

## Deployment Behaviors of CFRP Reflector under Zero-gravity Environment

Seungho Chae, Young-Eun Oh, Soo-Yong Lee, Jin-Ho Roh<sup>†</sup>

*School of Aerospace and Mechanical Engineering, Korea Aerospace University  
Goyang, KOREA*

*<sup>†</sup>E-mail: jinhoroh@kau.ac.kr*

### Abstract

A deployment mechanism is designed to stow into a small volume efficiently. The panels are fabricated by carbon fiber reinforced plastics (CFRPs). The parameters for the deployment are determined by considering the number of panels, the folding/twisting angles, and the driving force for a deployment device. In addition, a surface accuracy of the manufactured reflector is measured through a photogrammetry methodology. The deployment behavior of CFRP reflector is observed by using the zero-gravity device which compensates the gravity effect during the deployment. The zero-gravity device is constructed wire, motor, controller and loadcell. During the deployment of the reflector panel, the wire and motor compensate for its weight by the feedback process of the controller. Tests result show that a zero-gravity device compensates for the weight of the panel during the deployment of the CFRP reflector.

**Key Words :** Deployable antenna, CFRP, Zero-gravity device

### 1. Introduction

Small satellites with a synthetic aperture radar (SAR) antenna have been applied for the earth environment observation. A larger reflector increases the gain of the SAR, but increases the cost of the payload carrying the reflector. So, it is necessary to develop the lightweight and large reflector that can be folded into a small storage volume as possible and be deployed for the its mission in space. Deployable reflector antennas are classified into the solid, the mesh and the inflatable types of reflectors. The solid type antenna with several unfurlable panels has a

higher frequency bandwidth and a better surface accuracy than other types of antenna [1]. Deployable mechanism of the solid type reflector antenna has been actively or passively controlled. In addition, panels of the reflector are made of composite materials which have a high specific strength/stiffness of which property is useful for extreme environmental conditions in space.

The reflector antenna must have a reliable deployment characteristic. In addition, the reflector should be deployed as slowly as its behavior can not affect the satellite dynamics [2]. The accuracy of the deployed configuration should be verified through the deployment test because its shape after deployment also affects the RF performance of the antenna [3].

In this research, dynamic characteristics of the deployable composite parabolic reflector with several panels are investigated. The deployment mechanism is designed by considering number of panels,

---

Received: Oct. 01, 2018 Revised: Jan. 14, 2020 Accepted:  
Jan. 27, 2020

<sup>†</sup> Corresponding Author

Tel: +82-2-300-0289, E-mail: jinhoroh@kau.ac.kr

© The Society for Aerospace System Engineering

---

folding/twisting angles, and driving forces. The reflector is unfolded with 2-directional rotation of the panels which are fabricated by carbon fiber reinforced plastics (CFRPs). The surface accuracy of the manufactured reflector is measured through photogrammetry method. Moreover, a zero-gravity device is established using rails, springs, and loadcells for checking whether weight of the panel is compensated or not during the deployment. Finally, the deployment characteristics of the reflector are observed.

## 2. Fabrication of Deployable Reflector

### 2.1. Conceptual design of deployment mechanism

The deployment mechanism is designed for a parabola reflector to be folded/unfolded without interferences among panels linked into the central hub disk. So, the diameter of the antenna, the focal length and the radius of the central hub disk should be determined as the design parameters [4–5].

During the deployment, a motion of the reflector panels is represented by using the Euler transformation (Eqs. 1–2).

$$T = \begin{bmatrix} T_{xx} & T_{xy} & T_{xz} \\ T_{yx} & T_{yy} & T_{yz} \\ T_{zx} & T_{zy} & T_{zz} \end{bmatrix} \quad (1)$$

$$\begin{aligned} T_{xx} &= (1 - \cos\emptyset)a_x^2 \cos\emptyset \\ T_{yy} &= (1 - \cos\emptyset)a_y^2 \cos\emptyset \\ T_{zz} &= (1 - \cos\emptyset)a_z^2 \cos\emptyset \\ T_{xy} &= (1 - \cos\emptyset)a_x a_y + a_z \sin\emptyset \\ T_{xz} &= (1 - \cos\emptyset)a_x a_z - a_y \sin\emptyset \\ T_{yx} &= (1 - \cos\emptyset)a_y a_z - a_x \sin\emptyset \\ T_{yz} &= (1 - \cos\emptyset)a_y a_z + a_x \sin\emptyset \\ T_{zx} &= (1 - \cos\emptyset)a_x a_z + a_y \sin\emptyset \\ T_{zy} &= (1 - \cos\emptyset)a_z a_y - a_x \sin\emptyset \end{aligned} \quad (2)$$

Where  $\mathbf{a}$  represents the direction vector of the panel at the local coordinate system and  $\emptyset$  indicates the rotation (twisting and folding) angle of the panel. Figure 1 shows the transformed panel using the Euler transformation in the folded and deployed states, respectively. The reflector should be divided into several panels and be folded/unfolded by using two rotational degree of freedom such as folding and twisting angles. As the design parameter to be determined for the folded volume as small as possible, the number of panels and folding/twisting angles are determined by using several iterative simulations. So,

30 number of panels, 70° folding and 40° twisting angles are determined (Fig. 2). During unfolding procedure, any interaction between adjacent panels may cause an incomplete deployment. So, the trajectory of the panels is observed whether there are interferences between panels or not (Fig. 3). Finally, kinematic behavior of the panels can be investigated.

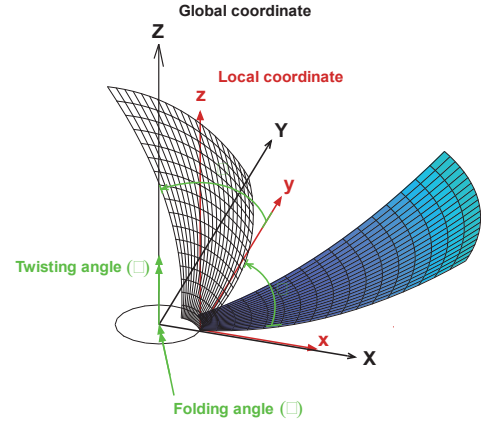


Fig. 1 Euler Transformed Panel

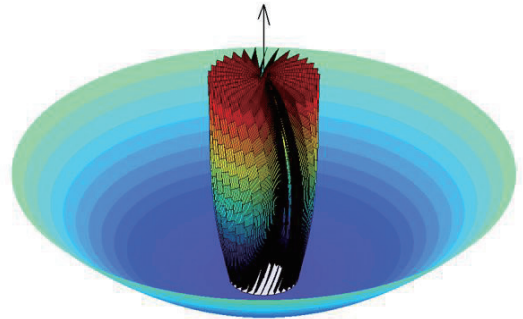


Fig. 2 Folded/unfolded Reflector Configuration

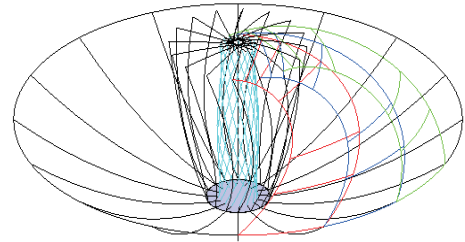


Fig. 3 Trajectory of Deploying Panels

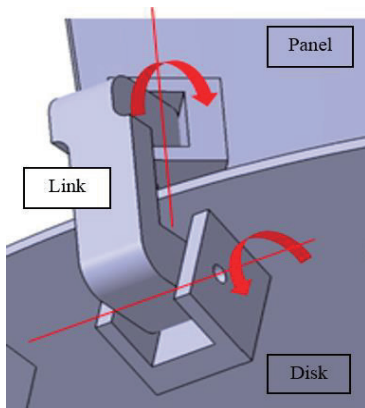
## 2.2. Fabrication of the composite panels and deployment mechanism device

Considering the outgassing problem in space, M55J/RS3 is used for a material of the reflector panel [6–7]. To minimize a thermal deformation in space which cause to reduce a RF performance of the antenna, the  $0^\circ$  and  $90^\circ$  laminated sequences are applied [8]. For curing the composite panel, an autoclave is used under recommended temperature and pressure for each curing cycle. The condition of a curing cycle, dependent on material characteristics, is a very important to precisely fabricate the designed configuration of the panel. Fig. 4 shows the fabricated panel.



**Fig. 4** Composite Reflector Panel

To implement deployment mechanism, the link, makes panels to be connected to the central hub disk with two rotational degrees of freedom, should be designed. Therefore, as shown Fig. 5, the shaft axis is considered so that the panel can be twisted and folded with respect to the hub disk.

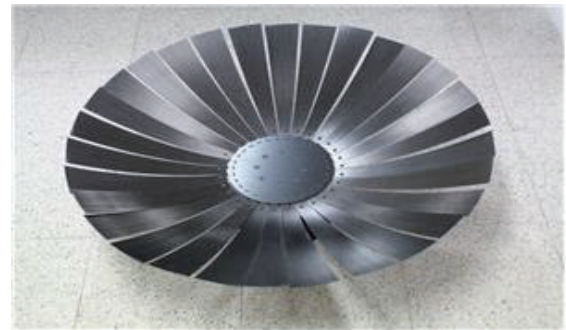


**Fig. 5** A Link with 2 D.O.F for the Deployment Mechanism

Rotational force to deploy the panels is generated by using torsional springs. For the synchronized deployment, the same spring coefficient are constructed to fit with each shaft. Figures 6 and 7 show finally fabricated composite reflector in state of the folded and the deployed states, respectively.



**Fig. 6** Folded Composite Reflector

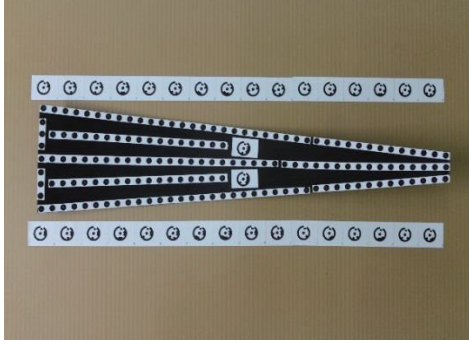


**Fig. 7** Deployed Composite Reflector

## 3. Surface Accuracy Measurement

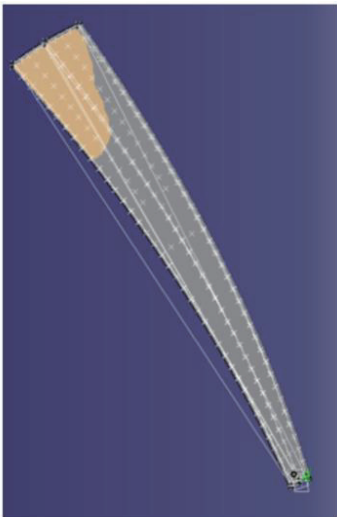
The photogrammetry methodology is used to confirm whether the panels are precisely fabricated as designed configuration. The method uses digital cameras to obtain a three-dimensional configuration based on a triangulation methodology. Unlike other three-dimensional measurement techniques, the infinite triangulation information can be represented simultaneously [9]. For the three-dimensional configuration of an object, at least two photos in another angle are needed [10]. The reflected target is attached to the reflector panel and five pictures are taken from the front, right and left sides. Figure 8

shows the prepared panel on which the reflected tapes are attached for the photogrammetry.



**Fig. 8** Prepared Panel for the Photogrammetry

After the target marking is completed, the three-dimensional values are obtained from five photographs. By displaying these coordinates through the commercial program, an accuracy of panel's configuration can be evaluated. The configuration error between the manufactured panel and the designed panel is observed (Fig. 9). The surface error is summarized in Table. 1. The maximum error is observed in an edge of the panel because curvatures of the panel in radial and circumferential directions make a difficulty in the curing to perfectly inject the resin into the material.



**Fig. 9** Comparison of the Surface Configurations

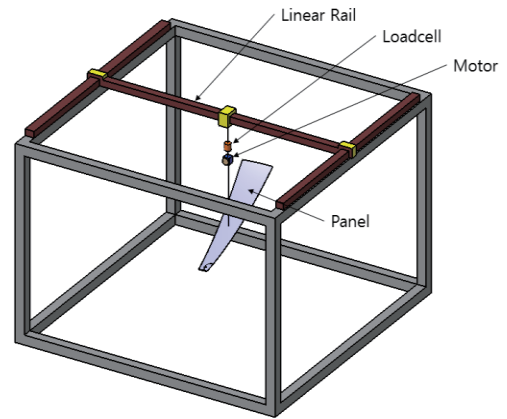
**Table 1** Surface Accuracy of the Panel

|           |           |
|-----------|-----------|
| Max Error | 0.982 mm  |
| Min Error | 0.017 mm  |
| RMS Error | 0.6625 mm |

#### 4. Zero-gravity Deployment Test

Unlike the ground with gravity, the space environment is governed with micro-gravity. A zero-gravity environment similar to the space environment must be simulated to carry out the ground deployment test.

An experimental device that compensates gravity of the reflector is developed as Fig. 10. The reflector panels translate and rotate during the deploying procedure. The rail with bearing is installed to follow this trajectory without friction. A loadcell is used to estimate the weight applied in the panel. A wire holding a center of gravity of the panel is connected to the motor. By using a pulley, they can be stretched together when the panel is unfolded. If the wire is loosened and the load is changed, a controller is required to regain the load to maintain a constant load. So, this device is able to compensate the load of the panel efficiently and make the panel be deployed without gravity.

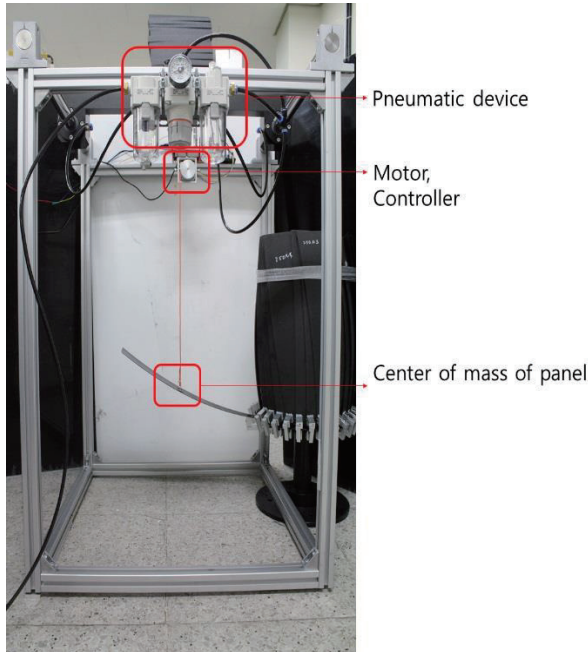


**Fig. 10** Gravity Compensation Device

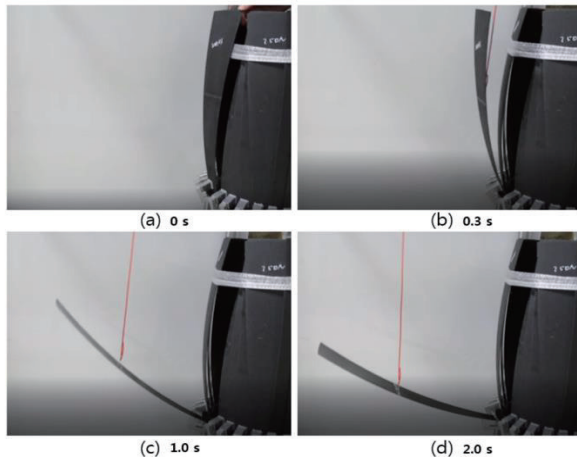
The deployment test is conducted to confirm the performance of the deployment mechanism (Fig. 11). The deployment test device uses the pulleys and wires along the expansion direction of the antenna panel and designed to minimize the friction of the rail by using air bearing. Figure 12 shows the process of deploying antenna panel under zero-gravity. As the



effect of gravity decreases, the speed of the panel's deployment slows, and an impulse at the end of the deployment is minimized.



**Fig. 11** Zero-Gravity Deployment Test Device



**Fig. 12** Deployment Sequences

## 5. Conclusions

The deployable parabolic reflector is conceptually designed and its deployment characteristics are experimentally and numerically investigated. The design parameters for the deployment are determined by considering the number of panels, folding/rotation angles, and the driving forces of actuating devices. In

addition, surface accuracy of the manufactured reflector is measured by using the photogrammetry. For the unfolding test, the zero-gravity simulator is established using a rail, a spring, and a loadcell. Finally, deployment responses of the reflector are demonstrated with the zero-gravity test.

## Acknowledgement

This work was supported by the Global Surveillance Research Center (GSRC) and funded by the Agency for Defense Development.

## References

- [1] Taek-Kyung Lee, "Design of Deployable Lightweight Antenna for Satellite SAR", *The Journal of Korean Institute of Electromagnetic Engineering and Science*, Vol. 25, No. 11, pp. 1104-1112, 2014.
- [2] Won Ho Cha, Goo-hwan Shin. "Research of Ground Test Equipment for Zero-gravity Deployment Test." *The Korea Society for Aeronautical and Space Science Conference*, 1020-1021, 2017
- [3] Kozba, Carl R, "Space Qualification Testing of Shape Memory Alloy Deployable Cubsat Antenna," Technical Report, AFIT WPAFB, United State, 2016.
- [4] Suk-yong Jeong, Seung-Yup Lee, Min-Ji Bae and Ki-Dae Cho, "Configuration Design of a Deployable SAR Antenna for Space Application and tool-kit Development", *Journal of The Korean Society for Aeronautical and Space Sciences*, Vol. 42, No. 8, pp. 683-691, 2014.
- [5] Seung-Yup Lee, Suk-yong Jeong, Yoon-hyuk Choi, Ki-Dae Cho, "Mechanism Modeling and Analysis of Deployable Satellite Antenna." *Journal of the Korean Society for Aeronautical & Space Sciences*, Vol.42, No.7, pp. 601-609, 2014.
- [6] Hyo Yeol Na, Byung Chul Yoon, Seung Hwan Kim and Seong Jae Lee, "Chemorheological Behavior of Cyanate Ester Resin and Properties of Carbon Fiber Reinforced Polymer Composite," *Elastomers and Composite*, Vol. 48, No. 2, pp. 133-140, 2013.
- [7] Michael L. Ramirez, Richard Walters, Richard E. Lyon and Edward P. Savitski, *Polymer Degradation and Stability*, Vol. 18, No. 1, pp. 73-82, 2002.
- [8] Sang-hee Kim, Optimal Analysis of Composite Reflector Panels using SQP Method, *Master Dissertation*, Korea Aerospace University, Korea, 2015.

- [9] Richard S. Pappa, Thomas W. Jones, Jonathan T. Black, Alan Walford, Stuart Robson and Mark R. Shortis, “Photogrammetry Methodology Development for Gossamer Spacecraft Structure.” *AIAA Paper* 1375, 2002.
- [10] Choi Jung-su, Park Eung-Sik, Kim Hyung-wan and yoon Yong-Sik. Han, “Current status and application of Photogrammetry”, *Current Industrial and Technological Trends in Aerospace*, Vol. 6, No. 2, pp. 80-89, 2008.