# STIFFNESS EVALUATION OF LAPAN-A5/CHIBASAT DEPLOYABLE SOLAR PANEL COMPOSITE PLATE USING SIMPLIFIED FINITE ELEMENT MODEL
# (EVALUASI KEKAKUAN PLAT KOMPOSIT PANEL SURYA LAPAN-A5/CHIBASAT YANG DAPAT DIBENTANGKAN MENGGUNAKAN MODEL ELEMEN HINGGA YANG DISEDERHANAKAN)

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Diterima: 19 November 2018; Direvisi: 7 Januari 2019; Disetujui: 7 Februari 2019

**ABSTRACT**

LAPAN-A5/ChibaSat, that will carry synthetic aperture radar payload, requires a lot more power generation capacity, compared to its predecessor. Therefore, its solar panel will be deployed in orbit to ensure maximum sun exposure. Since the deployable system requires solar panel plate that lightweight, strong and stiff, honeycomb composite material is selected. The selection of such material requires special treatment in the satellite structural stiffness calculation. Typical finite elemen model for such case is 3-layers model, which each layer is individually modeled and therefore used large number of elements. The objective of the research is to find stiffness model of the composite plate that used less number of elements or simplified, while not losing computational accuracy. The modeling used commercial finite element software, and the simplified honeycomb model is validated using standar plate stiffnes problem. After model validation, the boundary condition as in the LAPAN-A5/ChibaSat deployable system is imposed. The result shows that the stiffness of the deployable solar panel plate has met the launch requirement of PSLV's auxiliary payload. Therefore, the design model can be used in the development of LAPAN-A5/ChibaSat.

Keywords: *finite elemen model, deployable solar panel, LAPAN-A5/ChibaSat, honeycomb*

**ABSTRAK**

Satelit LAPAN-A5/ChibaSat, yang akan mempunyai muatan synthetic aperture radar, memerlukan kapasitas daya listrik yang lebih besar dibandingkan satelit-satelit LAPAN pendahulunya. Sehingga panel suryanya akan dibentangkan saat di orbit untuk memaksimalkan paparan sinar matahari. Bahan komposit honeycomb dipilih sebagai plat pembentang panel surya, karena harus ringan, kuat dan kaku. Pemilihan bahan yang khusus tersebut memerlukan perlakukan khusus saat perhitungan kekakuan struktur satelit. Pemodelan elemen hingga yang umum bagi kasus tersebut adalah dengan memodel tiap lapis plat, sehingga jumlah lemen menjadi banyak. Tujuan dari penelitian adalah mendapatkan model kekakuan plat komposist panel surya dengan jumlah elemen yang lebih sedikit, atau lebih sederhana. Pemodelan dilakukan dengan mengunakan perangkat lunak elemen hingga, dan model *honeycomb* sederhana divalidasi dengan kasus kekakuan plat standar. Setelah itu, kondisi batas sesuai dengan system pembentang panel surya LAPAN-A5/ChibaSat. Hasil pemodelan menunjukkan bahwa kekakuan plat pembentang panel surya yang didesain telah memenuhi persyaratan peluncuran untuk roket PSLV. Sehingga moda desain tersebut dapat digunakan dalam pengembangan LAPAN-A5/ChibaSat.


Kata kunci: *model elemen hingga, panel surya, LAPAN-A5/ChibaSat, honeycomb*

## 1 INTRODUCTION

LAPAN-A5/ChibaSat is a SAR micro-satellite joinly developed by National Institute of Aeronautics and Space (LAPAN), Indonesia, and Chiba University, Japan. The satellite will perform land cover and ice observation missions. Augmented with automatic identification system (AIS), the satellite will also carry maritime surveillance mission (Triharjanto, 2018). The reference notes that to perform the mission, the satellite needs a deployable parabolic SAR antenna and deployable solar panels as illustrated in figure 1-1. Unlike previous LAPAN's satellites, i.e. LAPAN-A1/TUBSAT, LAPAN-A2/ORARI, and LAPAN-A3/IPB, LAPAN-A5/ChibaSat requires higher power consumption. Therefore, deployable solar panels are needed for higher battery charging capacity.

During launch, the antenna and the solar panel will be folded, as illustrated in figure 1-2, so that the satellite could comply with the auxiliary payload envelope (Triharjanto, 2018). The figure shows that design of deployment mechanism assuming the use of spring-hinges and release mechanism on the plate containing the solar panel.

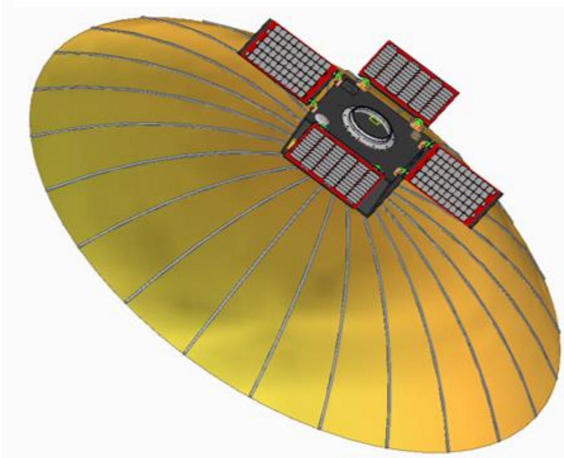

Figure 1-1: In orbit configuration of LAPAN-A5

Structural stiffness analysis, which is measured with natural frequency of the satellite structure is needed to ensure the satellite will not experience any structural failure due to mechanical load during launch. In the development of LAPAN-A1/TUBSAT and LAPAN-A2/ORARI, the structural stiffness analysis of the satellites has been performed using finite element analysis software, and the models are validated by vibration tests (Triharjanto, 2006)

(Huzain, 2013). Similar analysis will be performed for LAPAN-A5. Deployable solar panel, however, required additional structure to support the panel, which does not exist in the body mounted solar panel. The structure will have to be lightweight, strong and stiff, which in this case use honeycomb composite material. The selection of such material requires additional complexity in the satellite structural stiffness calculation

Due to such additional complexity in the satellite design, research is done to support the stiffness modeling effort. The objective of the research is to find simplest stiffness model of the deployable plate, so that later it can be integrated with the total satellite structural model without adding too much complexity. The modeling used commercial finite element software, and the simplified honeycomb model is validated using standard plate stiffness problem.

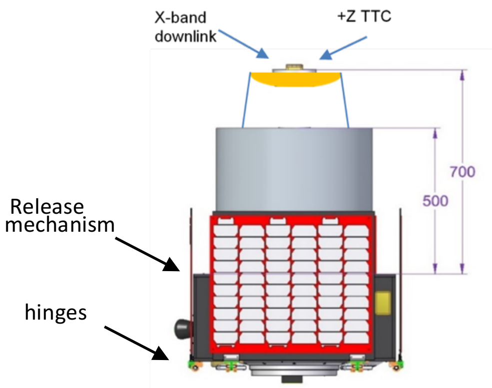


Figure 1-2: Launch configuration of LAPAN-A5

## 2 METHODS

### 2.1 Material Selection

The structure of LAPAN's previous satellites is made of solid aluminum alloy plates, so that the finite element models are fairly simple, i.e.

- solid elements of isotropic material properties with geometry of satellite structure subsystem (7 plates; only modeling cut-out of Z+ plate).
- rigid connection (nodal merging) between all the plates.
- lumped mass representing the satellite components on top and bottom of middle plates.

Triharjanto (2006) and Huzain (2013) showed that for structural dynamic analysis, the models have acceptable validity, compared to the natural frequency measured. It also could predict the displacement of protrusions (UHF/VHF antenna in this case) that need to be considered by the launch authority.

In LAPAN-A5 however, the design challenge is higher since the mass budget for structure is only allocated 30% of the total satellite mass (Triharjanto, 2018). Such requirement is much higher than in LAPAN-A1 and LAPAN-A2, where their structure mass is 50,8% and 43,3% (Triharjanto, 2014). In order so satisfy LAPAN-A5 design requirements, non-coventional materials are to be used.

References show that aluminum honeycomb panel is commonly used as deployable solar panel plate of micro-satellites. This approach was done by DLR's micro-satellits, i.e. BIRD, TET-1, and BIROS (Foeckersperger et. al, 2008) (Halle et. al, 2015), and Tohoku University's microsatellite RISESAT (Kuwahara et. al, 2011). Another approach used CFRP (SSTL, 2016). The manufacture of CFRP, however, not available in Indonesia yet. Meanwhile Aluminum honeycomb can be prepared by national aircraft industry, such as PT. Dirgantara Indonesia.

The material used for LAPAN-A5 honeycomb plate is aluminium alloy 5052 of face/skin with 1 mm thickness, dan aluminium alloy 5052 core of 8 mm thickness. Therefore, the total thickness of material is 10 mm. The dimension of dimensi honeycomb plate is 500 x 500 mm, and the material properties can be seen in table 1-1 (ASM, 2017) and table 1-2 (plascore, 2017).

Tabel 1-1: PROPERTIES OF ALUMINIUM ALLOY 5052

| Item | | Unit |
|---|---|---|
| Density | 2680 | kg/m$^3$ |
| Poisson Ratio | 0.33 | |
| Modulus Elasticity | 70.3 | Gpa |
| Shear Modulus | 25.9 | Gpa |

Tabel 1-2: PROPERTIES OF CORE ALUMINIUM HONEYCOMB AL-5052

| Item | | Unit |
|---|---|---|
| Density | 97.7 | kg/m$^3$ |
| Poisson Ratio 12 | 0.30 | |
| Poisson Ratio 23 | 0.30 | |
| Poisson Ratio 31 | 0.30 | |
| Modulus Elasticity 11 | 0.67 | GPa |
| Modulus Elasticity 22 | 0.283 | GPa |
| Modulus Elasticity 33 | 01.655 | GPa |
| Cell Size | 1/8 | inch |
| Cell Gauge | 0.0015 | Inch |

## 2.2 Honeycomb Simplified Model

The typical FE modeling of honeycomb sandwich is using 3 layers of material, where in the case of aluminum honeycomb, the core will be modeled as orthotropic material. For micro-saellite case, such approach was done by Onta (2007), for stress analysis and estimation of natural frequency.

The objective of creating simplified finite element model is to have model with less numbers of elements, and less number of metarial types, and therefore more efficient. For honeycomb sandwich plate, equivalent plate methods of had been established by Paik (1999). The method is illustrated as in figure 3-1. The equivalent plate method produces simpler model, that in Finite Element terms means use less number of elements.

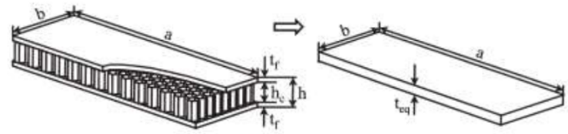

Figure 2-1: Equivalent plate theory illustration for honeycomb plate (Paik, 1999).

The method proposes to replace the honeycomb sandwich panel by an equivalent single plate. To estimate its stiffness, equivalent rigidity method is used. In the method, the equivalent material properties of the single material plate are :

$$t_{eq} = \sqrt{3{h_c}^2 + 6h_c t_f + 4{t_f}^2} \qquad (2\text{-}1)$$

$$E_{eq} = \frac{2t_f}{t_{eq}} \cdot E_f \qquad (2\text{-}2)$$

$$G_{eq} = \frac{2t_f}{t_{eq}} \cdot G_f \qquad (2\text{-}3)$$

where
$t_{eq}$ = equivalent plate thickness
$h_c$ = core thickness
$t_f$ = face/skin thickness
$E_{eq}$ = Young Modulus equivalent plate
$G_{eq}$ = Shear Modulus equivalent plate
$G_f$ = Shear Modulus face/skin

Paik (1999) also proposed equivalent weight method, in which the thickness of equivalent plate ($t_{eq}$) can be calculated from :

$$L.W.\ t_{eq}.\ \rho_f = L.W.2t_f.\rho_f + L.W.\ h_c.\rho_{ca} \qquad (2\text{-}4)$$

Resulting in :

$$t_{eq} = \frac{2t_f.\rho_f + h_c.\rho_{ca}}{\rho_f} \qquad (2\text{-}5)$$

## 2.3 Finite Element Model Validation

Before implementing the model in satellite solar panel case, standard finite element case/problem is performed to validate the model. The case is natural frequency analysis of composite plate in fixed 6 degree of freedom (DoF) constraints at one end and 5 DoF constrains at the other, as illustrated in figure 2-2.

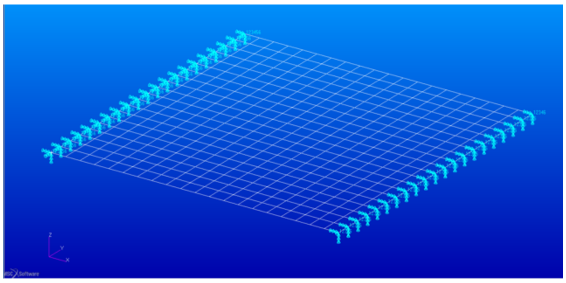

Figure 2-2: Boundary Condition on validation problem

The finite element models are generated using MSC Patran. Both conventional 3-layers and single layer simplified model were implemented at validation problem, and the results will be compared.

Based on formula (2-1) to (2-3) and (2-5) at subchapter 2.2 and material properties at subchapter 2.1, the equivalent plate model has thickness dimension of 15 mm, elasticity modulus of 9 GPa, and poison ratio of 0.33. 400 quad elements were used in the simplified/equivalent model, while 1200 quad elements and 2 material models are required for the conventional model. In the conventional model, the nodes in the contacting laminates are merged or the laminate are asummed to be perfectly bonded. The results of the two models are then compared to see whether the equivalent model can be implemented in LAPAN-A5 solar panel model.

## 3 RESULTS AND DICUSSIONS

### 3.1 Validation Case

Figure 3-1 and figure 3-2 show the shape modes of the 1st 3 natural frequencies from the conventional or 3-layer honeycomb model, and the equivalent honeycomb model. The results show that the two models have the same shape mode for their natural frequencies, except that the 2nd mode is in reversed direction. This indicates that the two models have very similar structural dynamics characteristics.

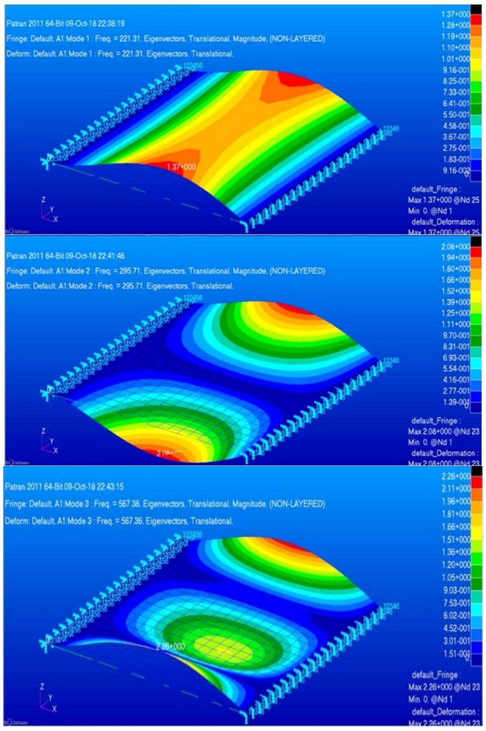

Figure 3-1: 1st, 2nd, and 3rd natural frequency from 3-layer honeycomb plate model

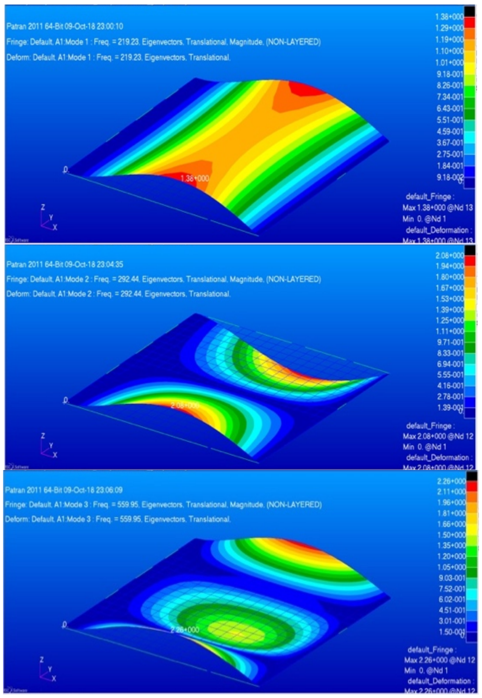

Figure 3-2: 1st, 2nd, and 3rd natural frequency from equivalent honeycomb plate model

The natural frequencies resulted from the models are noted in table 3-1, which show that the different is very small (under 1,3%). This means that the accuracy of the equivalent model is high enough to be used in the LAPAN-A5 honeycomb plate stiffness. The benefit from the use of the equivalent model is only used 1/3 number of the elements used in conventional model, and 1 material properties.

Tabel 3-1. HONEYCOMB PLATE MODELS NATURAL FREQUENCIES COMPARISON

| | Laminated Model | Equivalent Plate | Percent Difference |
|---|---|---|---|
| 1st Nat. Freq. | 221.31 Hz | 219.23 Hz | 0.94 % |
| 2nd Nat. Freq. | 295.71 Hz | 292.44 Hz | 1.11 % |
| 3rd Nat. Freq. | 567.36 Hz | 559.95 Hz | 1.31 % |

## 3.2 LAPAN-A5 Deployable Panel Model

The model of LAPAN-A5 deployable panel is shown in figure 3-3. The boundary condition in model is 5 DoF constrains in the left side of plate, i.e. no displacement of *x*, *y* and *z*, and no rotation of *x* and *z*, while rotation at y is free to represent the two hinges as illustrated in figure 1-2. 6 DoF constrain is applied near the right side of the plate to represent the hold-down/latch mechanism. Two additional 2 DoF constraints (no displacement in *x* and *z*) represent the two conical contact points (to prevent clapping effect). Total elements in the model is 400, with quad-4 type being used.

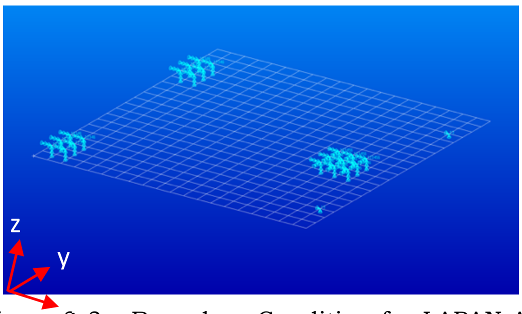

Figure 3-3: Boundary Condition for LAPAN-A5 deployable panel

The result of the analysis is shown in figure 3-5, which show that the 1st Natural Frequency occur at 344.21 Hz.

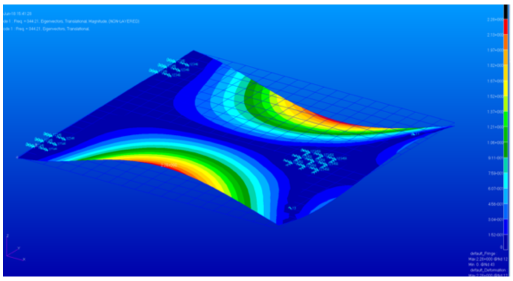
Figure 3-5: Simulation result of deployable panel model

The result shows that with 10 mm thickness, the honeycomb plate of 500 x 500 mm has enough stiffness to support deployable solar panel of a satellite launched by PSLV, i.e. 1st natural frequency higher than 90 Hz.

## 4 CONCLUSIONS

Simplified finite element model has been developed for honeycomb plate to be used as deployable solar panel of LAPAN-A5/ChibaSat. The model has been validated by comparing its structural stiffness result with concentional (3-layers) model.

The analysis shows that Aluminum Alloy 5052 honeycomb plate with 10 mm thickness, and 500 x 500 mm area has enough stiffness to be used for deployable solar panel for LAPAN-A5/ChibaSat, which projected to be launched with PSLV-class launcher. The model can later be integrated with the total satellite structural dynamics model.

## ACKNOWLEDGEMENTS

Authors wish to acknowledge Satellite Technology Center, LAPAN, for supporting this research, and Mr. Muhammad Hamzah Farrasamulya, student of Aeronautics and Astronautics Institut Teknologi Bandung, for his valuable discussion at the beginning of this research.

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