References

[1]Robbins, M. J., "Ground Test Program for New Atlas Payload fairing," *Research in Structures, Structural Dynamics and Materials*, NASA CP-3064, April 1990, pp. 194–205.

[2]Yasunaga, Y., Fukushima, Y., Nakamura, T., and Fujita, T., "Separation Jettison Test of Japanese H-ll Rocket Satellite Fairing," *Proceedings of the 28th Aerospace Sciences Meeting*, AIAA, Washington, DC, 1990, pp. 1–8.

[3]Kandebo, S. W., "Payload Capacity of Titan 4 to Expand with New Fairing," *Aviation Week and Space Technology*, 10 Dec. 1990, pp. 58–62.

[4]Anjaneyalu, M., Sudhakara Rao, K., and Srinivasan, S., "The Polar Satellite Launch Vehicle and Mission for the Indian Remote Sensing Spacecraft," International Astronautical Federation, IAF-88-168, Paris, 1988, pp. 1–8.

[5]Steinmeyer, J. F., Hofeditz, J. T., and Brierley, J. M., "Separation Testing of the Titan IV 86 ft Payload Fairing," *13th Proceedings of Aerospace Testing Seminar*, Inst. of Environmental Sciences, Manhattan Beach, CA, 1991, pp. 241–250.

[6]Cheng, S. C., "Payload Fairing Separation Dynamics," *Proceedings of the 35th Structures, Structural Dynamics, and Materials Conference*, AIAA, Washington, DC, 1994, pp. 2353–2359.

[7]Lochan, R., Adimurthy, V., and Kumar, K., "Separation Dynamics of Heatshield Fairing," *Journal of Aerospace Engineering*, Vol. 211, Pt. G, 1997, pp. 67–80.

[8]Elayuthu, M. N. G., and Abdul Salam, E. M., "Elastic Response of a Launch Vehicle Payload Fairing to Separation Shock," *Proceedings of International Conference on Finite Elements in Computational Mechanics*, Pergamon, New York, 1985, pp. 807–814.

[9]Zienkiewicz, O. C., *The Finite Element Method in Engineering Sciences*, 3rd ed., Tata McGraw–Hill, New Delhi, India, 1989, pp. 226–265, 329–353.

[10]Ramamurti, V., *Computer Aided Mechanical Design and Analysis*, Tata McGraw–Hill, New Delhi, India, 1992, pp. 7–9, 121–151, 240–248.

R. B. Malla
Associate Editor

Simulation for Deployment of an Inflatable Disk in Orbit

Kentaro Takahashi*
Mitsubishi Heavy Industries, Ltd., Yokohama 236-8515, Japan
and
Harunori Nagata† and Isao Kudo‡
Hokkaido University, Sapporo 060-8628, Japan

Introduction

A SMALL satellite is planned to be launched as a piggyback payload on a Japanese H-II vehicle to further investigate the cold-welding phenomenon that is observed when welding two metal rods together without heating in the ultrahigh-vacuum wake produced behind an orbiting spacecraft. Satellites that utilize the same concept have flown on the space shuttle several times before.[1] Because the allowable volume for the satellite is $50 \times 50 \times 50$ cm^3 and its maximum weight is 50 kg, a 2-m-diam wake shield disk must be folded at launch and deployed in space. An inflatable tube and disk were adopted for this purpose. The advantages of an inflatable structure can be seen in the weight reduction, small packaging volume, low production cost, and high reliability of deployment compared with a conventional mechanically erectable structure.[2,3] However, at the NASA-sponsored In-Space Technology Experiment Program (In-STEP) flight experiment on the Spartan207 satellite in 1996, two supporting inflatable struts doubled during the deployment. Even if doubled tubes were finally solved by adding gas into the tube, it was indicated that care must be taken regarding the behavior of the tube during its deployment. In the case of an inflatable wake shield, its behavior must be cleared before launch. Figure 1 shows the test satellite, and Fig. 2 shows the deployment scheme of the inflatable disk. The structure is a membrane disk supported by an inflatable tube that is placed at the center of the disk extending in the radial direction and continuing around the peripheral of the disk. Before launch, the disk is folded multiple times, and it is deployed on orbit by introducing nitrogen gas into the inflatable tube, as in Fig. 2. The disk and its tube are constructed of heat-resistant polyimide resin. Because it is an extremely small outgassing material, pressure around the satellite will be below 10^{-9} Pa, and, just after the orbit insertion, the wake shield surface will be directed toward the sun to degas the sticking gas on the disk and tube. This Note describes the behavior during deployment of the inflatable disk and tube.

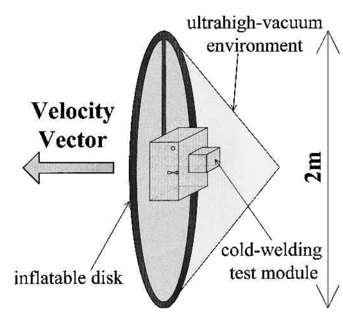

Fig. 1 Cold-welding test satellite.

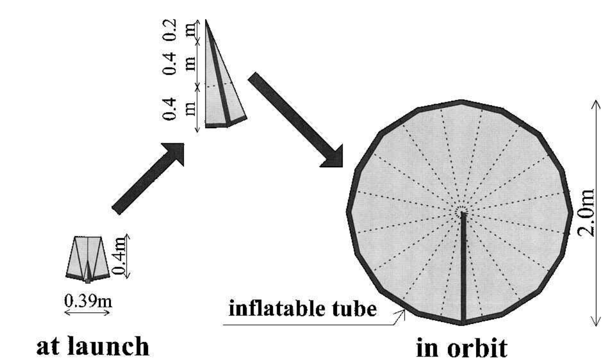

Fig. 2 Scheme of deployment of inflatable disk.

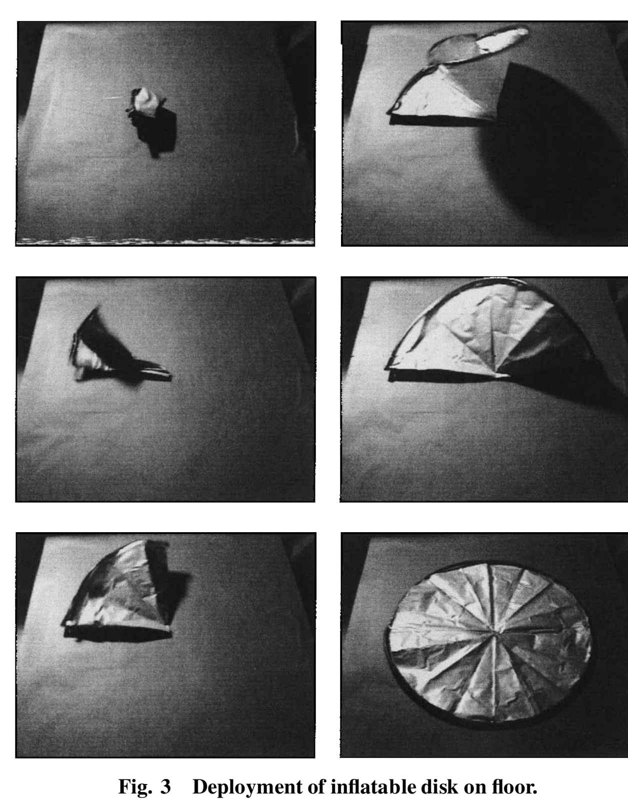

Fig. 3 Deployment of inflatable disk on floor.

Received 20 April 2000; revision received 30 June 2000; accepted for publication 15 July 2000. Copyright © 2000 by the authors. Published by the American Institute of Aeronautics and Astronautics, Inc., with permission.

*Engineer, Yokohama Works, 8-1, Sachiura, 1-chome, Kanazawa-ku.

†Assistant Professor, Faculty of Engineering, North 13, West 8, Kita-ku.

‡Professor, Faculty of Engineering, North 13, West 8, Kita-ku. Senior Member AIAA.

Test and Results

Two ground simulation methods for deployment were tested. The first one, which utilized a 1:4 scale model disk, was carried out on a floor under 1 g. The behavior during deployment was monitored using a charge-coupled device camera. This simulation is a very inexpensive and simple method. Expansion from the stowed shape, a, to the deployed shape, f, is shown in Fig. 3. The behavior on the floor apparently simulated the deployment in the space environment. However, we had overlooked that the disk was deployed by the spring force of the folded tube against the floor, that is, deployment in orbit could not use such restoring force. Therefore, the deployment behavior was completely different from that under microgravity.

The second simulation test was carried out at the Japan Microgravity Center facility, which provides 10-s-duration microgravity on the ground. A 1:10 scale model disk was fabricated and placed in a test apparatus as shown in Fig. 4. Owing to volume limitation of the drop capsule, the scale of the disk had to be changed to $\frac{1}{10}$ of full-scale model. The disk was a combination of a 200-mm-diam paper circle and a 4-mm-diam polyethylene tube. Although polyimide resin, which was characterized as small outgassing material, should be used as a test material through the ground test, we chose polyvinyl chloride for the floor test and paper for the dropshaft test because resin could not maintain the proper folded configuration when it was set up in the air, that is, it drooped downward. The inflatable disk was intended to deploy as shown in Fig. 5.

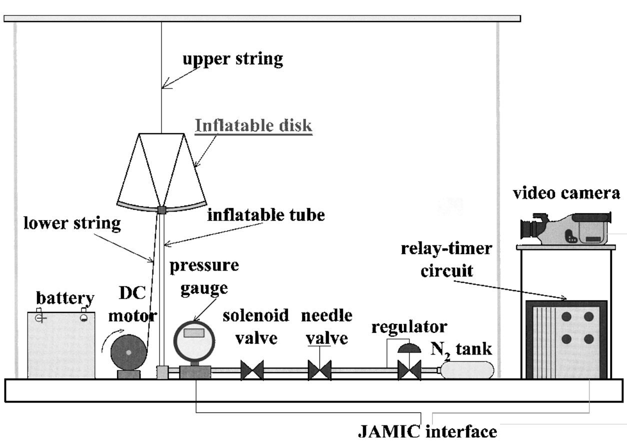

Fig. 4 Inflatable disk for microgravity test.

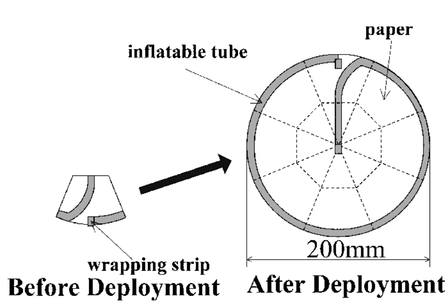

Fig. 5 Test apparatus.

The disk was folded three times and then once more in the radial direction. A wrapping strip fixed the folded model, preventing it from unfolding. The strip was used as a result of simplicity and safety considerations at the ground test. In the space experiment, pyrotechnics will be used for this purpose. The apparatus was placed in a drop capsule that was dropped into the 700-m-high dropshaft. The folded disk was pulled from the ceiling of the apparatus by an upper string. After the drop command was given, a lower string was pulled with a dc motor to cut the wrapping strip. At 0.9 s after the signal, a solenoid valve was opened, and nitrogen gas was introduced into the inflatable tube. Two video cameras monitored the deployment of the disk. After 2.2 s, the wrapping strip was actually cut by the lower string and deployment started. The disk was completely deployed at 4.5 s. Figure 6 shows the deployment of the inflatable disk with a gas flow charge in the tube. A sudden increase in the gas flow occurred at 2.3 and 4.5 s, resulting from the extension of the folded tube and further gas flow to the tube. Pressure at the gauge was monitored, and it showed 0.37 MPa during the test. The disk was deployed in a fashion quite similar to the one that had been deployed as a reference test in a 1-g environment prior to the microgravity test. These ground tests were carried out in the air. The effect of drag force on the disk at the deployment was estimated to be 5% of tube's restoring force when acting drag force was $D = (\frac{1}{2})\rho V^2 C\,\mathrm{d}A$. The behavior of the disk deployment and gas flow characteristics in the dropshaft is considered to simulate deployment in orbit.

Conclusion

Two deployment methods of an inflatable tube and a disk model were compared. The first method was carried out under conditions in which a test specimen was placed on the floor. It was found that the inexpensive and simple deployment of an inflatable structure on the floor has a substantial flaw because a portion of the disk interacted with the floor. On the other hand, at the second simulation, in which the test specimen was placed in the air, data obtained at both the dropshaft test and 1-g ground test before a microgravity test showed satisfactory simulation.

References

[1]Ignatiev, H. C., "Epitaxial Thin Film Growth in Low Earth Orbit on the Wake Shield Facility," AIAA Paper 95-3853, Sept. 1995.

[2]Veal, G., and Freeland, R., "IN-STEP Inflatable Antenna Description," AIAA Paper 95-3739, Sept. 1995.

[3]Takano, M., Nagata, H., and Kudo, I., "Deployment of an Inflatable Tube Under Microgravity Condition," *Transactions of Japan Society of Mechanical Engineering*, Vol. 65, No. 633C, 1999, pp. 1978–1984.

I. E. Vas
Associate Editor

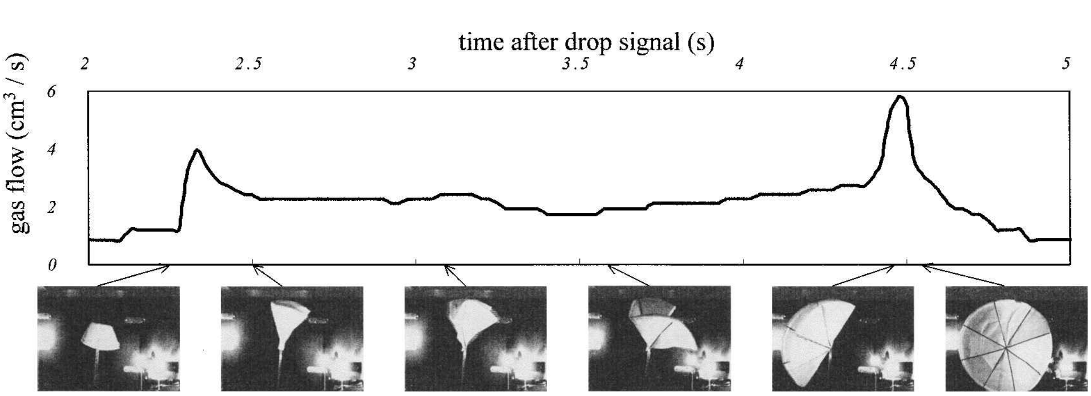

Fig. 6 Gas flow charge in the tube and behavior of the inflatable disk.