3-3 Large Deployable Reflector (LDR)

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Large Deployable Reflectors (LDRs) are carried on Engineering Test Satellite VIII (ETS-VIII), which is scheduled to be launched in 2004 (JFY) and demonstrates mobile communications via geostationary satellite using cellular-phone-sized terminals. LDR is required to have a tennis-court-sized reflector and high accuracy of its surface. To meet the requirements, LDR is designed based on a modular-mesh concept in which the structure consists of several basic modules. This paper describes concept of design and verification tests of LDR.

Keywords
Large Deployable Reflector, LDR, Engineering Test Satellite VIII, Deployable antenna

1 Introduction

Large Deployable Reflectors (LDRs) will be installed on the Engineering Test Satellite VIII (ETS-VIII) scheduled to be launched in 2004. To allow for mobile satellite communications via small handheld terminals, the LDR must be larger than any such reflector in existence today (with a surface of approximately 19 m × 17 m), and to offer sufficiently high surface accuracy of the reflector (2.4 mm RMS) to support S-band communications (2.5 / 2.6 GHz). To permit the construction of such an LDR, we are currently working to establish the following technologies:

(1) Engineering design of cable-mesh deployable antenna structure

The reflecting surface structure, consisting of metal mesh and cables, is supported by a deployable truss structure; this configuration provides efficient folding operations and a highly accurate reflection surface.

(2) Engineering design and verification testing of a modular deployable structure

The large-scale structure is to be constructed using elements (modules) featuring a degree of dimensional accuracy that will allow precise manufacture, adjustment, and verification testing. Linking multiple modules will provide greater accuracy, reliability, and expandability than available under conventional designs involving the manufacture and testing of a large-scale integral structure.

(3) Coupled analysis of cable-mesh and truss structures, and motion analysis of the flexible structure

The structural characteristics of the flexible nonlinear deployable structure are precisely analyzed, ensuring high surface accuracy and reliable deployment.

This paper describes the design, development, and verification of the LDR.

2 Outline of LDR

2.1 Structure of LDR

Two LDRs are to be deployed on the ETS-VIII. One LDR will serve as a transmission reflector and the other will function as a reception reflector. When both LDRs are fully deployed, the reflector area of the LDR will be as broad as a tennis court (Fig.1). Whereas conventional large reflectors are designed, manufactured, and tested as integral structures, the LDR features a modular design in which structural elements (modules) of high dimensional accuracy are combined to allow for highly precise manufacture, adjustment, and verification ground testing. Fig.2 shows a single module.

Each module features a reflector surface made of radio-reflective metal mesh (gold-plated molybdenum) and a cable network, all supported by a truss structure. A parabolic surface is formed by adjusting the lengths of the rod members (standoff) forming the truss structure of each module and by extending the rods from the vertexes of the hexagon formed perpendicular to the reflector surface. In order to guarantee an orbital service life of 10 years for the materials constituting these modules (e.g., cables, mesh, CFRP), various types of service tests (involving ultraviolet rays, radiation, etc.) were conducted, and the design was modified to reflect the results of these experiments.

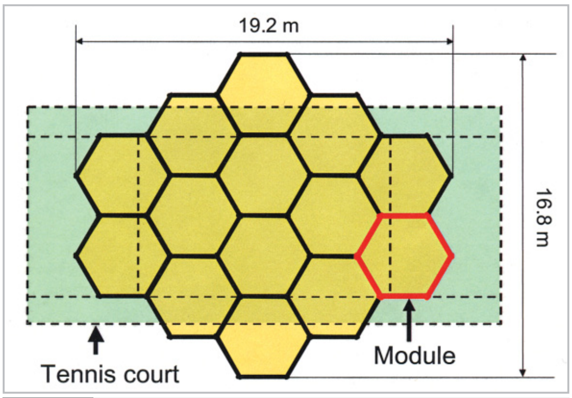

Fig.1 Schematic diagram of deployed LDR

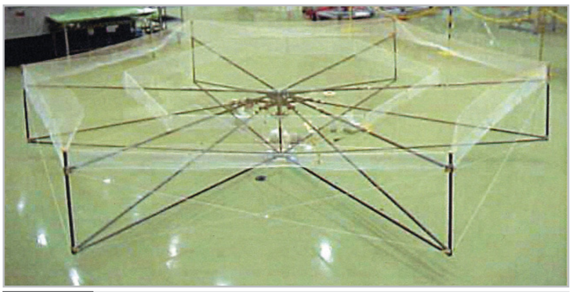

Fig.2 Single LDR module

2.2 LDR deployment

The deployment mechanism is shown in Fig.3. The principle behind the deployment of the LDR is the same as that of an automatic umbrella; a spring is attached to the center of the module. Additional springs are mounted on the structure to provide sufficient force for initial deployment.

In order to ensure a controlled deployment speed for each module and to synchronize deployment of the modules, the length of wires extending from the deployment mechanism are controlled. These wires are gradually extended by means of stepping motors, with a total of four such motors controlling the deployment of the 14 modules of the LDR. Fig.4 shows the arrangement of the motors.

Fig.5 shows the configuration of the LDR at the time of launch. The LDR is designed to withstand the load at launch. When the LDR is within the stowing the reflector is held in

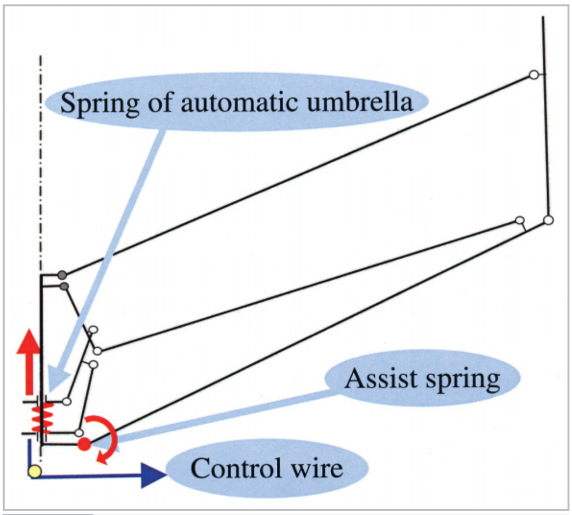

Fig.3 LDR deployment mechanism

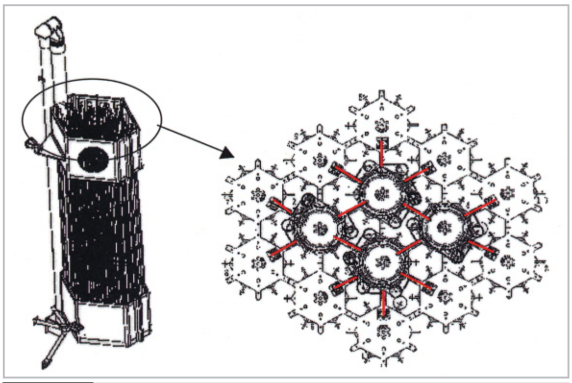

Fig.4 Arrangement of deployment motors

place by two mechanical arms equipped with hold-on/release mechanisms (HRMs).

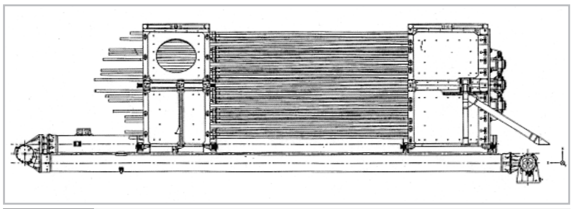

Fig.5 *Configuration of the LDR at the time of launch*

3 Outline of development of LDR

3.1 LDR development schedule

Preliminary design of the LDR began in 1997. A basic design was completed in 1998, followed by critical design from 1999 to 2001 and design follow-up currently underway in 2003. Test breadboard model (BBM) including seven modules modified to reflect the results of preliminary design was manufactured and was put through various tests, which confirmed the feasibility of the basic technologies involved.

Next, engineering model (EM) including 14 modules was manufactured to reflect the results of basic design and BBM testing, providing subsequent confirmation of the overall feasibility of the flight model. At the same time, the deployment performance and reliability of the LDR were evaluated through coupled analysis of the cable-mesh and truss structures using, among other means, the analysis program “SPADE” (NTT Network Innovation Laboratories) for flexible structures. Based on the results of these development tests, fully functional machines of a prototype flight model (or “PFM,” designed for reception) and a flight model (“FM,” for transmission) were manufactured and subject to testing (separately, each as a single LDR) in September 2003. Testing of the flight model integrated with the satellite main body will begin in early 2004.

3.2 Features of LDR development testing, in-orbit experimentation, and reflection

In conventional deployable structures (involving solar paddles, for example) accurate orbital deployment was ensured through ground deployment tests in which specimens were suspended in order to counteract the effects of gravity. However, deployment of the LDR is more complex than the single-step deployment of conventional structures. The behavior of the LDR is thus more difficult to predict using such suspension techniques. Consequently, we decided to add the following tests, based on the conclusion that ground experimentation alone was insufficient to guarantee successful orbital deployment.

(1) Micro-gravity test using aircraft (using BBM)
(2) Orbital experiment using a small model via the rocket-borne “piggy-back” method
(3) Deployment test in a vacuum chamber

Among the above-described tests, (2) provided the most useful results. In this orbital experiment, a small partial model (LDREX) of the large deployable reflector was chosen as the test specimen, and was carried “piggy-back” on an Ariane 5 rocket. The LDREX was half the size of the actual machine, with 7 modules. Fig.6 shows the installation of the LDREX on the Ariane 5.

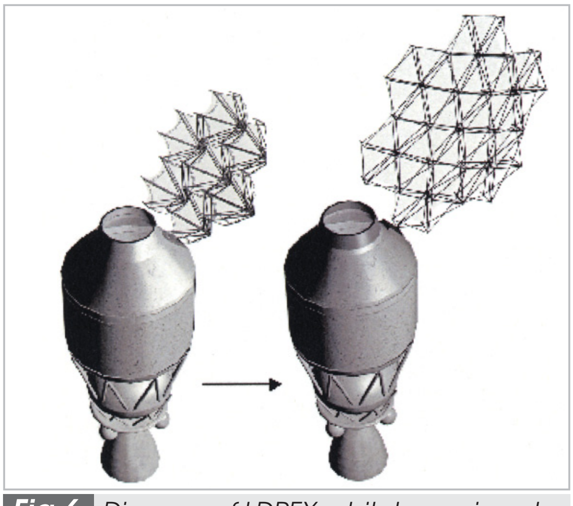

Fig.6 *Diagram of LDREX orbital experiment*

In an experiment conducted in December 2000, an unexpectedly large amount of oscillation occurred in the initial stage of deployment, immediately after the hold-on/release mechanisms (HRMs) were disengaged. This caused the reflector mesh to become caught in the truss members, halting deployment halfway. However, since the LDR was deployed by about 10 degrees (0 degrees in the stowed state and approximately 90 degrees when fully deployed), estimations of frictional resistance and the like were able to be confirmed, with successful comparison of experimental results in orbit with test data obtained on the ground. On the other hand, to prevent the oscillation seen in the initial stage of deployment (and the resultant entanglement of the reflector mesh), the following design modifications were incorporated into the LDR.

(1) Suppression of the oscillation of the reflector upon disengagement of the HRM

- Modification of the disengagement sequence for the HRM (previous method of simultaneous release of the upper and lower elements of the HRM is replaced by one in which the lower element is released after the upper element).
- Reduction of the speed of release (damper is attached to reduce shock when the HRM is disengaged, coupled with regulation of the mechanism’s deployment speed)

(2) Prevention of entanglement of reflector mesh

- Installation of a strip preventing extruding of the reflector mesh from the stowed position
- Installation of a standoff rod (preventing the reflector mesh from reaching the stand-off physically even in cases in which the reflector mesh does extrude)

Moreover, in order to ensure that the LDR could provide reliable deployment, additional springs were incorporated into the design to increase deployment force in the initial stage of deployment.

To verify the validity of these design improvements, the following additional tests were conducted.

(1) Micro-gravity test with aircraft (using EMs, for 7 modules and for 14 modules)
(2) Cup-up test (using EMs)
(3) Deployment force check test (using EMs)

Fig.7 shows the configuration of the micro-gravity test using the EMs. This experiment was conducted in France in April 2002. Data was then recorded relating to the behavior of the reflector immediately following release with renewed release sequence, in addition to information on the behavior of the reflector in the initial stage of deployment. This experiment confirmed that even if acceleration perturbation was greater than seen in orbit, the LDR reflector was sufficiently robust. Further, experimentation confirmed that the redesigned reflector did not cause entanglement of the mesh or any similar problem in a micro-gravity environment.

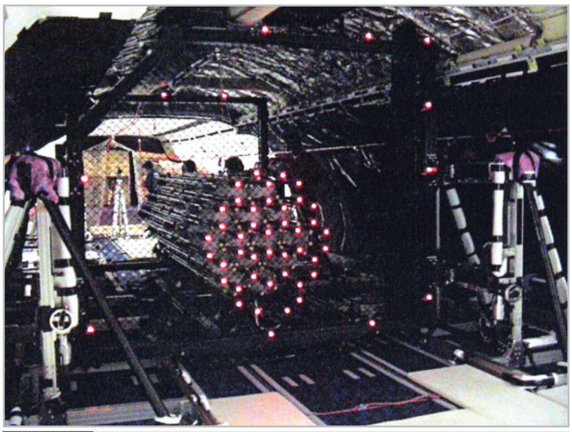

Fig.7 Configuration of micro-gravity test (14 modules)

Fig.8 shows the configuration of the cup-up test. This test was conducted in the summer of 2002. When the LDR is in the suspended state (cup-down), the reflector faces downward. In this case, the oscillation of the reflector upon release of the HRM is suppressed by gravity; thus, this test is likely to underestimate the effects of oscillation. To

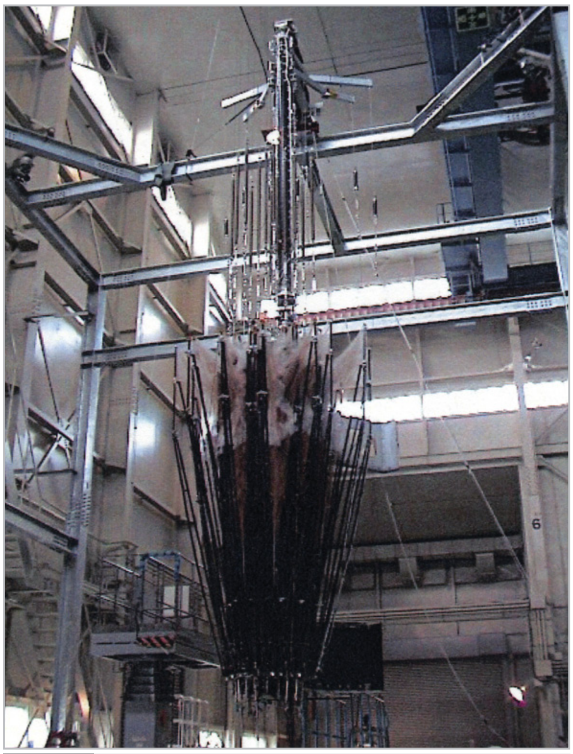

Fig.8 *Configuration of the cup-up test*

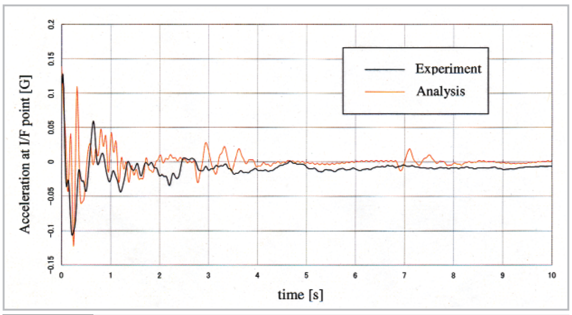

Fig.9 *Comparison between cup-up test results and analytical results (acceleration at a given point on the installed module)*

remedy this, we configured the experiment such that the reflector was made to face upward (cup-up), and the boom was linked to the reflector and tested, where the reflector would be linked to the main body of the satellite by the boom if the LDR is mounted on the satellite structure. This experiment confirmed that modification of the disengagement sequence of the HRM did not impair the strength of the boom. Further, the perturbation exerted on the main body of the satellite upon disengagement remained within interface spec.

These experiments have led to improved accuracy in analytical orbital models predicting the effects of deployment of the HRM on reflector motion. These tests also allow for revision of the models of reflector behavior based on the results of micro-gravity experimentation. Fig.9 shows a comparison between cup-up test results and analytical results.

The results of the micro-gravity and cup-up testing described above thus attest to the sufficiency of the countermeasures implemented to suppress the reflector oscillation and mesh entanglement seen in the orbital LDREX experiment.

On the other hand, in the deployment force test, a limit value was identified through the intentional addition of an anti-deployment force. Comparison of these test results with results of analysis confirmed the validity of the analytical model, demonstrating that attachment of an assisting spring will increase deployment force in the initial stage of the deployment by the required margin.

3.3 Test of standalone LDR

Beginning in the latter half of fiscal 2002, a proto-flight test (PFT) was conducted for the reception LDR, and an acceptance test (AT) was conducted for the transmission LDR. The main test items are as follows.

(a) Boom deployment test
(b) HRM deployment test
(c) Reflector deployment test
(d) Environmental tests (sinusoidal-wave vibration test, acoustic test, and thermal vacuum test)

In order to confirm the stability of deployment characteristics (i.e., to confirm satisfactory deployment in orbit) before and after the LDR is subject to environmental load, check items (a) to (c) were evaluated before and after the environmental test. The boom deployment test is outlined in Fig.10, the reflector deployment test is shown in Fig.11, and the vibration test is illustrated in Fig.12.

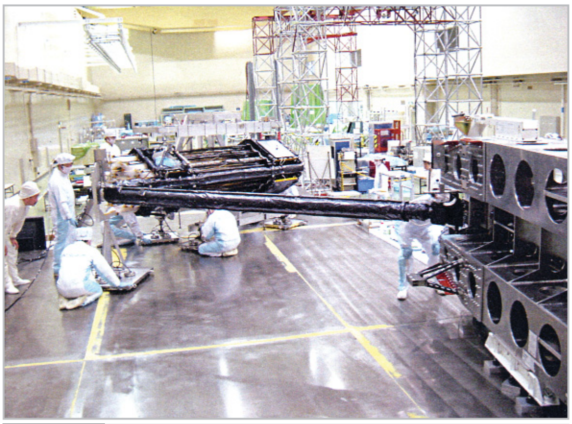

Fig. 10 *Boom deployment test*

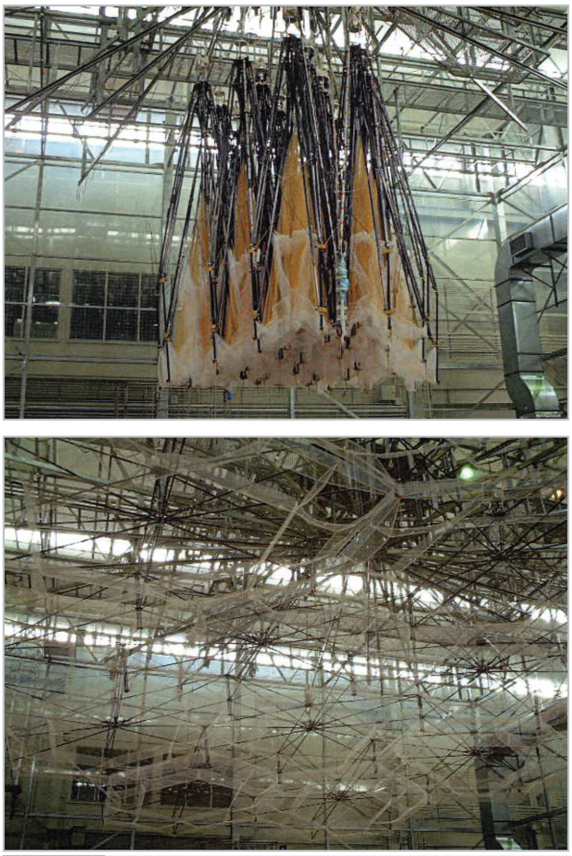

Fig. 11 *Reflector deployment test*
Initial deployment (top)
Full deployment (bottom)

The PFT/AT results confirmed that the finished design is of a quality satisfying the requirements for a standalone LDR. Accordingly, the LDR will soon be installed on the main body of the satellite for subsequent overall prototype flight testing. Upon completion of these tests, the LDR is scheduled to be removed from the satellite main body, as a standalone LDR to be subject to final testing

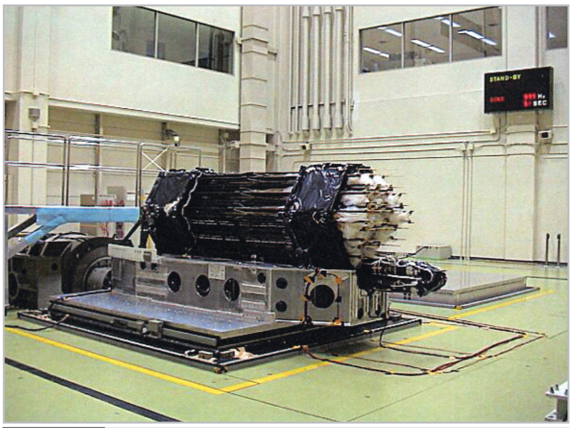

Fig. 12 *Vibration test*

of items (a) to (c); we will then await launch.

4 Conclusions

This paper described the outline and development history of the LDR. Long years of development of the LDR has now brought us to final testing of a completed flight model incorporating numerous design improvements. Although the flight model is somewhat heavier due to these design improvements (reflecting the results of the orbital LDREX experiment), the overall design remains lightweight, satisfying the initial target value of 1 kg/m^2, i.e., the reflector's weight is now approximately 143 kg (0.7 kg/m^2).

The LDR has been developed with the aim of ensuring successful deployment in orbit, and we have conducted every feasible test to reduce the risks involved. Nevertheless, in the future development of similar large deployable structures, it is necessary to divide development items into two in order to increase development efficiency; (i) those requiring and permitting ground testing, and (ii) those not permitting ground testing and subject to design assurance. Furthermore, it is a technical challenge to establish innovative design and ground testing techniques. The test data accumulated in the course of development of the LDR to date, in addition to the orbital data following launch, will prove to be valuable resources in resolving the technological challenges of any such future development.

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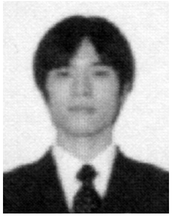

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