BUILDING BLOCKS OF ADVANCED LARGE STOWABLE PRECISION MEMBRANE REFLECTORS

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ABSTRACT

A design concept for a family of large deployable high-precision space reflectors is proposed. Its building blocks consist of radial bi-stable ribs eventually combined with additional annular ribs or with tensioned membranes which together form the backside structure of a reflector. Mesh or different versions of membranes, including parabolically curved quasi-membrane, might be used as reflective surfaces. Studies were carried out in quasi-membrane technology and preliminary results are presented.

Controllability for deployment is provided and possibilities for shape control could be also included.

Discussion of these building blocks shows considerable design flexibility and adaptability which challenges for further investigations of proposed concept.

1. INTRODUCTION

Large deployable reflectors (LDR) in space are those which due to their diameter in the range typically between 10-25 m and more are to be stowed in the launcher's cargo bay and deployed in orbit. Applications of such reflectors range from communication over earth observation up to radio-astronomy. (Large) reflectors for IR or optical wavelengths require special technology only briefly mentioned at the end of this paper. Though basically deploying something in orbit sounds quite achievable – it somehow reminds to everybody's umbrella – it is the size and especially the relatively high final shape accuracy typically in the range of (sub) mm rms to be reached with high reliability. This together with other requirements poses a severe technical challenge. This challenge and even more so the limited market pull has caused some development activities in Europe in the eighties to dry out. It is only in the recent years if not months that this field has got new interest.

2. AVAILABLE AND PARTLY FLIGHT PROVEN CONCEPTS

In spite of or because of the technical challenges there is quite a number of different concepts of LDRs published in literature. Irrespective of their kind, one can identify the following building blocks

- the reflecting surface, ranging from meshes over membranes up to solid sections (which also is the order of increasing shape accuracy but also increasing complexity for deployment, mass etc.)
- the backside stiffening structure, composed either of trusses, radial and annular ribs, inflatable designs, and combinations. Due to stowage and geometric requirements, the structural elements either have to have (structurally integrated) hinges or be extremely flexible and stiffened in orbit.
- the deployment mechanisms, ranging from using inherently stowed elastic energy up to motor driven truss structures such as pantographic rings. Irrespective of the deployment concept and its mechanisms, the deployment has to be controllable (eventually taking many minutes) and reliable
- shape providing elements, either caused by the backside structure, adjustable elements, the reflecting surface itself and proper combinations of these
- and the proper synthesis between reflecting surface and structures, such as the deployment pantograph which in its final position provides overall stiffness and tensions the reflecting mesh.

These features of LDRs, will form the building blocks of the concept to be discussed below.

EGS Reflector in Flight, 28.07.99.
Photo is taken from O/S “MIR”

Harris Mesh Reflector

Tension truss antenna reflector, Japan

“Thuraya” AstroMesh Reflector

Fig.2.1 Large deployable communication reflectors

A typical albeit by far not complete list of examples for such reflectors especially for communication purposes is (see also figure 2.1.)

- the EGS mesh reflector, with circular pantograph ring and tensioned structural membrane ribs
- the Harris rod-cable reflector
- the tension truss antenna reflector, Japan
- the “Thuraya” AstroMesh ropes/strut-ring reflector
- or among the class of „pneumatic“ or inflatable structures the pressurized and space rigidized reflector e.g. developed by Contraves. After inflation, the material is rigidized e.g. by space radiation.

A comprehensive overview and discussion of these and other designs is given in [1,2].

3. THE ‘SMART’ CONCEPT

Efforts have been made and are underway at the Aerospace Institute of Technische Universität München, Germany, together with visiting scientist of the Georgian Institute of Space Constructions, Technical University Tbilisi, Georgia, in order to research concepts and building blocks of future LDRs [1,3,4,5,6,7]. The folowing design gols are taken as reference for these activities:

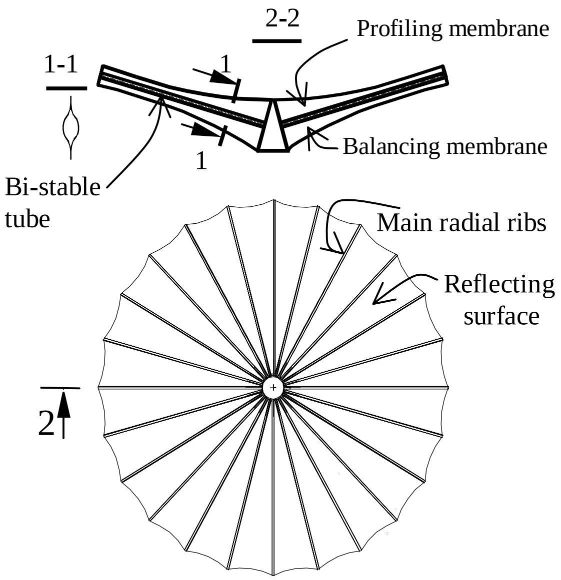
3.1 Design Goals

- reflector aperture diameter typically in the range of 10-25 m (with smaller diameters of course to be achieved as well)
- shape accuracy in the range of mm rms and better
- low mass of typically 0,5 kg/m^2
- sufficient design flexibility to apply different building blocks or design elements, if needed or appropriate
- sufficient growth potential to cope for future developments e.g. in reflecting membranes or active shape control.

3.2. Family of ‘SMART’

A result of these investigations is the concept [1] of **‘SMART’ (**Synthesized Munich Antenna Reflector from Tbilisi) with the following versions:

- the baseline version [4] as shown in figure 3.1., consisting of several bi-stable tubes (compression load only) combined with



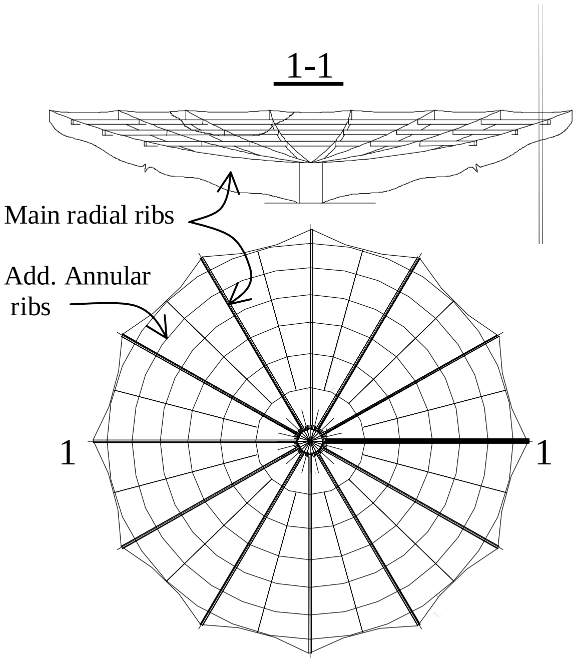


Fig. 3.2 SMART with additional annular and radial ribs

thin upper membranes providing the required shape and lower membrane for structural balancing and adjustment possibilities. This combination forms the main radial ribs of the reflector.

- possibly further additional radial and/or (circular or elliptical) annular ribs (e.g. C-shaped) with a smaller number of main radial ribs [5] (figure 3.2.), in order to enhance shape accuracy, which can be further extended to
- a relatively small number of main radial ribs together with a higher number of lightweight tensioned membrane ribs with proper geometry to provide shape accuracy (Fig 3.3.)

For the material mostly carbon fiber composites are used

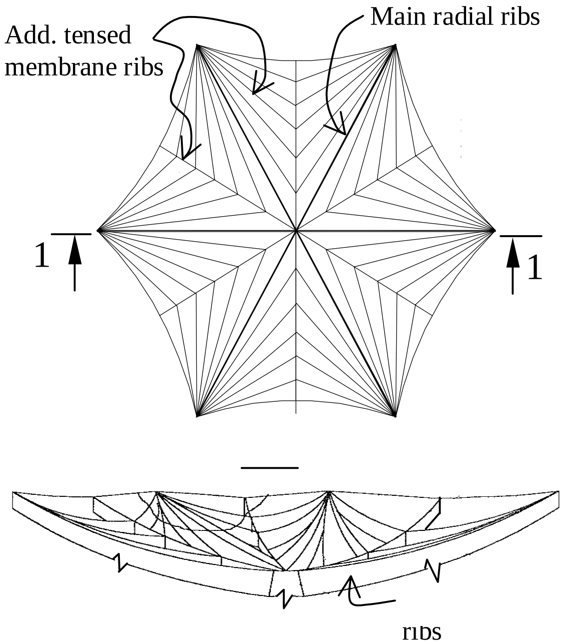


Fig. 3.3 SMART with some radial ribs and tensioned membrane ribs

It should be noted that symmetric and offset reflectors are possible, and in principle meshes as well as membranes can be considered as reflecting surfaces. Deployment is achieved by release of stowed deformation energy (eventually backed up e.g. by prestressed springs or inflatable elements within the main ribs [7]), while deployment is controlled e.g. by properly attached strings or other means briefly discussed below. Tensioning is provided by moving main ribs in the radial planes (as outlined in figure 4.3), which then also provides proper position for actuating in eventual active shape control.

In regard to the mass of the reflector, especially ‘SMART’s third version of Fig. 3.3 is very attractive, where the number of main (heavy) ribs is reduced to the minimum. Surface shape formation in between of them is achieved by many lightweight and slightly tensed membrane ribs (Fig. 3.4.).

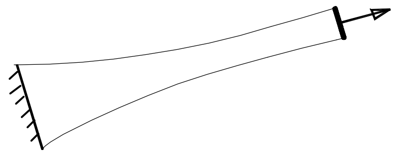


Fig. 3.4 Additional tensed membrane rib

For stowability, there is an important geometrical limit for the radial position of the first joint of the additional membrane ribs (Fig. 3.5). On the figure 3.6. lower limits of radiuses of the first joint positions are given for the different values of the reflector diameter and the number of main ribs.

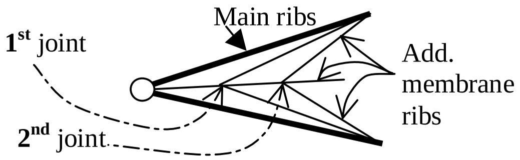


Fig. 3.5. Section of ‘SMART’s third version

Results look acceptable from the accuracy point of view for any flexible reflective surface.

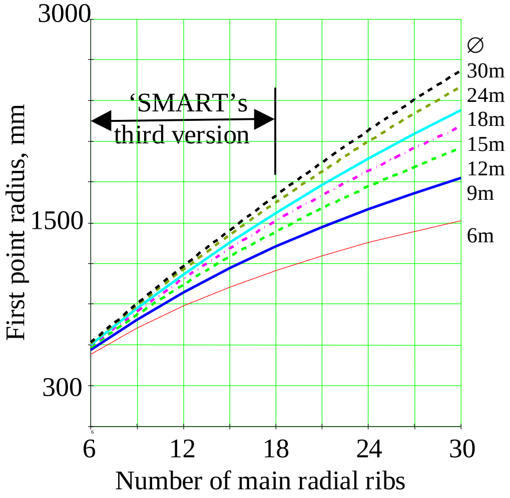


Fig. 3.6. Radius of the first joint of the additional membrane ribs vs. number of main ribs and reflector diameter

Though ‘SMART’ still is in its early R.a.D. stage, most of its building blocks have been thought about in some detail, with analytical models and laboratory tests, some of which are briefly described in the following.

4. DISCUSSION OF BUILDING BLOCKS

there are first importance building blocks listed below

- type of reflecting surface (mesh, membrane or parabolic quasi-membrane);
- the design of ribs and its „membranian“ interface to the reflecting surface;
- deployment control system
- overall tensioning of reflecting surface (especially for mesh) including some form of shape control and others, as well as the fulfillment of electromagnetic functionality requirements. Some of these items mentioned will be addressed in some detail in the following.

4.1. Reflecting surface

The flexible reflecting surface can be of knitted mesh, tensed metalized membrane or parabolic quasi-membrane (flexible shell-membrane). Each version of ‘SMART’ provides support backside structure to provide for required shape of the reflecting surface.

Design and technological problems and advantages of first two types of reflecting surfaces are more or less known from the literature [10,11].

Novelty is the parabolic quasi-membrane, [1,4] which is characterized by two “states” of stiffness:

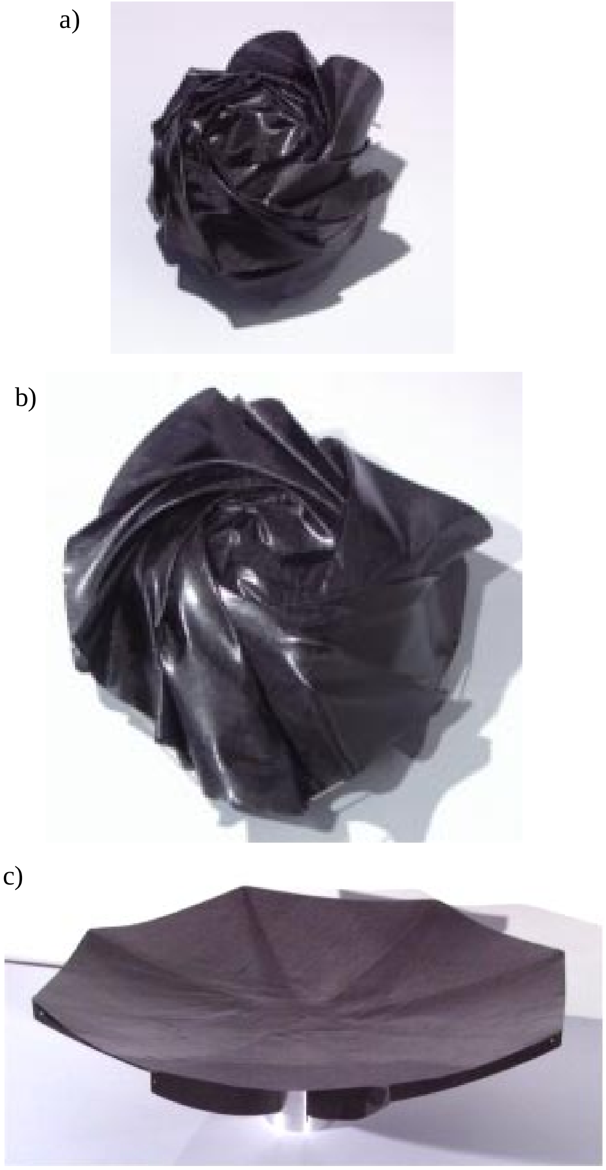


Fig. 4.1. Deployment of quasi-membrane reflector model (600mm in diameter), a) - stowed, b) – deploying, c) – (scaled) deployed

in operation state it is not pretensioned (no need in prestressing) and in between ribs (in the cell of backside structure) it works as a shell with a low but finite bending stiffness. In stow-deploy cycles it acts as a membrane with a negligible bending stiffness. Therefor it is not able to interfere any kind of stowing and deploying processes.

It is important to note that inside of the support cell parabolic membrane forms it's shape due to it's elastic deformation energy.

There are other significant parameters for such a reflective surface:

- CTE of the membrane composite material is close to zero and is compatible to the support cell (i.e. to ribs) material CTE;
- Membrane creep deformations during stressing in the stowed state should be negligible in order to obtain proper shape after deployment.

The possible candidate for such a reflective surface material is fiber (carbon, Kevlar, glass) reinforced silicone (FRS). Preliminary experimental investigations of the building technology of such a shell-membrane have been carried out at TU München, some early results of which can be seen on Fig. 4.1. It should be noted that carbon FRS (CFRS), where the carbon fiber net is reflecting net at the same time, shows good adaptability to the a. m. stiffness requirements.

In order to reduce solar drag holes in the membrane or membrane net then should be considered.

4.2. Main radial ribs

One of the backbones of SMART and its variations is the radial rib. As mentioned, it consist of a (straight) foldable composite central part with double-c-shaped cross-section (see also similar metallic satellite booms, or the solar array boom [9]). It has to carry compression load only (in contrast to additional bending in other design concepts), thus allowing for high accuracy even under reflector's pretensioning. Attached on top there is the membrane-type profiling part for the reflecting surface, and on the lower side the membranian balancing part. In order to save mass, holes could be introduced in these membranes, but in the final position pretensioning without surface waves has to be provided e.g. by integrated thin cables.

An alternative design would be the use of thin CFRP sheets eventually again perforated, or by using a cellular design.

4.3. Deployment control

An important feature for large reflectors is their deployment control. This not only relates to the LDR itself to avoid collision, but also to short-time changes in inertia or dynamic effects disturbing satellite attitude control, or even endangering structural integrity of flexible appendages. Deployment energy basically is provided by stowed strain energy in the stowed ribs, eventually amended by additional C-springs, if needed. Two ways of possible deployment control are shown in figure 4.2. One possibility is the use of control cables, with one end attached to the central part and the other end at a rib, while the rope passes through the other ribs. During deployment the cables are loosened, the velocity of which controls deployment speed. Another possibility is the use of a deployment control mechanism integrated in the inner drum which controls the release of the radial ribs. Properly shape openings and wheels as shown in figure 4.2. can be used which, in principle, are similar to the tape measure case or to those applied and verified in DLR's solar sail concept [9]. Since the deployable structure doesn't contain „classical“ hinges but those are structurally integrated, high deployment reliability and accuracy can be achieved.

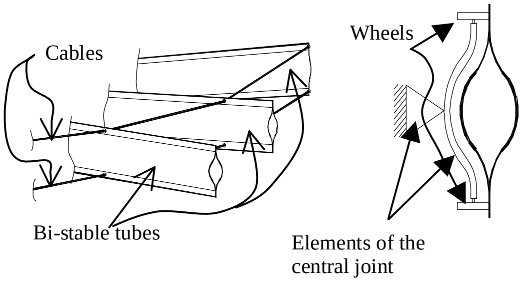


Fig. 4.2. Two approaches for deployment control

4.3. Overall tensioning and shape control

Overall tensioning of the reflecting surfaces, which has to be in the range of several N/m for a metal mesh and can be marginal for tensed membrane, can be provided by movement of the ribs in the radial plane as shown in figure 4.3. For that purpose, also for prestressing of the radial rib itself force/displacement actuators attached to the central part and to the lower membrane of the radial rib can be applied. In addition, this also provides a good position for actuating in an eventual shape control [8] as outlined in figure 4.4.

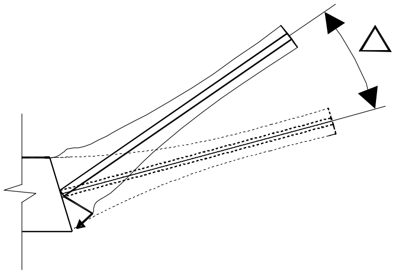


Fig. 4.3 Pre-stressing of the main rib moving in a radial plane

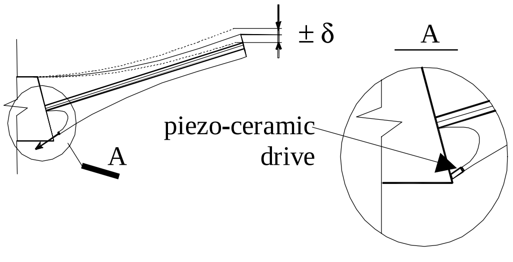


Fig. 4.4 Control of rib position and shape

4.4. Further considerations

Of course, many other features are to be considered as well, which are not described here in detail, such as

- the kind of fixation of the rib to the inner part, the load introduction at its outer part, as well as the adjacent membrane tensioning devices.
- the storage process of structural parts and reflecting surface
- and last but not least the interaction with the electromagnetic functionality requirements.

Substantiation of these features mentioned in this chapter by mathematical models has been partly carried out but is still to be complemented and verified by laboratory models. Mass estimation shows the achievability of the 0,5 kg/m^2 requirement.

4.4.1. Small deployable reflectors

Deployable reflectors could be also interesting for smaller apertures (say up to 3 m) in order to achieve low stowage volume e.g. for small and micro-satellites. Many of the concepts presented above can be also used within such a context, and the smaller diameter even allows "relaxed" technical approaches to achieve stowage, deployment, stiffness and accuracy requirements.

4.4.2. Relations to high precision reflectors

Large communication reflectors typically require rms shape accuracies in the order of millimeters, while high precision telescope reflectors require accuracies in the µm or sub-µm range for infrared or optical wavelengths. Such accuracy requirements are much more significant if not overriding compared to communication reflectors design criteria. This then leads to significantly higher reflector masses as shown in figure 4.5. For example, Hubble´s reflector does have a specific mass of about 150 kg/m^2 of reflecting area. Future reflectors with higher diameters in the range of 8m and higher are envisaged. This then requires both significant mass reduction of roughly and at least one order of magnitude, as well as deployment in orbit. The first could be achieved by proper design, materials and thermal / shape control. Feasible solutions for these items are not readily available and still need significant research and development. In addition, deployment then also becomes a significant design driver. While up to about 8 m diameter rigid reflectors with „some“ folding hinges still are a viable option, this is no longer true for larger diameters. This then would also result into a „deployment comes first“ design approach, which together with stringent accuracy and mass requirements call for novel concepts. One of these is outlined in figure 4.6, where the membrane reflector design together with an eventually inflatable and self stiffening outer ring [7] is to be combined with extensive active shape control techniques. Reduced effort for the latter could provide solutions for applications with lower accuracy requirements such as in communication, radio astronomy or SAR reflectors. Though such

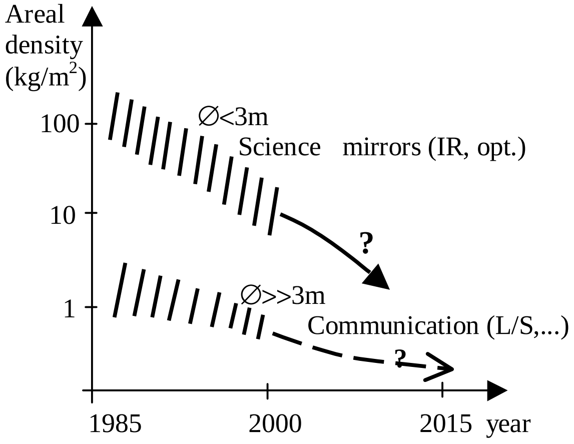


Fig. 4.5. Typical specific reflector mass

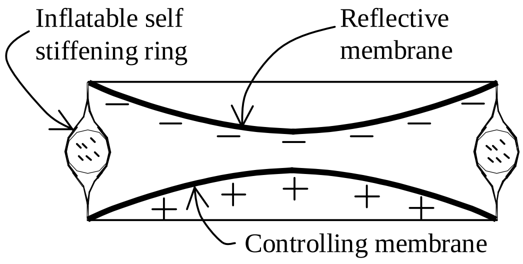


Fig. 4.6. Electro-statically controlled membrane reflector
(different ring arrangements are possible)

concepts are still in early development stages, they call for bridging the gap between deployable (communication) reflectors and highly precise mirrors.

5. CONCLUSIONS

Large reflectors in space are to be applied for communication, earth observation and astrophysics, often with increasing required shape accuracy in that order. The SMART concept is proposed consisting of different building blocks which allow for adaptation in the development process or in case of increasing accuracy requirements in a certain mission. Further substantiation especially by more extensive analytical and laboratory models is needed.

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