Comparative study of MYSat attitude stability effect on power generation and lifetime

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Comparative study of MYSat attitude stability effect on power generation and lifetime

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Abstract. Universiti Sains Malaysia Space System Lab (USSL) is currently developing a 1U cubesat named MYSat. The satellite mission is to measure electron-density in the Ionosphere E-Layer. Power generation from a solar panel is limited due to a small area of the satellite. Apart from that, the satellite is expecting to continuously spinning and tumbling throughout the mission lifetime as the satellite will be launched without an attitude control system. This paper compares the effect on power generation and the lifetime of MYSat of two conditions; first is with attitude controll where satellite pointing to nadir and later is uncontrol attitude of the satellite. The analysis has been conducted using Analytical Graphics, Inc. (AGI) Systems Tool Kit (STK) software. This study assumed the satellite used a hexagonal solar cell with a theoretical efficiency of 29% identical to an Ultra Triple-Junction (UTJ) solar cell. The simulation is done in one year duration on different attitude configuration. The worst-case condition, where the Earth is positioned at apogee, has been chosen for the comparative study and the lifetime of the satellite is also simulated and compared.

1. Introductions

Space projects becoming a trend in recent years with the development of small-satellites. These small-satellites concepts has decreased the development and mission cost [1]. Cubesat deployer [2], [3] such as P-POD and J-SSOD have enabled further reductions in the launch costs acting as a standardized deployment system. The typical small-satellite system usually uses commercially off-the-shelf (COTS) components and mainly operates for scientific research purposes and to prove new technology [4]. Nevertheless, constraint in weight and size challenges small-satellites developer in all aspects as it limits power generation, computational performance, and accurate attitude measurements and control [5].

Despite these limitations, small-satellites can be equipped with ambitious scientific payloads and technology for in-orbit demonstrations that lead Universiti Sains Malaysia (USM) to build an in-house small-satellite namely MYSat or Malaysian Youth Satellite. This small-satellite is planned to be deployed using J-SSOD (KIBO) module in the International Space Station (ISS) with the mission of measuring electron density in the Ionosphere E-layer. The 1U satellite will have dimensions of 10 cm x 10 cm x 10 cm and a maximum weight of 1.3 kg as standardized by the deployer requirements [3].

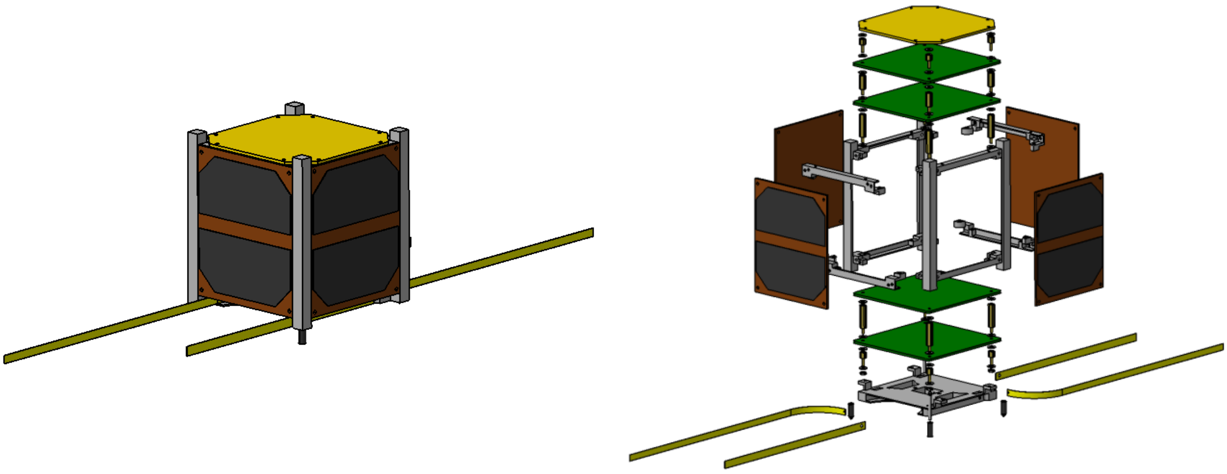
Nevertheless, the need of having attitude control in MYSat is abandoned due to power and thermal issues. Thermal issues are expected to occur when one side of the solar panel is facing the sun at all time. This will induce thermal heating to the MYSat [6]. Power generation is clearly affected by the withdrawing of the attitude control system here as the satellite will continuously spinning which in turn solves the thermal issues. The attitude control usually applied on a satellite that requires pointing accuracy [7], [8] such as FITSAT-1 [9], COMPASS-1 [10], and OUFTI-1 [11]. With the mission requirement does not require pointing accuracy, the needs of having control are rendered moot. Typical spin rate for cubesat is 1 deg/s [12] with 10 deg/s being the worst-case condition [1].

Power generated from the solar cell is a function of their efficiency, area, cell density, and temperature, Orbital parameters and satellite architecture (e.g. deployed panel configurations) and orientation all affect the anticipated power generation levels for solar panel systems [13]. Nevertheless, most of the solar energy is transformed into heat or rejected off the surface of the PV-cell. The efficiency of the PV-cell refers to percentages of the solar energy that is successfully transformed to electrical energy [14]. It is determined by the doping characteristics of the semiconductors.

The paper discusses the methods used in the analysis in Section 2 then continues with the results and discussion in Section 3.

2. Methodology

MYSat is expected to be deployed using J-SSOD (KIBO module) in ISS, thus the specifications is laid out in the JEM handbook documented by JAXA engineers have to be followed [3]. MYSat has a 10 cm x 10 cm x 11.35 cm in dimension with a maximum mass of 1.3 kg. Figure 1 depicts the MYSat structure and configuration. Each four sides of MYSat is covered with solar panels. The top and bottom surface are equipped with Electron Density and Temperature Probe (TeNeP) science unit and antenna deployment mechanism, respectively. Figure 1 show assembly and exploded view of MYSat.



(a) (b)

Figure 1. (a) MYSat assembly CAD design. (b) MYSat exploded view.

In order to perform the analysis, the CAD model has been exported in *.dae format to define the solar panel area. Then, it was save in *.anc format to set the efficiency of the solar panel. The orbit is propagated using the Simplified General Perturbations Model 4 and analysis conducted using Analytical Graphics (AGI) System Tool Kit (STK) [15], [16]. It considers Earth magnetic field (International Geomagnetic Reference Field 11), third body gravity, and Earth atmosphere (NRLMSISE-2000). Atmospheric density model NRLMSISE-2000 is chosen due to its latest model in modeling atmospheric density. The model have statistical accuracies of about 15 % and that there has been no significant improvement in density models over the last two decades [17].

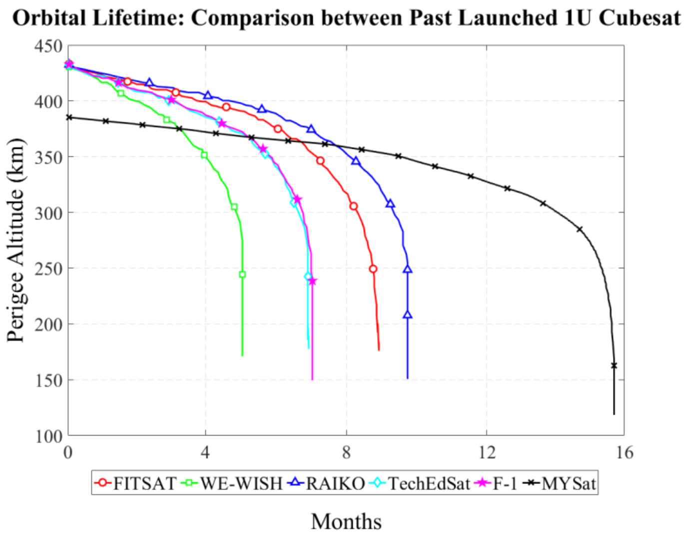


Figure 2. Comparisons of MYSat STK lifetime results and previously launched 1U cubesat

Previously launched Cubesat only manage to orbit for 6 to 12 months based on Figure 2, the analysis predicts that MYSat will be on-orbit for more than a year [18]. Choi Ha-Yeon et. al [19] gives the similar trend on their research. It is an utmost importance to remember that the result is an estimation. Simulated satellite lifetime has an approximately 10% error due to difficulty in accurately predict environmental effects such as solar and geomagnetic activities, atmospheric density and others [20]–[22]. The satellite lifetime can be increased by increasing its dry mass, reducing its cross-sectional area, or increased deployed altitude [23].

Next, the attitude is set Nadir oriented or spinning in all direction. The case study settings are presented in the Table 1 and are set in the STK's object properties window.

Table 1. Orbit settings

Orbit	
Propagator	SGP4
Step Size	60 s
Attitude: Standard	
Type	Nadir alignment with ECI velocity constraint Spinning
Spinning	**Body** Type: Cartesian X: 0.57735, Y: 0.57735, Z: 0.57735 **Inertial** Type: PR Angles Pitch: 0 deg, Roll: 0 deg Spin Rate: 1,3,5,7,10 deg/s Spin Offset: 0 deg Epoch: 1 Jan 2018 00:00:00.000 UTCG
Model	
*.dae and *.anc file	

The settings setup for solar panel analysis is shown in Table 2. Lifetime analysis is done using STK with the setting the parameters shows as in Table 3.

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Table 2. Solar Panel analysis setup

Parameters	Descriptions
Obscuring Objects	Facility (optional) Bound Radius: 0.1 m
Visualization	Solar Panel Groups: Plus-Y, Plus-X, Minus-X, Minus-Y (user defined)
Data	Start: 1 Jan 2018 00:00:00.000 UTCG Stop: 1 Jan 2019 00:00:00.000 UTCG Time Step: 60 s
Data Reporting	Type: Power Generate: Report/Graph

Table 3. Lifetime analysis setup

Parameters	Description
Atmospheric Drag, C_d	2.2
Solar Radiation Pressure, C_r	1.5
Drag Area	$0.01m^2$
Area Exposed to Sun	$0.01m^2$
Mass	1 kg
Atmospheric Density	NRLMSISE-2000
Solar Flux File	SolFlx_CSSI.dat

The summary of the analysis is represented in the flowchart shown in Figure 3.

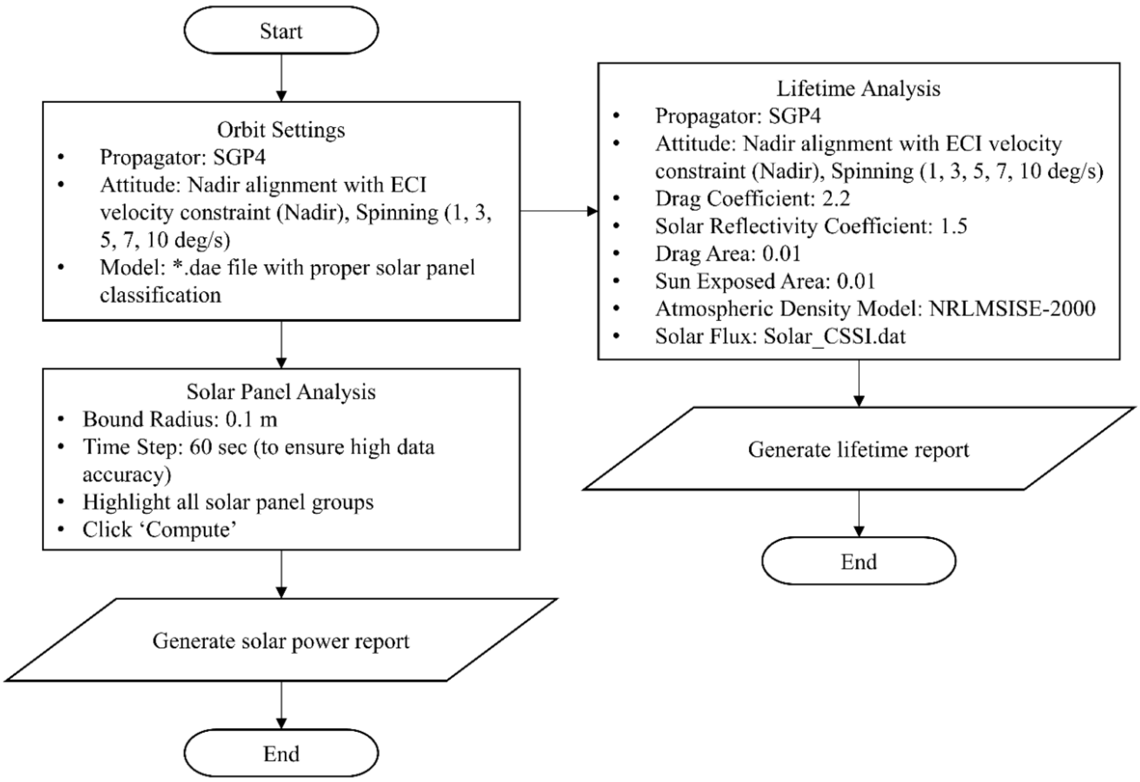

Figure 3. Attitude and lifetime analysis flowchart

3. Results and Discussion

3.1. Power Generation

Table 4 shows different shape of the solar panel and cell area resulted in the different amount of power generation. Hexagonal cell shape produces most solar power as it has bigger surface area. The solar cell area is based on the allowable size of the solar panel.

Table 4. Power generation based on different solar cell shapes

Cell Shape	Maximum (W)	Mean (W)
Hexagon	3.46	1.65
Square	2.81	1.34
Triangular	2.82	1.35

The solar cell efficiency plays an important role in selecting the best solar panel in the market [24]. This effect is shown in Table 5 where, higher efficiency will produce higher solar power output. This includes a safety margin of 20% from the theoretical efficiency to simulate actual solar cell performance. Note that, theoretical efficiency assumed the incident light is perpendicular to the solar panel while in actuality, the orientation changes.

Table 5. Comparison of power output on different solar cell material and efficiency

	GaAs (UTJ)	GaAs (SJ)	GaAs (MJ)	Thin Sheet Amorphous Si	Indium Phosphide	Crystalline Si
Efficiency	30.32%	22.00%	26.08%	11.20%	18.24%	20.24%
Max. Power	3.46	2.54	3.01	1.27	2.10	2.34
Avg. Power	1.65	1.21	1.43	0.60	1.00	1.11

The total solar power generated at any instances are from the solar power from each panel. Figure 4 shows the solar output from each solar panel with MYSat spins at 1 deg/s in all direction. Throughout one orbital period, there will a high and low output or no output at all from the panel depending location of MYSat with respect to the sun.

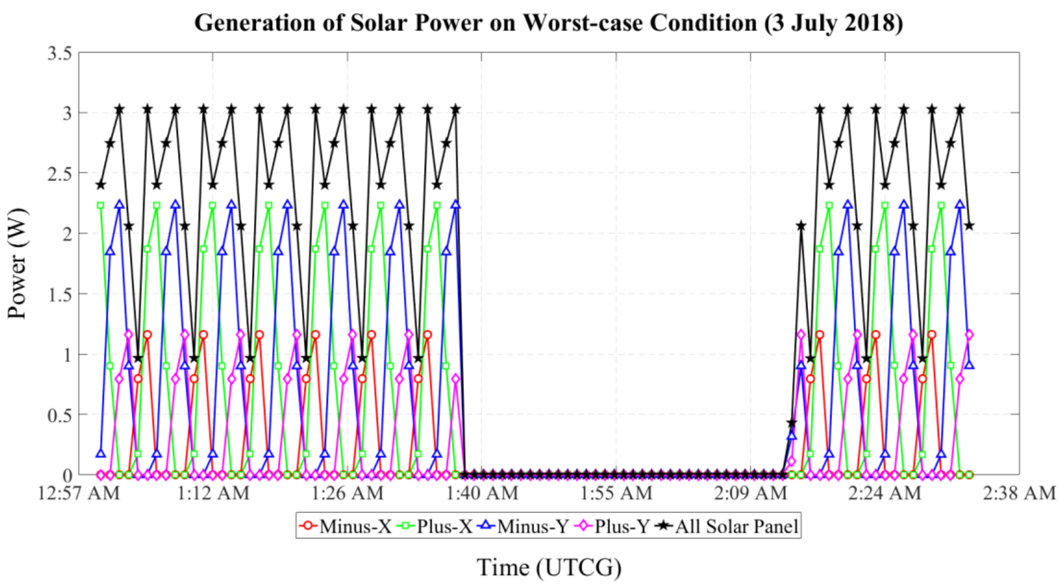

Figure 4. Individual solar panel output

Based on Figure 4, solar panel on -Y and +X produces the highest solar power while +Y and -X panel produces the lowest. The sum between all four panels produces the 'All Solar Panel' results. It can be seen to that, -Y and +X panel manage to produce about 2.3 W of power while +Y and -X produces 1.3 W. This shows, if only one solar panel is used, there will be power issues.

In addition, from 1:40 AM to 2:13 AM, the power graph drops to zero. This indicates that there is no power generation due to the eclipse. On this time, the battery will not be charged and battery is essential as it provides power to sustain the components used. Thus, power management needs to be properly set to avoid power loss [25].

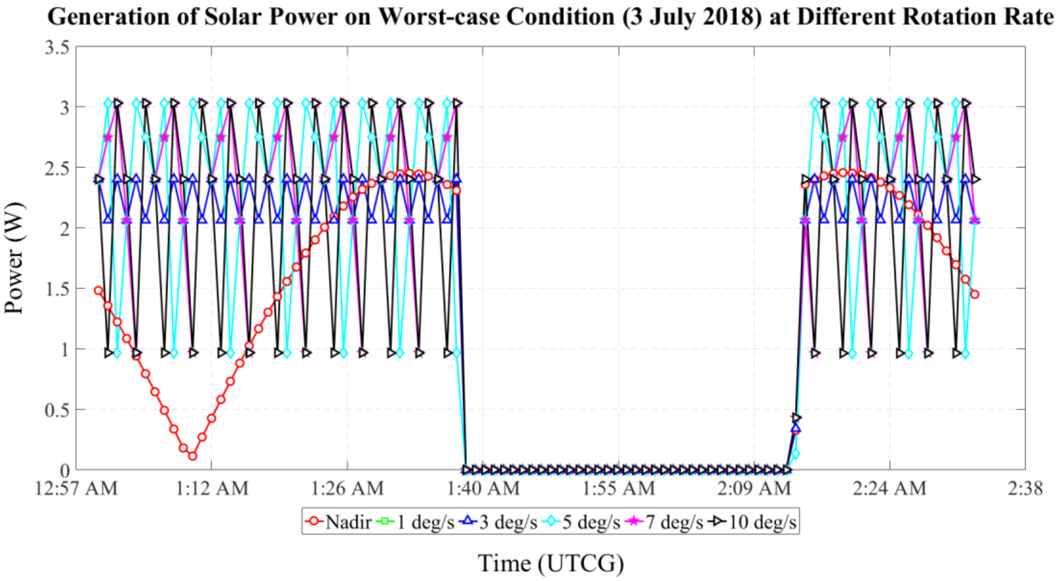

Figure 5. Comparison of generated solar power on different attitude spin rates

Figure 5 depicts the comparison of MYSat spin rate on total power generation. The power generated is oscillating in a short period of time due to rapid changes of the solar panel orientation while the Nadir pointed MYSat has a longer period. This is because of each solar panel able to spend a longer time in the sun. Thus, creating a constant power generation. However, the drawback is the power generated is limited by the efficiency of the solar cell creating a lower power output [26].

With referencing to Figure 5, different spin rate produces a same power output pattern but with lead-lag circumstances. 1 deg/s and 10 deg/s spin rate results produce the same output and probably due to STK's computation while 5 deg/s spin rate leads 7 deg/s spin rate results as it spun slower and have more time receiving sun rays. Interestingly, the spin rate of 3 deg/s produces a power generation oscillation with small differences compared to other spin rates. Overall, the power generated is approximated at 2 W to 2.7 W. In reality, MYSat cannot maintain its attitude spin rate without attitude control and external disturbance might induce the attitude spin rates [27].

3.2. *Lifetime Results*

As shown in

Table **6**, the spin rate does not affect the orbital decay date. This is because lifetime computation in STK only considers, drag coefficient, solar reflectivity coefficient, drag area, sun exposed area, atmospheric density model, and solar activity cycle [15]. In a circumstance where the attitude is unknown such as this research holds, a mean cross-sectional is assumed that produces a uniform attitude behavior which relative to the velocity direction [28]. The more detailed analysis shown in Figure 6 where the changes of perigee altitude are identical regardless of attitude behavior.

Table 6. Evaluation of decay date and duration on attitude spin rates

Spin Rate (deg/s)	Decay Date	Duration (years)
0.00 (Nadir)	21/4/2019	1.3
1.00	21/4/2019	1.3
3.00	21/4/2019	1.3
5.00	21/4/2019	1.3
7.00	21/4/2019	1.3
10.00	21/4/2019	1.3

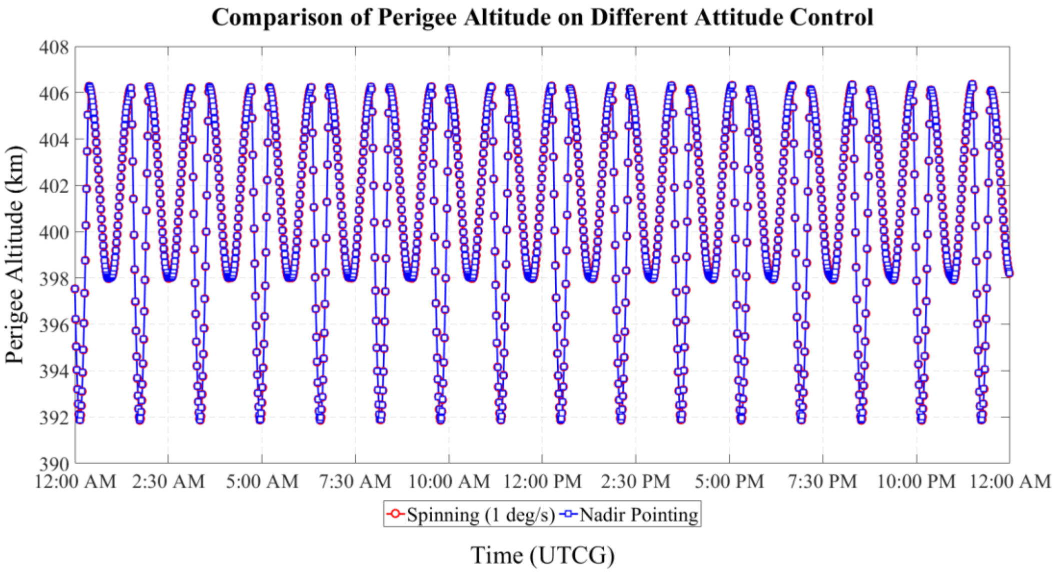

Figure 6. Assessment on perigee altitude on attitude control behavior

4. Conclusion

The effect on power generation and the lifetime of MYSat of two attitude behaviors i.e. Nadir oriented and continuously spinning condition for one year is done using Analytical Graphics, Inc. (AGI) Systems Tool Kit (STK) software. The study assumed the satellite used a hexagonal solar cell with a theoretical efficiency of 29% identical to an Ultra Triple-Junction (UTJ) solar cell. It can be seen that, power generated occurs in oscillation with Nadir oriented has a longer period compare to other spin rates. This is due to rapid changes of the solar panel orientation. Different spin rate produces a same power output pattern but with lead-lag circumstances. 1 deg/s and 10 deg/s spin rate results produce the same output while 5 deg/s spin rate leads 7 deg/s spin rate results as it spun slower and have more time receiving sun rays. The spin rate of 3 deg/s produces a small oscillation compared to other spin rates. The power generated is approximated at 2 W to 2.7 W. As for lifetime analysis, the spin rate does not affect the orbital decay date because of lifetime computation only considers, drag coefficient, solar reflectivity coefficient, drag area, sun exposed area, atmospheric density model, and solar activity cycle.

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