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Modal behavior of a new large reflector conceptual design

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ABSTRACT

A new conceptual design for the architecture of a large deployable space reflector is presented. The reflective parabolic surface is made of a mesh shaped by a cable net and the supporting rim structure is based on scissor mechanisms associated with flexible joints. These joints replace complex articulations while allowing the storage of the energy required for deployment. They also affect the stiffness of the structure and the tension of the cable net. The dynamic behavior was studied by finite element modeling and through tests on an experimental prototype with a gravity compensation device. We focused on the first natural mode, which is an important design criterion for space applications. The measurements are compared to simulation results and we discuss the influence of suspension threads and gravity in the model.

0. Introduction

Large parabolic reflectors are now being developed to meet the growing need for telecommunications facilities. Reflectors of greater than 10 m diameter are deployable because of their incompatibility with the volume available in the launch capsule.

The main large parabolic reflector concepts are presented in several previous reports [9,2]. Concepts based on a deployable rim structure with a parabolic surface made of a reflective mesh supported by a cable net seem to be the most promising because they are light, have no elements behind the reflecting surface and have good surface accuracy for high frequency transmissions. The AstroMesh antenna developed by TRW Astro Aerospace is clearly the most renowned of all existing large reflectors [8]. It is composed of two symmetrical composite cable nets attached to a truss rim structure (Fig. 1), which is made of composite tubes arranged in deformable parallelograms, and a reflective mesh stretched on the upper net. The reflector is deployed by shortening a cable that runs continuously through the telescopic diagonal tubes and deployment synchronization is achieved through special joints with internal gears [6]. Several satellites with AstroMesh antenna have been launched since 2000, which are operational for S-band (2–4 GHz) to Ka-band (26.5–40 GHz) communication frequencies [7]. The total mass of a 12 m diameter reflector is 57 kg and its first natural frequency is 0.80 Hz [1]. In this configuration, the rim structure involves 30 parallelograms of 2.52 m height with a 1.26 m base.

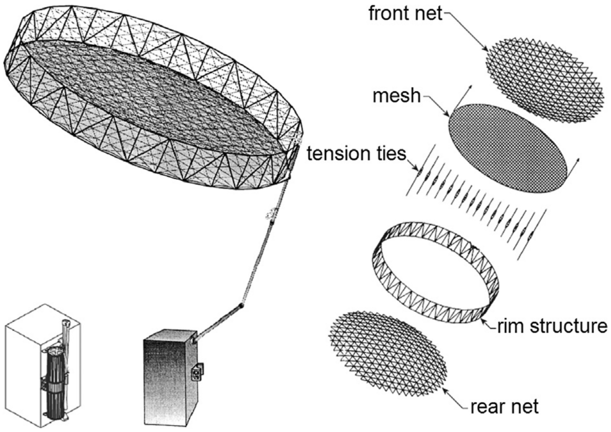

Fig. 1. The large deployable AstroMesh reflector.

A key design parameter for a large reflector is the frequency of its first natural mode. Indeed, being subjected to zero gravity in space, the deployed reflector should not be too sensitive to excitations from the Attitude and Orbit Control System (AOCS) that controls and steers the satellite in its orbit around the Earth. The frequency of the first mode of the reflector must therefore be outside the frequency range of the controlling signal, which is roughly between 0 and 1 Hz. This key design specification guides choices

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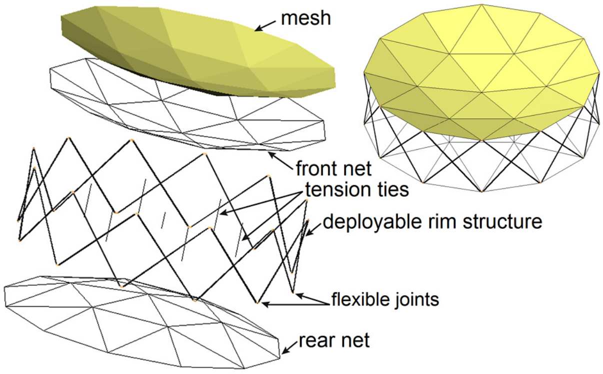

Fig. 2. Reflector concept.

in terms of architecture, stiffness and mass. Moreover, given current technologies, a mass per unit of deployed area of less than 500 g/m^2 is generally targeted. This represents a total mass of 56.5 kg for a 12 m diameter (113 m^2) reflector.

In this paper, we address the modal analysis of a new conceptual large space reflector design and assess how to validate the simulations of its in-orbit behavior through ground testing. First, we introduce the reflector concept and particularly its innovative rim structure. We then present the numerical model that allows determining the first vibration modes and the impact of cable nets on the behavior. Next is presented a reduced scale prototype that was built to check the feasibility of the concept and to perform a series of tests. The measurements are compared with the simulations results if order to validate this numerical model for predicting the in-orbit behavior of the structure. As zero gravity conditions are difficult to reproduce on Earth for large lightweight structures, a method is proposed to account for the influence of a gravity compensation system in the model so as to justify the zero gravity simulations with ground test measurements.

1. New space reflector concept

Several concepts comparable to the AstroMesh system were studied, as that of Tibert and Pellegrino [10] based on a tensegrity structure, and that proposed by You and Pellegrino [12] with a cable-stiffened pantographic ring. However, these studies generally focused on the structural architecture or on the accuracy of the reflecting surface but not on the dynamic behavior. In this paper, we present a concept involving a scissor rim structure with flexible joints (Fig. 2).

Indeed, flexible joints can advantageously replace complex and heavier joints composed of several pivots oriented in accordance with the deployment kinematics. Each scissor opens in a plane corresponding to a side face of the rim structure, of polyhedral form, so the pivot axes at the center of bars should be perpendicular to this plane to be kinematically compliant. In addition, the joints between two consecutive scissors must be composed of two pivots with axes perpendicular to each side (Fig. 3a). Spherical joints may also be used, however they are seldom used in space applications (few certified models) and joints with only one degree of freedom are generally preferred. Also, spherical joints would increase the number of degrees of freedom, which is very detrimental to the deployment control. A three-pivot joint can be used to overcome this issue: one with its axis oriented perpendicular to the plane formed by the connected tubes and two along the axes of the tubes with rotation limited to few degrees (Fig. 3b).

Beside simplicity, flexible joints (Fig. 3c) bring the possibility to deploy the reflector by exploiting the accumulated deformation energy when folded. The rim structure may then be kept folded simply using ties, which would be released to initiate the reflector deployment.

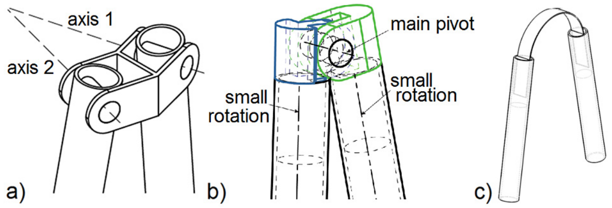

Fig. 3. a) Two-pivot joint; b) Three-pivot joint; c) Flexible joint.

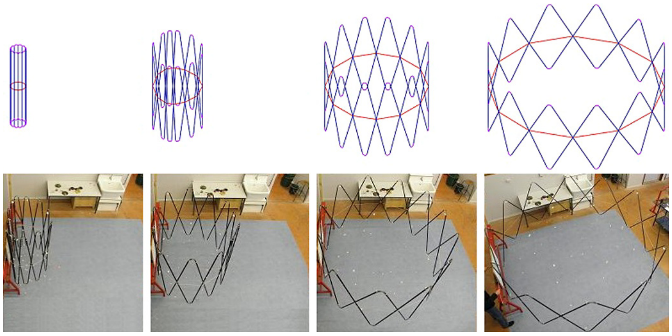

Fig. 4. Deployment of the scissor rim structure with flexible joints.

The deployment of the scissor rim structure with flexible joints was numerically simulated using an implicit transient two-stage analysis (presented in Quirant et al. [5]). Deployment tests were also performed on a prototype (described in part 3) suspended by vertical threads on a rail system. A cord encircling the rim structure, slowly unrolled, was used to control the deployment. The tests and simulations demonstrated the feasibility of the concept; the deployment kinematics obtained are presented in Fig. 4.

2. Modal characteristics in space

To compare the modal behavior of a scissor rim structure with flexible joints to that of an operational reflector of the AstroMesh type, we simulated the behavior of a 12 m diameter model for the two architectures. In this study, the rim structure is composed of 30 sides (scissors or parallelograms) and the parabolic surface is supported by the same cable net for the two antennas. The parabolic surface characteristics (focal length 5.4 m, center offset 8.3 m) result in a front cable net depth of 67 cm. The rim structures are also designed to have an identical mass.

2.1. AstroMesh reference model

The parameters of the “AstroMesh model” were determined by running a series of analyses to obtain a first frequency of 0.8 Hz. For confidentiality reasons, it is very difficult to find the exact dimensions in the literature. In the numerical model (Fig. 5), we thus considered horizontal and vertical tubes with 62 mm diameter and 1 mm thickness. The diameter of the diagonal tubes is equal to one third of the others (21 mm). Tubes are made of carbon/epoxy composite (1550 kg/m^3, elastic modulus 125 GPa). The cable nets (including the reflective mesh mass) are modeled by cables with a 1 mm^2 section, a 2500 kg/m^3 mass density and a 125 GPa elastic modulus. These choices result in a total mass of 57.1 kg, close to that of a 12 m AstroMesh (53 kg for the rim structure and 4.1 kg for the cable nets).

This reference model was investigated using the ANSYS™ finite elements software package. Each tube is composed of four *Beam* elements and each cable is represented by one *Link* element. The