panels receive direct solar radiation when the satellite is illuminated passage while no panels receive direct solar radiation when the satellite is in the eclipse.

Beta angle is another important parameter influencing the amount of total absorbed heat from external thermal sources in space. Hence, the simulations are performed for the beta angles of 0, 15, 30, 45, 60 and 75 degrees at SSO 800 km.

Before performing thermal simulations, the time that a satellite spends in the illuminated and shadow passages for different beta angles at SSO 800 km are obtained as in Table 2. The beta angle of 0° has the longest eclipse duration. As the beta angle increases from 0° to 60°, the satellite spends less time in shadow. Besides, the satellite flying at SSO 800 km with higher beta angles experiences less time in umbra and more time in penumbra regions. When the beta angle is as high as 75°, there is no shadow passage anymore for the selected orbital configuration.

Table 2. Illuminated and shadow periods for different beta angles at SSO 800 km.

Beta Angles	Illuminated	Shadow		
0°	65.19%	34.81%	U	99.15%
			P	0.85%
15°	65.77%	34.23%	U	99.08%
			P	0.92%
30°	67.78%	32.22%	U	98.87%
			P	1.13%
45°	72.44%	27.56%	U	98.20%
			P	1.80%
60°	86.51%	13.49%	U	90.21%
			P	9.79%
75°	100.00%	0.00%	U	0.00%
			P	0.00%

U-Umbra; P-Penumbra.

Before performing thermal simulations, the times that a satellite spends in the illuminated and shadow passages for different beta angles at SSO 800 km are obtained as in Table 2. The beta angle of 0° has the longest eclipse duration. As the beta angle increases from 0° to 60°, the satellite spends less time in shadow. Besides, the satellite flying at SSO 800 km with higher beta angles experiences less time in umbra and more time in penumbra regions. When the beta angle is as high as 75°, there is no shadow passage anymore for the selected orbital configuration.

Satellites flying at orbits with smaller beta angles are exposed to less direct solar radiation and spend more time in shadow while they receive more sunlight per orbit at higher beta angles and they may get overheated when no proper thermal control measures are applied [3]. Therefore, it is very essential to understand how external heat inputs vary with respect to the beta angle. With this aim, 1U-sized small satellites flying at SSO 800 km with different beta angles are simulated and the total heat input profiles with respect to beta angles are demonstrated in Figure 10.

The maximum instantaneous heating is reached for the beta angle of 30° and the instant heat of 33.35 W is absorbed by the satellite. However, the maximum heating per orbit is 621.36 W and that amount is received for the beta angle of 60°. This is because the satellite spends less time in eclipse while it receives higher heat inputs when it is illuminated. The total absorbed heat is 565.82 W for the beta angle of 75° where no eclipse is present. The orbit-averaged total heating for the beta angle of 75° is 1.57 W per degree orbit.

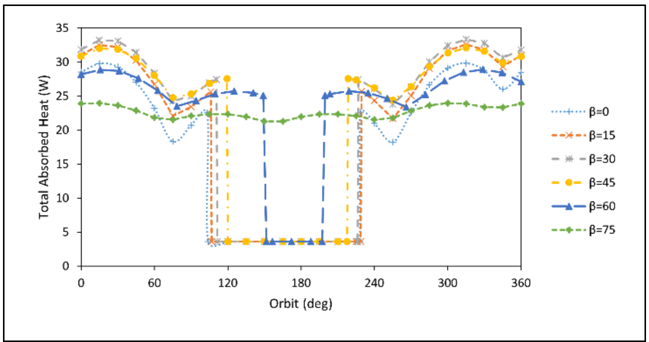

Figure 10. Total absorbed heat by 1U CubeSat for different beta angles at SSO 800 km.

The sizes of satellites influence absorbed heat powers from external thermal sources in space because the rate of heat received is directly dependent on the areas of satellite panels. Total absorbed heat powers for different satellite sizes traveling at SSO 800 km are introduced as shown in Figure 11.

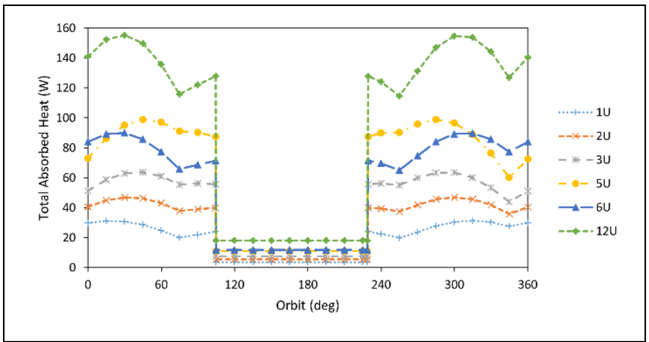

Figure 11. Total absorbed heat by different sized CubeSats at SSO 800 km.

For satellites sized 1U, 2U, 3U and 5U have the nadir-facing -Z panel with the dimension of 0.1 x 0.1 m^2 while 6U and 12U sized satellites have that panel with the dimension of 0.1 x 0.2 m^2 and 0.2 x 0.2 m^2, respectively. Having the least surface area, 1U CubeSat absorbs the minimum total heat from external source while 12U CubeSat that has the greatest surface area absorbs the maximum total heat as expected. The amounts of total absorbed albedo heat per orbit are 69.60 W, 106.13 W, 142.68 W, 215.77 W, 230.36 W and 351.42 W while that of total absorbed Earth IR are 100.35 W, 153.10 W, 205.52 W, 310.80 W, 332.64 W and 507.08 W for 1U, 2U, 3U, 5U, 6U and 12U CubeSats, respectively. As the size of the satellite increases, the total absorbed heat from albedo and Earth IR per orbit also increases.

Table 3. Absorptivity and emissivity of coating materials.

	White Paint	Black Paint	Kapton	MLI	OSR	Solar Cell
α	0.25	0.95	0.85	0.52	0.20	0.74
ε	0.81	0.90	0.85	0.71	0.81	0.82

The amount of heat transferred from external thermal sources to the satellite depends on the material properties. Therefore, different coating materials are applied to outer surface of satellite panels to analyze the change in heat inputs from external thermal sources. White paint, black paint, Kapton, MLI, OSR and solar cell are chosen since there are commonly used in satellites for thermal control and power management purposes and their properties are given in Table 3.

Total absorbed heat profiles for different coating types for 1U CubeSat traveling at SSO with the altitude of 800 km are shown in Figure 12. The total received heat inputs per orbit are 184.84 W, 483.98 W, 437.53 W, 286.72 W, 164.12 W and 388.93 W for the coatings of white paint, black paint, Kapton, MLI, OSR and solar cell, respectively.

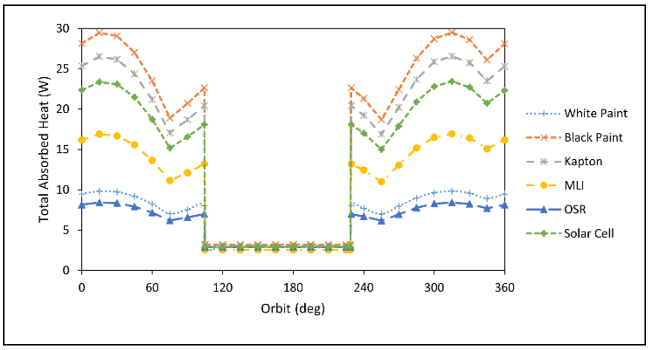

Figure 12. Total absorbed heat for different coating types at SSO 800 km.

The maximum heat is received for the case with black paint having the highest ratio of absorptivity/emissivity among the analyzed coatings. The higher the ratio of absorptivity/emissivity results in the higher heat power that a satellite receives while the lower ratio of that causes the lower heat inputs. Even though the emissivity of OSR and white paint are same, OSR receives lower heat input since its ratio of absorptivity/emissivity is lower. Changing the values of absorptivity and emissivity by applying different coating materials to satellite panels is a passive thermal control measure and that is commonly used for thermal control of small satellites. These results exhibit that panels of a satellite can be coated with OSR and white paint to minimize the received heat input in terms of thermal management or they can be coated with black paint and Kapton to maximize that.

5 Conclusions

This study presents the influence of space thermal environment on the panels of CubeSats for various orbital parameters and satellite configurations by performing numerical simulations on Systema Thermica v4.9.0 software with Monte Carlo Ray Tracing (MCRT) method. Different altitudes for sun synchronous orbits are simulated for the same size, beta angle and material properties and the results showed that the altitude affects the heat input. The amount of absorbed heat from direct solar radiation increases when the amounts of absorbed heat from albedo and Earth IR decrease as the altitude gets higher. Satellites at lower altitudes experience longer eclipses as well.

The panels of satellites received different heat powers according to their position with respect to celestial bodies. While the satellite passing through the illuminated passage, only three panels receive direct solar radiation. However, no panels receive direct solar incident when the satellite is in the eclipse.

Results of this study also demonstrate that both the amount of total absorbed heat from space thermal sources and eclipse durations are influenced by the beta angle. The maximum heating is achieved for the beta angle of 60 degrees while no eclipse is present for the beat angle of 75 degrees.

The satellite size also affects the absorbed heat power since the heat rate is directly proportional to the surface area. Numerical simulations indicate that as the size of the satellite increases, the total absorbed heat per orbit also increases. The results can be linearly adapted to model and analyze CubeSats having different sizes that are not included in this study.

Results also reveal that surface properties of satellite panels are greatly influential on absorbed heat power in space condition. As the ratio of absorptivity/emissivity increases, the total absorbed heat by the satellite increases as well. Satellites can be coated with black paint to increase the absorbed heat energy whereas they can be coated with OSR to decrease that.

In conclusion, understanding the influence of space thermal environment is very crucial task at the design stage of satellite projects. A proper thermal control can be designed and facilitated by analyzing how a heat budget of a satellite is affected depending on different parameters. The results of this study can be very beneficial for several satellite thermal scientists and engineers during the design phase and the thermal analysis of small satellites operating in similar orbits.

6 Author contribution statements

All authors contributed to the study conception and design. Thermal analyses were performed by Cihan ATAR and interpretation of data was performed by Cihan ATAR, Metin AKTAS and Nedim SOZBIR. The first draft of the manuscript was written by Cihan ATAR and all authors commented on previous versions of the manuscript. All authors read, checked and approved the final manuscript.

7 Ethics committee approval and conflict of interest statement

There is no need to obtain permission from the ethics committee for the article prepared. There is no conflict of interest with any person/institution in the article prepared.

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