KOLOKIUM PENYELIDIKAN 2022

Solar Radiation Disturbance on Deployable Solar Panels of Nanosatellite

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Outline of Presentation

1. Introduction
2. Literature Review and Hypothesis Development
3. Research Methodology
4. Analysis and Findings
5. Research Limitation
6. Importance of the Study
7. Current Status and Their Implications on Relevant Government Policies
8. Conclusion

1. Introduction - Nanosatellite

- Artificial satellites with mass between 1-10 kg.
- Nanosatellites normally follow CubeSats specification.
- A CubeSat is made up of multiples of 10cm × 10cm × 10cm cubic units (i.e. 1U = 10x10x10cm^3; 3U = 10x10x30cm^3).
- In Malaysia, the CubeSat standard has been adopted and successfully launched by a private firm; ATSB (InnoSAT-2, 2018) and a university; UiTM (UiTM-Sat, 2018).

(a) (b)

Figure 1. (a) CubeSats order from left to right: 1U, 1.5U, 2U, and 3U; (b) Examples of CubeSat with deployable solar panels

1. Introduction – External Disturbances in Low Earth Orbit (LEO)

Major external disturbances for satellites in LEO (altitude < 2000km)

- Gravity gradient
- Magnetic field
- Aerodynamic drag
- Solar radiation

Figure 2. Major external disturbances for satellites in Low Earth Orbit

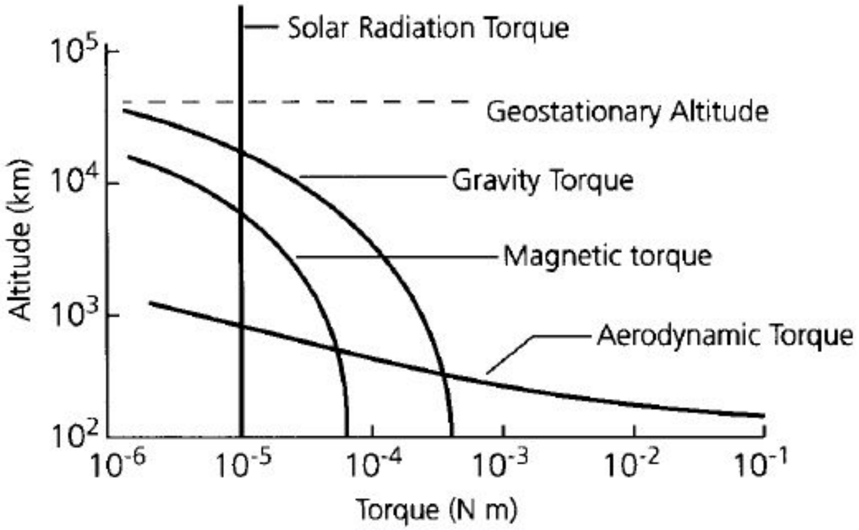


Figure 3. Level of external disturbance torques versus satellite's attitude [1]

- The level depends on surface area facing the solar radiation.
- Recently there are more CubeSats use deployable solar arrays to increase solar power generation.

[1] Meyer, R.X. Elements of Space Technology. Academic Press, London. 1999

1. Introduction – Thermally Induced Dynamics Phenomena

- Satellites in low earth orbit (LEO) experience periodic heating in sunlight (T° ≈150°) and cooling in shadow (T°≈-150°) regions of the Earth.

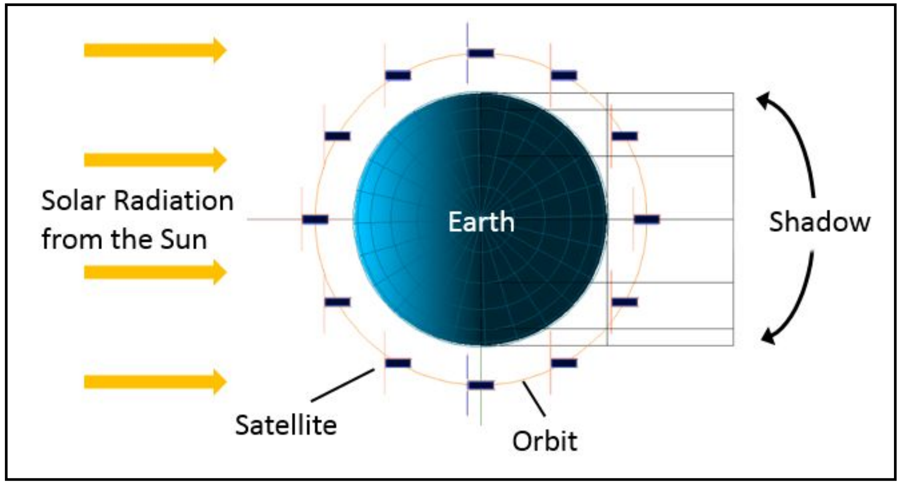


Figure 4. The in-orbit thermal environment of a satellite

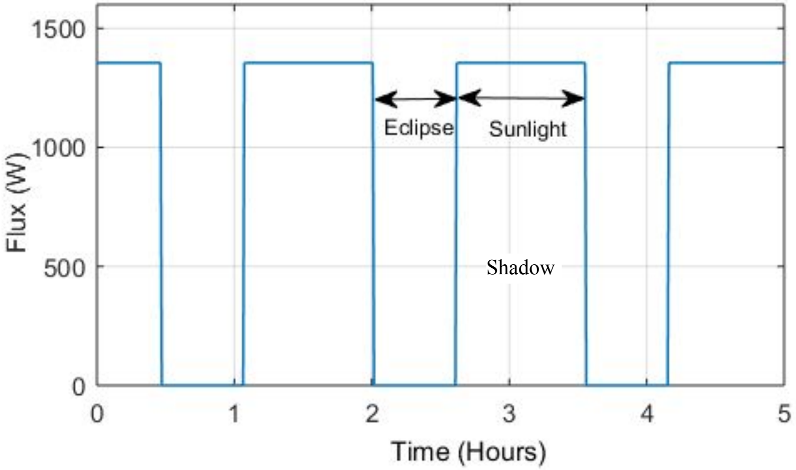


Figure 5. Example of Solar radiation from the Sun (altitude 400km)

- Sudden thermal loading can generate an impulsive torque on the deployable solar panel resulting in a dynamics response (TID phenomena).

1. Introduction – Thermally Induced Dynamics Phenomena

TID effects on satellite's orientation:

- The solar panel motions result in an internal disturbance torque that acts to change to orientation of the satellite.

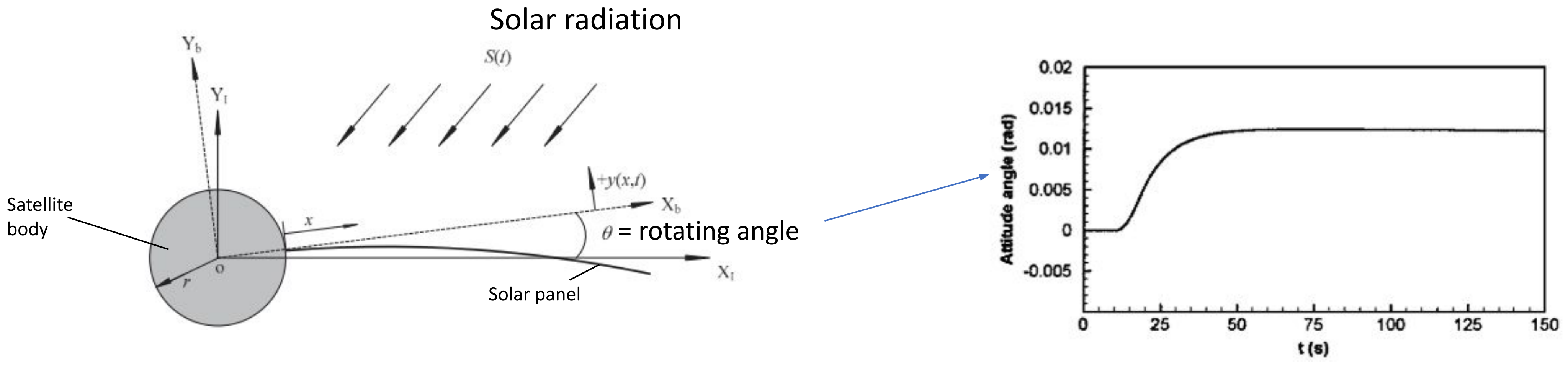
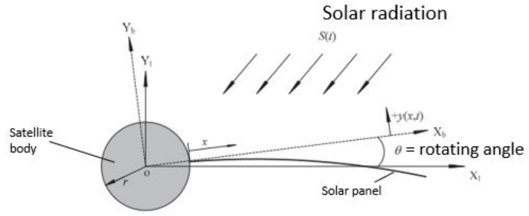


Figure 6. Example of attitude disturbance due to TID phenomena

2. Literature Review and Hypothesis Development

- Majority of CubeSats are low Earth orbiting. Available research focused on large satellites whose size and mass are in orders of magnitude larger than miniaturized size satellite like CubeSats.

- Since large satellites normally have one or two large solar panels, the effects of TID disturbance on the orientation (i.e. attitude dynamics) of the satellites were studied analytically using a simple spacecraft consisting of a rigid body with cantilevered flexible appendages (2D Model).



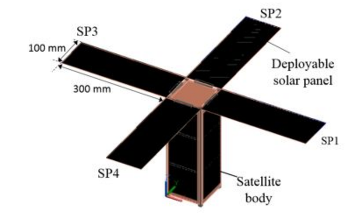
Given this apparent research gap, the following question is addressed in this research:

How can the attitude dynamics of a CubeSat, mounted with deployable solar panels be affected by TID phenomena?

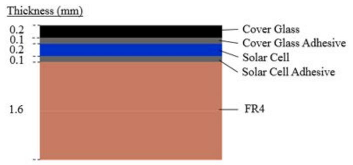
3. Research Methodology

1) Research Scope: Determine analysis model and thermal environment → 2) Thermal analysis using Thermal Desktop software → 3) Thermal structural analysis in Abaqus software → 4) Pointing Displacement Analysis using inertia relief method in Abaqus

Figure 7. Flow chart of TID Analysis



Model of 3U CubeSat with deployable solar panels.



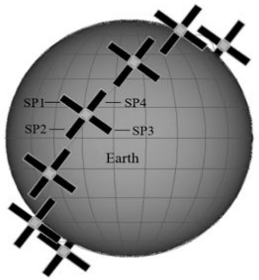
Sectional view of the solar panel.

Material	Density (kg/m³)	Thermal Conductivity (W/m K)	Specific Heat (J/kg K)	Absorptivity	Emissivity
Cover glass	2600	1.4	737	0.95	0.88
Cover glass adhesive	1100	0.15	1030	-	-
Solar cell	5315	48	360	0.696	0.85
Solar cell adhesive	1100	0.15	1030	-	-
FR4	1900	0.29	1200	0.64	0.82

Thermal properties of different materials for the solar panel

Material	Young's Modulus (GPa)	Shear Modulus (GPa)	Poisson's ratio	CTE (1E-6)
Cover glass	75	30.74	0.22	7
Cover glass adhesive	6	2.31	0.3	54
Solar cell	84.8	32.37	0.31	5.7
Solar cell adhesive	6	2.31	0.3	54
FR4	$E_1 = 25.4$ $E_2 = 21$ $E_3 = 21$	$G_{12} = 11$ $G_{13} = 0.7$ $G_{23} = 11$	$v_{12} = 0.162$ $v_{13} = 0.138$ $v_{23} = 0.138$	$\alpha_{11} = 20$ $\alpha_{22} = 20$ $\alpha_{33} = 86.5$

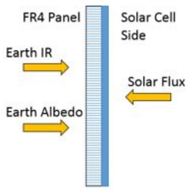
Mechanical properties of different materials for the solar panel



Orbit Profile:

- Altitude = 400 km
- Inclination of 56°
- **Mission:** Solar cells point to the Sun in daylight.

Orbital profile of the CubeSat from the Sun view



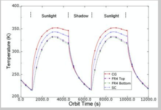
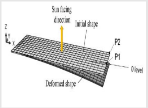
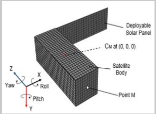
Constants:

- Flux = 1354 W/m²
- Earth IR = 221.5 W/m²
- Solar Albedo Factor = 0.35

External heating conditions on a solar panel during daylight.

Figure 7. Analysis model and thermal environment for TID Analysis

4. Analysis and Findings

No	Analysis	Purpose	Findings
1	Thermal Analysis	To obtain the temperature average on different layers of the deployable solar panels during the shadow-sunlight transition as a function of orbit time.	Temperature profile of the solar panels. 
2	Thermal Structural Analysis	To classify the types of TID disturbances that may occur on the current CubeSat model and quantify their levels.	The type of TID categories that may be encountered are quasi-static deformation and thermal snap. 
3	Pointing Displacement Analysis	To quantify the change in the orientation of the satellite body due to disturbance torque produced by the acceleration motion of the solar panels.	The thermal snap phenomenon could result in disturbance on pointing direction of the CubeSat. 

4. Analysis and Findings

4.1 Thermal Analysis - To obtain the temperature average on different layers of the deployable solar panels during the shadow-sunlight transition as a function of orbit time.

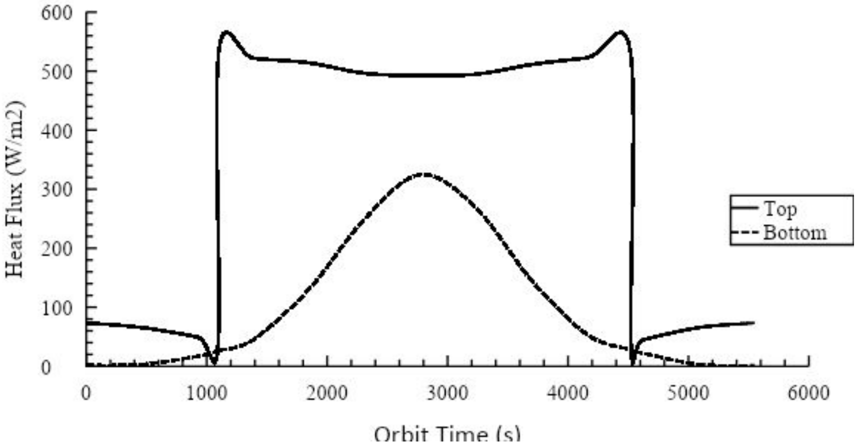


Figure 8. Absorbed heat flux on the top and bottom surfaces of the deployable solar panel in one orbit period

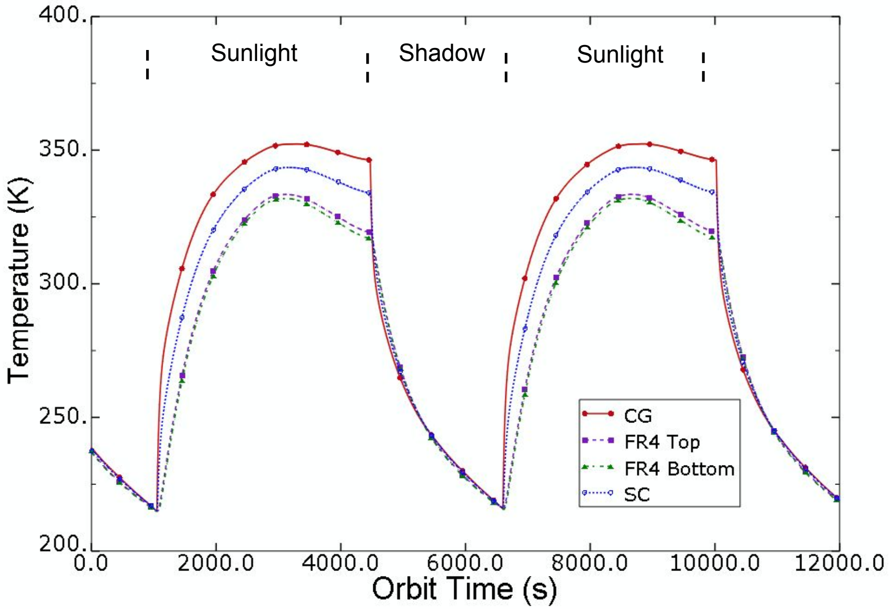


Figure 9. Temperature profile of the solar panel (SP1) in two orbit periods

4. Analysis and Findings

4.2 Thermal Structural Analysis - To classify the types of TID disturbances that may occur on the current CubeSat model and quantify their levels.

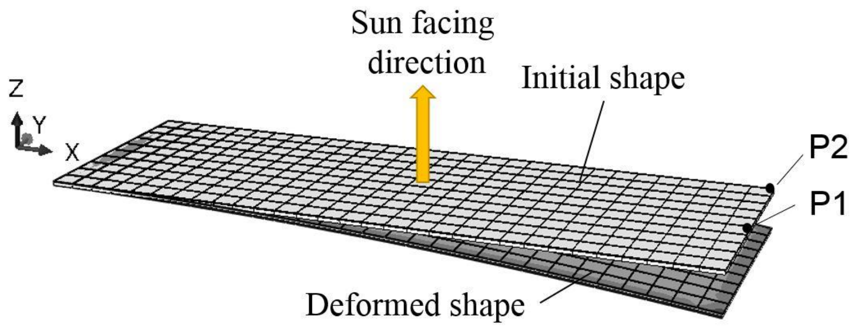


Figure 10: Illustration of the thermal deformation

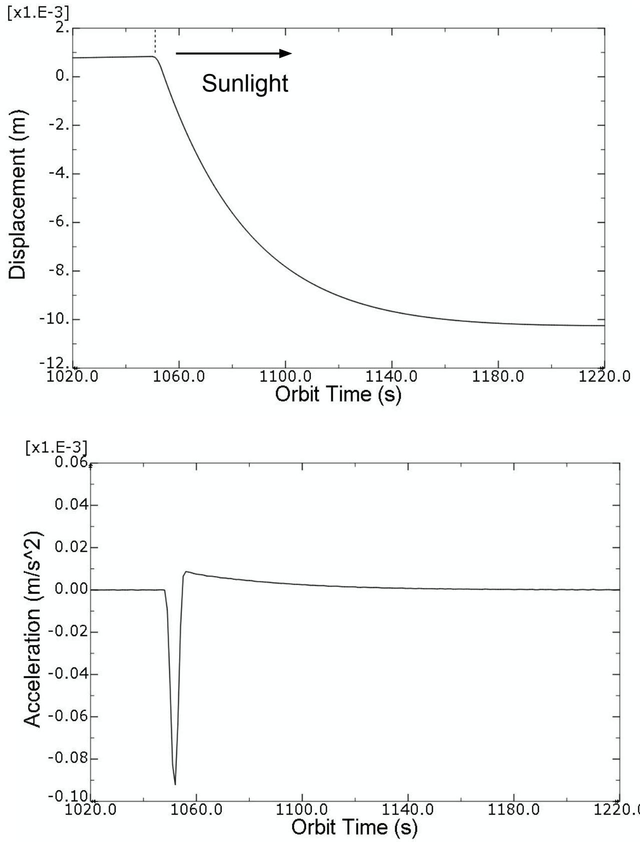


Figure 11: Solar panel structural response during shadow to sunlight transition; (a) Solar panel (point P1) displacement; (b) point P1 acceleration

4. Analysis and Findings

4.3 Pointing Displacement Analysis: Inertia relief method (IRM) is used to find the displacement of point M due to thermal disturbance on the solar panel.

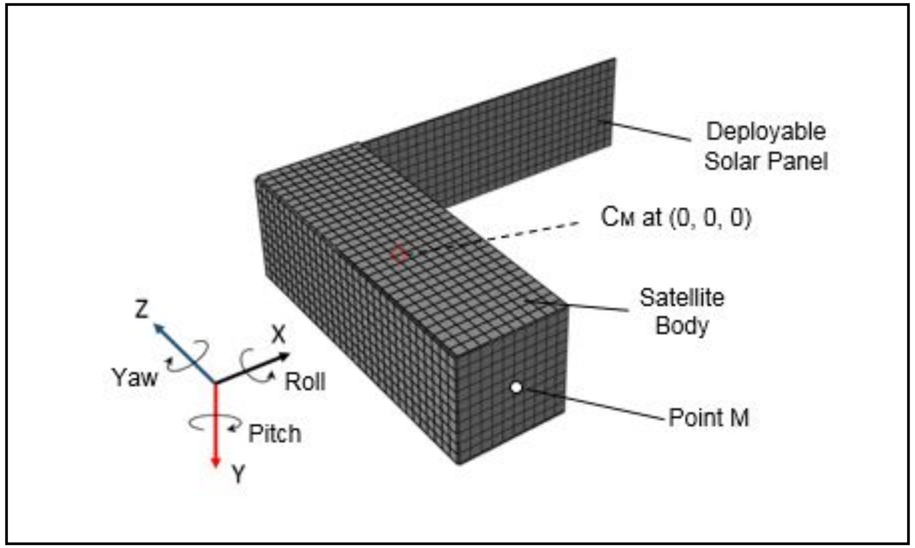


Figure 12. 3U CubeSat model with one deployable solar panel for attitude motion numerical simulation

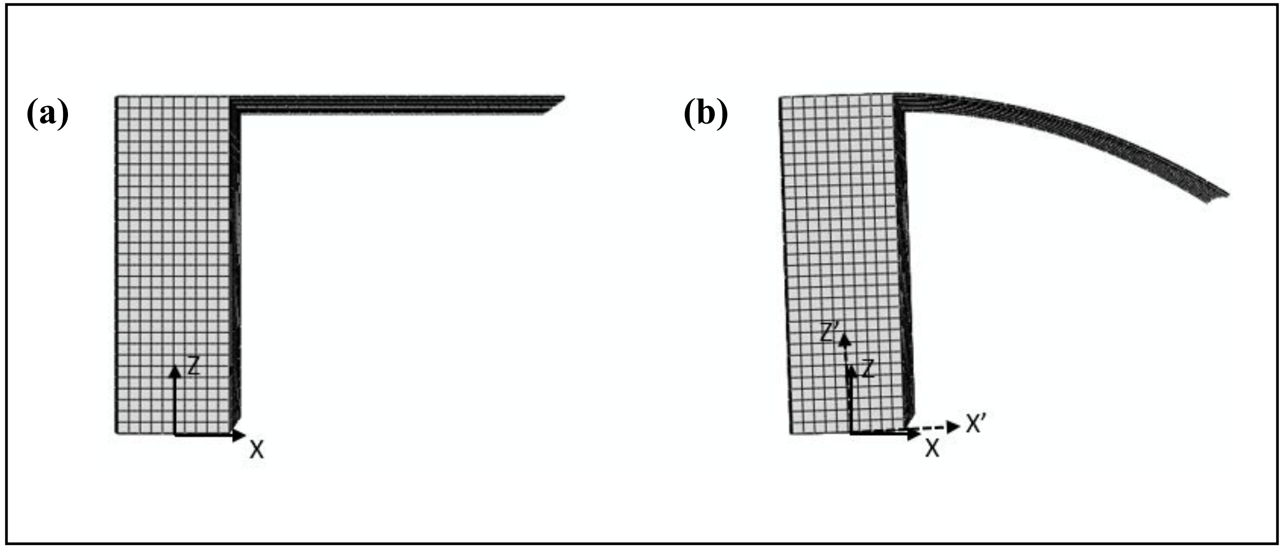


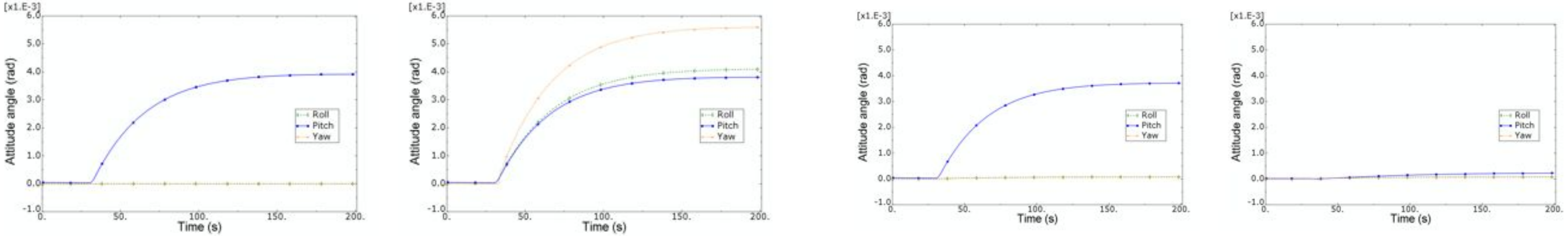
Figure 13. (a) Un-deformed and (b) deformed states of the CubeSat.

4. Analysis and Findings

4.3 Pointing Displacement Analysis: Analysis with different deployable solar panels configurations.

(a) One deployable solar panel (b) Two asymmetric deployable solar panels (c) Three asymmetric deployable solar panels (d) Four deployable solar panels

Figure 14. CubeSat with different deployable solar panels configurations

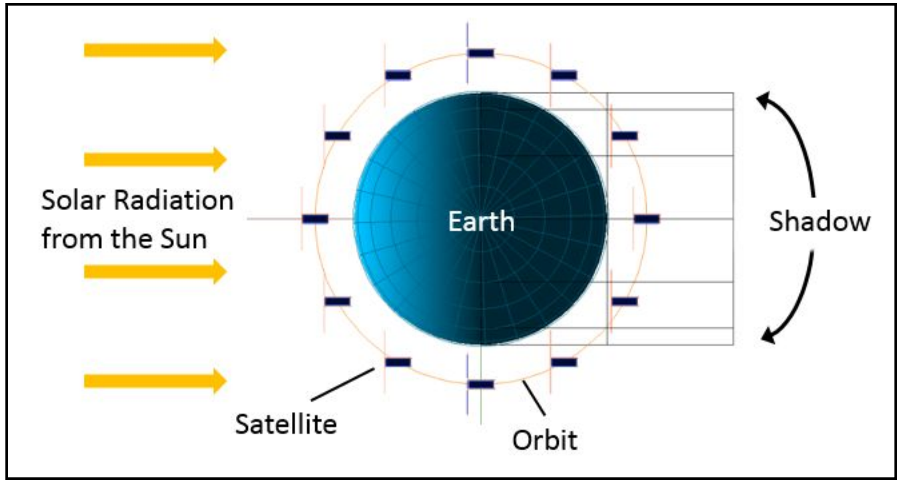


(a) One deployable solar panel (b) Two asymmetric deployable solar panels (c) Three asymmetric deployable solar panels (d) Four deployable solar panels

Figure 15. Attitude angle rotations due to TID on different deployable solar panel configurations

5. Research Limitation

- Simplification is made to the CubeSat structure and some parameters in the space environment. However, a nanosatellite has a short average operational lifetime.
- Only consider sun pointing mission (i.e solar panels face the sun) as the mission would be the worst-case scenario for TID phenomena.



6. Importance of the Study

- Contribution to the small satellite community with TID analysis specific to the nanosatellite class.
- The study presents complete analysis from thermal to structural and concludes with pointing displacement analysis in 3D model using FE software.

7. Current Status and Their Implications on Relevant Government Policies

- Nanosatellite technology in Malaysia is still in its infancy.
- The launch of UiTM–Sat has greatly improved the motivation and enthusiasm.
- There is a growing interest from private firms and local universities to conduct tests at the MYSA's Assembly, Integration and Test (AIT) facility for satellite in Banting, Selangor.
- Through a program between JPA with Japan International Collaboration Agency, MYSA sent 9 researchers to Kyutech's Center of Nanosatellite Testing to learn about the design and testing of nanosatellites.
- The efforts is part of the strategic thrust contained in the **National Science, Technology and Innovation Policy** that is to advance scientific research in government agencies.
- **Thrust 3 in the National Space Policy 2030** that is to drive the development of space science, technology and increase expertise.

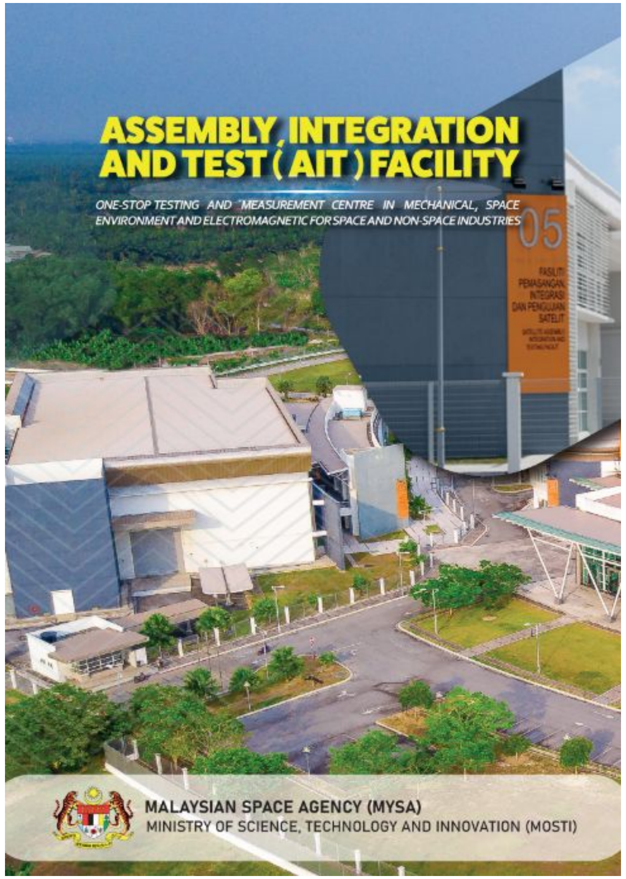


Figure 16. AIT building at Kompleks Teknologi Angkasa, Banting, Selangor

7. Research Findings and Their Implications on Relevant Government Policies

National Space Policy 2030:

Thrust 3: Driving the Development of Space Science and Technology and Building Expertise.

i. Coordinate priorities and activities of R, D, C and I as well as training in space technology.
   - CanSat Competition (Siswasat) for universities and schools;
   - Collaboration with local industry and university to build a CubeSat through Researcher Industry Scientific Exchange program.

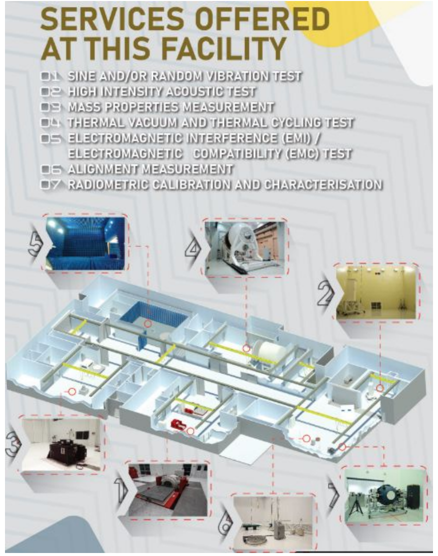
ii. Develop local expertise and competitive domestic industry capabilities.
   - MYSA’s goal now is to further accommodate our testing facilities for nanosatellites through the use of our existing equipment and upgrades.

CanSat Competitions:

MALAYSIA SISWASAT COMPETITION2019

MALAYSIA SISWASAT COMPETITION2020

Services offered at AIT Facility:



8. Conclusion

i. A procedure that combines usage of a thermal analysis software and finite element analysis software to investigate TID phenomenon on a satellite in LEO has been presented.

ii. The skills and experience gained while at Kyutech can assist MYSA in contributing to government policy to increase R&D activities in the space sector.

THANK YOU