International Conference on Textile Composites and Inflatable Structures
STRUCTURAL MEMBARNES 2009
E. Oñate, and B. Kröplin, (Eds)

LIGHTS IN THE SKY: MEMBRANE STRUCTURES FOR ART IN SPACE

MARCO C BERNASCONI[1] & ARTHUR R WOODS[2]

[1] MCB Consultants, 8953 Dietikon, Switzerland
e-mail: mcb@ieee.org

[2] spaceOp sarl, Yverdon-les-Bains, Switzerland
e-mail: arthur.woods@spaceop.com

Key words: Inflatable Structures, Art in space, large orbital sculptures.

Summary. Inflatable space structures and proposals for large orbital sculptures seem to have been strictly interrelated. Not only have essentially all such space art projects been based on the use of inflatables, but past use of such flexible-wall, expandable space structures has been associated with those effects that have caused the main criticism applied to art in space: creating new lights in the sky. The paper reviews the history of such objects, both the technically-oriented ones that have flown, and the artistically oriented concepts, as well make, them possible.

1 INTRODUCTION

A recognition of the reality of the Universe beyond the terrestrial boundaries (s.e.g. Ehricke, 1957) provides the ground for creating art works in the extraterrestrial environment: one most interesting, early category consists in art in space to be seen from the Earth (Malina, 1989). In this context, proposals for visible – and hence, large -- orbital sculptures seem to have become strictly interrelated with inflatable space structures, i.e. with membrane-like items. After all, the surfaces and expanses of the 40-m balloon satellites remain unequalled, even though – in linear terms – several members of the International Space Station have now outrank them in size. (Outclassing them in terms of cost, as well.)

The paper reviews the history of these projects, with a strict focus on lights mirrored by membrane structures (i.e. to the exclusion of e.g. other expandable sculptures or of items building on visible-light laser devices). We begin with a summary of technical items, flown and planned, which embody some of the necessary technologies. Indeed, the idea of orbiting large, lightweight objects, visible to the naked eye, long predates the concept of infusing an artistic significance to such artifacts.

After WW-2, some promoters of Astronautics perceived that the recourse to very small and very light vehicles would greatly accelerate the realization of their plans. At the Second International Astronautical Congress, Gatland and colleagues (1951) suggested to "incorporate a metallised 'paper' balloon for use as a radio reflector" -- as well as for optical tracking and drag studies – in their MOUSE (Minimum Orbital Unmanned Satellite – Earth) concept, so named by Prof Singer. Realization began in earnest, however, with the 1956 proposal by William J. O'Sullivan (NACA Langley Research Center) to use a 20-inch (0.51-m) spherical inflatable subsatellite for measuring atmospheric density (Coffee, Bressette and Keating, 1962). Soon, the Langley team undertook to construct a 12-foot (3.66-m) inflatable sphere for this purpose, orbiting the first “Air Density Explorer” -- Explorer IX -- on February 16, 1961. Actual observations determined that this sphere, at its zenith, reached an apparent magnitude of 5 to 6 (Woerner & Coffee, 1964).

In parallel, Pierce (1955) had presented a communication satellites analysis including the possibilities offered by passive (i.e. purely reflecting) systems. Project Echo originated in 1958, to apply the Langley Research Center experience with inflatable structures to the experimentation of the passive communication satellite concept. The Echo I satellite took the form of a 100-foot (30.5-m) inflatable sphere of Mylar with a vapour-deposited aluminum coating (Pierce, 1985). Fast progress led to a first (failed) suborbital deployment test on October 28, 1958, and to the actual launch on August 12, 1960. The first artificial satellite seen easily by the naked eye, Echo I succeeded in its passive communication satellite tests, and paved the way for long-baseline geodetic measurements. Analyses of its orbital evolution experimentally confirmed the impact of the solar pressure, and its potential for propulsive functions (solar sailing).

These results led to an improved-quality, larger (40-m) balloon satellited, PAGEOS (for PAssive Geodetic Earth Orbiting Satellite), to provide a luminous target for simultaneous photography against the starry background from a plurality of ground stations of a worldwide geodetic network (Teichman, 1968). Launched into a 4200-km circular orbit on June 24, 1966, this item designed to create a new light in the sky became the last large balloon satellite orbited by NASA.[1] In the following years, a technology development line aimed at rendering inflatable space structures largely invisible to light – mainly to limit the solar-pressure-induced orbital change, although additional smaller object continued to fly, to continue measurements of the upper atmosphere and for other technical purposes. Also, many more applications for flexible-wall space structures were studied (Forbes, 1964; Bernasconi and Reibaldi, 1985; Williams, 1987), but the era of new lights in the sky seemed past.

2 LIGHTS IN THE SKY

2.1 Prehistory

During the 1960s, the discussion of the social significance of Astronautics flourished, advanced space application concepts appeared, but apparently the artistic dimension only remained as a footnote. Early mentions of space art projects thus deservedly assume the glow of visionary precursors. Albert Notarbartolo (1975) described four distinct concepts for ***spaceworks*** to “serve as beacons of man's presence in the solar system” which he began to sketch in 1971. While his brief paper did not include any specifics concerning the objects' size or structural design, Notarbartolo

1 Wilson (1981) provided a good summary of the history of balloon satellites. The monography by Elder (1995) focuses on the history of Echo I.

(1975) mentioned to have given consideration to structural and materials aspects, and offered to provide more details. **Beacon** would have taken the form of a hemispherical solar reflector in geostationary orbit, passing light towards Earth through a prism of transparent materials of different colors; the whole structure would oscillate, thus providing an observer with modulated images. With **Star-Cloud**, he suggested an evolving collection of transparent, hollow spheres, each holding a rotating, reflecting, colored, transparent disk. A space travelers would add a sphere to the ensemble and set the interior disk in motion by hand.

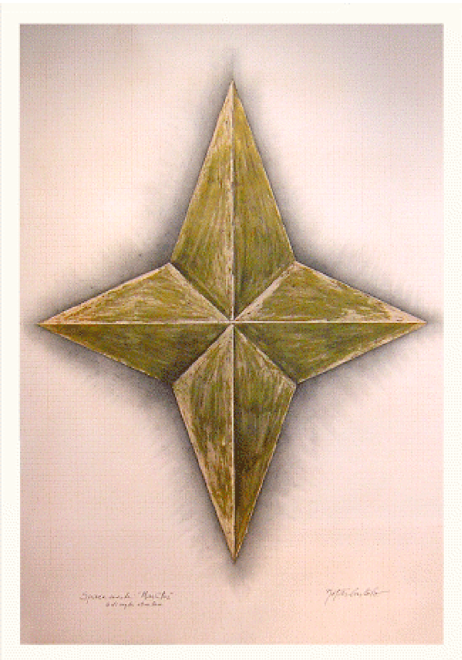

Figure 1:Notarbartolo's spacework drawing for the Man Star plastic.

Man-Star was the project for an inflatable object assemble from transparent and from reflecting films. Up to 1.6 km in extension, it would fly in a stationary lunar orbit, above a Moon settlement. Finally, **Earthlog** proposed an archive for recording humanity's accomplishments, in part as a through-the-time CETI attempt. To be placed in a high Earth orbit, it was to be shaped with the outline of the mathematical symbol for infinity, and gold-coated. (Notarbartolo (1975) suggested that space facilities could have their exterior designed to function as art objects.)

Around 1980 (although in a less documented fashion), Jean-Marc Philippe "began to think of using space as an infinite canvas. [His] very first concepts included ***autonomous satellites with highly reflective surfaces*** or laser beam systems installed aboard multipurpose satellites. These surfaces or lasers could create lasting or ephemeral 'shows'" (Philippe, 1990 – emphasis added). In the **Celestial Wheel** space artwork, laser beams would be relayed among geostationary-orbit satellites, creating a circle of 39 illuminated "stars" around Earth. Another project, **Venus+**, would utilize inflatable satellites also in geostationary orbit for defining 'the four corners of the sky' -- lights to be seen first in the evening and to last till dawn (Philippe, 1990).

2.2 The Movement

a. ARSAT. In 1982, Pierre Comte initiated a number of actions that may be said to have started a space art movement. They take on a particular interest when one consider their multidisciplinary character, in that they included:

- direct cooperation with scientists and engineers (e.g., C Marchal and M Ferroniere);
- the constitution of the Association Internationale Arsat (AIA) to support the art projects
- an attempt at creating an evolutionary framework for his Arsat projects.

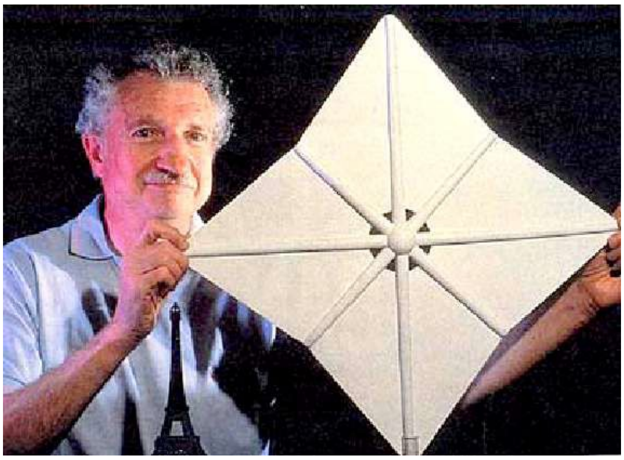

Figure 2:Pierre Comte (ca 1984) holding a model of an Arsat satellite concept, as used in the "Eiffel Tower in space" competition.

An initial space art work concept was referred to as ARSAT-0 "Dialogue." It consists of a plane, square reflector of metallized plastic film tensioned by a backbone structure of four conical ISRS beams, radiating in a diagonal layout (cross backbone) from a large central ISRS node (Comte, 1987). To ease its realization, its size was reduced from 20,000 m^2 originally down to 1,800 m^2 (42.4 m on a side). Further design modifications included a conventional spacecraft bus for supporting the beams, built with a constant cross section, but with their outer half bent to follow a slight dihedral ($\sim$1.5°), to widen the satellite's field of visibility by spreading out the reflected light. The AIA evolutionary line would have continued with ARSAT-1 "Helios," a larger solar sail to fly over the solar polar regions: here the priority would have gone to the technical application.

The recourse to a specific technology seems central to Comte's Arsat concept, in that he explicitly advocated using to inflatable, space-rigidized structures (ISRS) technology to realize his objects. Thus, the first author (MCB) had several opportunities to meet him since May 1984, when the European Space Agency (ESA) first referred the artist to Contraves, as the company developing ISRS technology. Overall. the ARSAT concept appears as very ambitious but suffered, in artistic terms, because of some characteristics that made it strong in other fields. If the aesthetic rationale for putting the lights in the sky remained sketchy, its identification with the ISRS maintained AIA in a somewhat ambiguous role as a technology's promoter.

b. OURS. In 1985, Arthur Woods launched the concept for the Orbiting Unification Ring Satellite (OURS), to make a circle visible in the night sky as a "symbol of the interconnectedness and interdependence of all things, to remind us of our responsibility to preserve the environment and to insure the survival of our planet and ourselves as species... an expression of hope... [to celebrate] our passage in the next millennium" and into the new environment of space (Woods, 1986). Its presentation at the 1st Space Commerce Conference (Montreux, Switzerland) as a technology-neutral project for realizing a 1-km ring in the year 2000 led to the authors' first meeting in July 1986. A intense collaboration followed, eventually resulting in the creation of the OURS Foundation and in the evolution of an ample line of OURS activities.

In 1987, a small (6-10 m in diameter) project prototype -- the OUR Space Peace Sculpture (OUR-SPS) was conceived, intended to use Contraves technology, and to be released in orbit from a U.S. or a Soviet facility. However, Glavcosmos exploited Contraves' reluctant support for the concept to make it a fully Soviet-supplied project. OUR-SPS was to have flown in the spring of 1992, as a cultural contribution to the International Space Year (ISY) but -- failing the needed sponsorship the Foundation eventually terminated the project (Woods and Bernasconi, 1990).

A generalized attachment to cultural activities and astronautics formed a basic characteristic of the OURS Foundation's activities. Nor consisted all its art-in-space projects in OURS-like sculptures: for instance, the SPS study was paralleled by the realization of the Cosmic Dancer (Woods, 1992), “a study in the emancipation of sculpture from the influence of gravity” that flew to the Mir station in 1993.

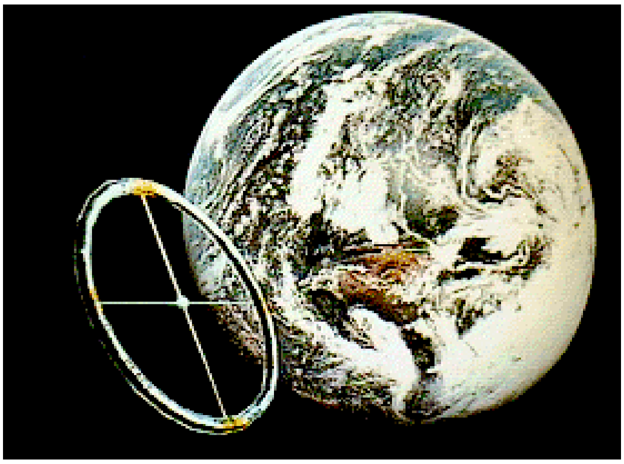

Figure 3: A symbolic representation of the OUR-SPS: the actual plans foresaw a very low Earth orbit, the plastic being intended for release from the Mir station.

c. The Goodwill Constellation. In the same time-frame, James Pridgeon proposed a sculpture consisting of (seven, then reduced to two) tethered reflecting balloons (Pridgeon, 1990). After technology-export issues combined with the astronomers' opposition to new lights in the sky (Malina, 1990) stopped this plan, the project was reformulated as a technology experiment and an ISY beacon (Pridgeon, Maley, and Lang, 1990).

2.3 Advertising?

One of the most commonly feared consequences of any space art work is seen in the subsequent "misuse" of their concepts and techniques for advertising purposes. In the authors' opinion,the first attempt of space-based advertising is already behind us -- and it failed. In 1986, the Société Nouvelle de la Tour Eiffel (SNTE) launched a contest for celebrating the one-hundredth anniversary of the erection of the Eiffel Tower by flying an "Eiffel Tower in Space". Some hundred entries were submitted in response (Anon, 1987). A number of these concepts again proposed the utilization of inflatable space structures. Again, this led to discussions between some of the principals and the first author.

In October 1986, a first jury (including CNES and ESA representatives) evaluated the entries during the XXXVII International Astronautical Congress (Innsbruck, Austria), naming three winners: the **“Space Disk”** by Dieter Kassing, **“Arsat”** by Pierre Comte (both building on ISRS technology), and the **“Anneau de lumière”** by Jerome Gerber and Jean-Pierre Pommereau. Surprisingly, a further evaluation “by CNES and ESA” (Anon, 1987) selected for possible realization the “Ring of Light” -- the largest and riskiest object. Eventually, confronted with a growing resistance from astronomers fearing excessive light pollution from the visible artwork and with a design appearing too unstable to maintain its shape in orbit, the SNTE canceled the project.

Without doubt, the Eiffel Tower competition helped many people to begin thinking about possible access to and uses of space in ways, outside the full control by the official space agencies. On the the other hand, the lack of closure by a project supported by a well-connected bureaucracy and by those same agencies, created a negative reference for any succeeding activity.

On a cultural plane, the SNTE failed to prepare the competition's rationale in significant domains, especially in relation to the artists (who one could reasonably expect to represent the main community interested by the project),

2.4 Technology, Again: Solar Sails

Many space projects call for large structures, which could become visible from the ground: here, solar sails occupy a special position, because of size, high solar reflectance, and relatively simple technology. Several initiatives came to interact, and to follow the “lights in the sky” road.[2]

Between 1979-1985, researchers, engineers, and enthusiasts established three associations to promote solar-sail propulsion. The World Space Foundation (WSF – Pasadena, California) had a Solar Sail Project, building on the the 1970's JPL studies during, aimed at the design of an Engineering Development Mission spacecraft. A half-scale (15x15 m) sail deployment test occurred already during August 1981.

The U3P (for “Union pour la Promotion de la Propulsion Photonique” -- Toulouse, France) included technical people from the local CNES and ONERA centers. They soon discussed with WSF a potential solar-sail race to the Moon, underlining its educational import, in general andfor Astronautics. Pignolet (1983) suggested a three-party race, with the sails forming a composite spacecraft for a secondary Ariane-4 payload under a SPELDA system. Finally, the Solar Sail Union of Japan (SSU – Samigahara, Japan), moving forward from a Japanese Rocket Society's solar sail study committee, became the logical third party for the race (Prado, Perret & Ozcariz, 1990).

In the summer of 1987, Dr Klaus Heiss proposed to the (US) President's “Columbus 500 Quincentenary Jubilee Commission” a “Space Sail Cup” competition -- a race to Mars via the Moon – as a space element within the celebration (Heiss, ca 2004). Publicly, announced on May 1988 (TBC), it stimulated a number of new entries, and not only in the US. However, the financing issue deeply affected the Space Sail Cup. One can organise a race and offer prestige through patronage, with people able to obtain sponsoring for cars, sailing boats, balloons, aircraft... This is not so easily done for spacecraft: major companies and universities may come forward with a proposal, but they will need a funding source before they start translating the proposed design into real hardware.

The established research groups, however, continued their efforts, with a number of workshops during 1989-1990, setting up the race guidelines, a common-launch agreement, and collecting support from the International Astronautical Federation (IAF), the Spanish Comision Estatal del Quinto Centenario and, also, from the Columbus 500 Commission. Launch was to occur possibly during 1994 (Perret, LaBombard & Miura, 1989; Miura, Prado & Staehle, 1991).

Although the end of the cold war brought to the space field only deep cut-backs as peace dividend, and the Moon race initiative dissolved, the European activists continued to research the

2 By far, what follows does not present a history of the solar sail concept; it also does not cover design ideas treated with projects of the OURS Foundation.

solar sail concept, even obtaining some support from the EU funding for young researchers' exchanges. Prado, Perret, Pignolet & Dandouras (1996) defined a unique mission, enabled by solar sailing but feasible with current technologies: holding a spacecraft at a virtual first Sun-Earth Lagrange point. VigiWind – positioned twice as far from Earth as the actual L1 -- could have observed the solar weather and provided storm warnings with an advance double that of current sensors.

At the same time, the ESA Long-Term Space Policy Committee (LSPC) proposed to the ESA Council a participation in the celebrations for the new millennium, and recommended that the Agency perform, during 1997, two feasibility studies. LSPC further recommended for the “smaller project” study a combination of VigiWind 2000 and of the “Star of Tolerance.” Thus, the proposed Daedalus solar sail spacecraft would have served as technological precursor and as a cultural new light in the sky. But before we come to that, we have to visit a last point.

2.5 The Double Star – Art or Affairs?

Figure 4: Comte's original concept for the Arsat Double Star, two dissimilar spheres connected by a tether (Credit: Pierre Comte).

Around 1990, Pierre Comte had introduced a multiple-light concept with the Arsat Double Star, where two spheres (30 m and 50 m in diameter) would be deployed and rigidized, remaining connected by a 2-km (TBC) tether. The complex would be designed to rotate around its center of mass, tensioning the tether and causing the lights to show motions lateral to the orbital track.

In 1994, Nersi Razawi picked up Comte's Double Star concept, and inserted it into a wider marketing scheme intended to celebrate and support the UN-declared “Year of the Tolerance” in 1995. The space segment consequently received the name of Star of Tolerance (TolStar, for short). The project could not take off, but its elevated ideal claims and the supposed high-level support, sufficed for a recommendation to share the flight with the VigiWind sail prototype in a hypothetical ESA contribution to the Third Millennium Celebration. An updated marketing concept still bore the “Star of Tolerance” name.

Thus, ESA undertook a sail prototype feasibility study, under the name of Daedalus, which remained without any follow-on activity.

2.6 More from the OURS Foundation

Celebrations have a good aspect: an expiration date. Eiffel-tower centenary? 1989. Gone! Five-hundred years after Columbus' landing? 1992. Gone! “Year of tolerance”? 1996. Gone!

Figure 5: The SEEDS orbital time capsule would be enclosed by a large icosahedron.

The OURS Foundation did not aim at creating only new “lights in the sky,” nor did it focus on specific technological solutions. It existed and acted at the interfaces between Astronautics' techniques and cultural aspirations.

The SEEDS Project (Synergizing Earth's Evolutionary Development Spacewards) began at the idea stage around 1990 and had a first public installation at the 46th International Astronautical Congress in Oslo (Norway) in October 1995. SEEDS wished to initiate a realistic program to develop and send artistic payloads containing organic material into space. Woods (1997) proposed to scientists working on planned planetary missions to incorporate "SEEDS" payloads into them. The "Millennium SEEDS" would then have involved a large inflatable object in Earth orbit, visible to all humanity as a blinking star, designed to return to Earth a thousand years from now carrying with it the "seeds" of our time -- “in case it becomes necessary to "reseed" Earth in order to maintain life in this part of the cosmos” -- a clear and permanent symbol for humans development and growth.

Just as the torus for plane structures, because of its low complexity, the authors like the icosahedral skeleton for simple 3-D enclosure, and this geometry has surfaced in a number of successive concepts and studies, also to create special lights in the sky.

With the recent renewed interest for inflatable and rigidizable space structures, the OURS Foundation re-examined the OURS concept, to identify feasible alternative designs to the continuous torus concept. This study looked at several new designs for inflatable sculptures that would create a visible "circle in the sky" and have a mass around 4,000 kg.

3 TECHNOLOGY BACKGROUND

Three kinds of expandable-structure technologies have appeared in the discussions of visible space sculptures:

- pure inflatable (Echo I): typically using thin (around 25 mm), metallized PET films, deployed by stored gas or sublimating compounds; pressure maintenance used subliming powders with lower vapour pressure; leakage rate increases rather rapidly, causing loss of shape within months, in absence of a significant mass of replacement gas;
- mechanically rigidized inflatable (Explorer IX series, Echo II, later elements): using a laminate of 3 or 4 layers, including at least an aluminum foil (several mm in thickness), together with the plastic films; the pressurization process stresses the metal past the yield point, achieving a stiffening that suffices to make the structure stable against the space-environment loads; the technique is exacting as pressure levels come near to tear values (Echo II had a seam opened during inflation);
- chemically rigidized structures (as proposed for Arsat, Space Disk, OURS): using a laminate with fibre-reinforced composite layers, whose matrix polymerizes in the final space environment; this technique remains at the experimental stage, unfortunately.

Indeed, the realization of a large orbital plastic employing gossamer structures would make -- in a single action -- these technologies mature and established. A few years ago, one of us drafted a rough “yearly utilization model” for gossamer materials (Bernasconi, 2003), with rather hearty assumptions (e.g. one solar sail and one telescope shield every year, etc). The estimated buy of structural materials weighted in at less than 500 kg. In contrast, a kilometric ring like the one shown in the background would mass some 2600 kg, translating in the procurement and processing of some 3.5-4 t of specific materials. Such a large run would support elaboration and application of economic production methods, and provide a substantial experience base. In consequence, it would lower the cost for any successive applications to an extent hardly possible through “normal” operations, where limited usage encourages continuous tweaking of the technology, essentially negating any economy of scale.

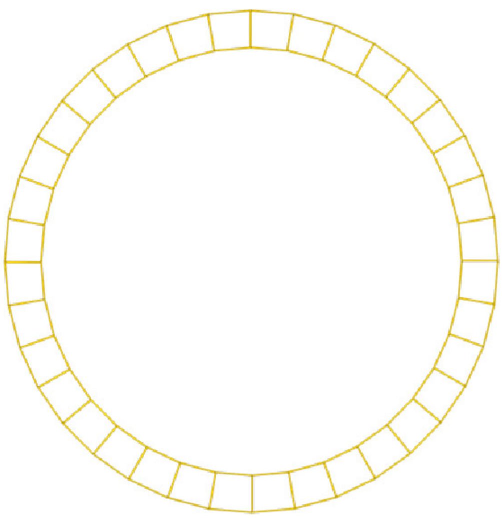

Table 1: A Summary of Lights in the Sky.

Satellite	Technology	Shape	Size	Mass	Maximum Magnitude			Assumed reflector
					Predicted	distance	Actual	
NASA Beacon	rig/membr/mech	sphere	3.66 m	~5 kg	1.9	650 km		hemispherical
NASA ADE	rig/membr/mech	sphere	3.66 m	~6 kg	1.8	600 km	4 (1600 km)	hemispherical
Echo I	inflatable	sphere	30.48 m	~60 kg	-0.7	1600 km		hemispherical
Echo II	rig/membr/mech	sphere	41.15 m	~238 kg	-2.2	1100 km		hemispherical
PAGEOS	inflatable	sphere	30.48 m	55 kg	1.4	4300 km		hemispherical
OV1-8	rig/grid/mech	sphere	9.14 m	10.3 kg	3.2	1000 km	4.75 (after 4 d)	hemispherical
Moon Balloon	rig/grid/mech	sphere	4.26 m	1.22 kg	15.4	384,000 km		
ARSAT 0 Dialogue	rig/membr/chem	square	42.4 m		-17.1	400 km		Flat, 1,800 m2
					-2.1	37,000 km		shaped
ARSAT 1 Helios	rig/membr/chem	square	140 m					20,000 m2
OUR-SPS-1	inflatable	torus	6 m	~22.5 kg	-3.3	450 km		hemicylindrical
OUR-SPS-2	rig/membr/chem	torus	8 m	~3 kg	-5.7	225 km		hemicylindrical
OURS 2000	rig/membr/chem	torus	950 m	~6300 kg	-10.9	800 km		hemicylindrical
OURS 2000 with sail		circle	944 m	~12.3 t	-13.9	800 km		shaped
Venus+	inflatable	sphere?	4 km	1000 t?	-4.3	40,000 km		hemispherical
Goodwill Constellation	inflatable	sphere	30 m	20 kg?	-2.3	750 km		hemispherical
Daedalus	Coilable or inflatable booms	square	10 m					flat

4 ASSESSMENT

The problematic financing of orbital sculpture projects, and finally the issue of a cooperation between the actors in this field.

The potential of modern inflatable systems to implement space art's basic structural elements is presented. At the same time,, practitioners are warned about typical pitfalls on the way to the realization of such projects, such as the tempting connection with technological experiments, and the risk of excessive commercialization of an idea. The problems associated with obtaining access for 'private' purposes to a technology developed for governmental organizations are mentioned.

5 REFERENCES

Anon. (1987). One Hundred Years Later: An Eiffel Tower ln Space? *AIAA Student J.* **24**[04], 44-45.

Marco C Bernasconi (2003). The Need for Standardization of the Materials for Inflatable Structures' Sublaminates. Remarks at the *Inflatable Structures Working Meeting*, ESTEC (The Netherlands), October 8-9.

M.C. Bernasconi & G.G. Reibaldi (1985). Inflatable, Space-Rigidized Structures: Overview of Applications & Their Technology Impact. Paper *IAF-85-210;* also: *Acta Astronautica* **14**[] (1986), 455-465.

C.W. Coffee, Jr, W.E. Bressette, & G.M. Keating (1962). Design of the NASA Lightweight Inflatable Satellites for the Determination of Atmospheric Density at Extreme Altitudes. NASA *TN D-1243*, Washington (DC).

P. Comte (1987). Leonardo in Orbit: Satellite Art. *Leonardo* **20**, 17-21.

Krafft A Ehricke (1957). The Anthropology of Astronautics. *Astronautics* **2**[11], 26-68.

Donald C Elder (1995). Out from Behind the Eight-Ball: A History of Project Echo. AAS *History Series* **16**.

F.W. Forbes (1964). Expandable Structures. *Space/Aeronautics* **42**[07], 62-68.

K.W. Gatland, A.M. Kunesch, & A.E. Dixon (1951). Minimum Satellite Vehicles. *JBIS* **4**[10], 287-294.

Klaus P Heiss (ca 2004). The Columbus 500 Space Sail Cup: Sails of Exploration. Unpublished memoir.

D Kassing (1997). European Solar Sail in Space for the New Millennium Celebrations in 2000 -- Feasibility Assessment Report. ESA document IMT-T/FSA/dk/18.8.97

RF Malina (1989). Space Art As Public Art: The Artist As Space Researcher. Delicate Balance: Technics, Culture & Consequences, , October 20-21; Proceedings, 260-266.

Roger F. Malina (1990). Art ln Space. *Technology Review* [03], 62-69.

Koryo Miura, Jean-Yves Prado, & Robert L Staehle (1991). Report on SSU, U3P & Foundation Activities for the Earth-Moon Race. Paper *IAF-91-513*.

A. Notarbartolo (1975). Some Proposals for Extraterrestrial Space. *Leonardo* **8**, 139-141.

A Perret, E LaBombard, & Koryo Miura (1989). The Solar Sail Race to the Moon. Paper *IAF-89-539*.

Jean-Marc Philippe (1990). Space Art: A Call for a Space Art Ethics Committee. *Leonardo* **23**[01], 129-

132.

Guy Pignolet (1983). Making the High Frontier Highly Visible with a Solar Sail Race to the Moon. Paper *AAS-83-226* presented at the *Sixth Princeton/ SSI Conference on Space Manufacturing*, Princeton (NJ), May 9-12; also: *Advances in Astronautical Sciences* **53**, 249-257.

J.R. Pierce (1955). J.A.R.S., 153-157.

J.R. Pierce (1985). Satellite Communications. In P.W. Goetz, Ed., *The New Encyclopaedia Britannica,* 28, 15th Edition. Encyclopaedia Britannica, Inc., Chicago/Geneva. p. 504-511.

J-Y Prado, A Perret, & I Ozcariz (1990). Solar Sail on the Track. Paper *IAF-90-496*.

Jean-Yves Prado, Alain Perret, Guy Pignolet, & Iannis Dandouras (1996). Using a Solar Sail for a Plasma Storm Early Warning System. Paper *IAA-96-IAA.3.3.06* presented at the *XLVII International Astronautical Congress*, Bejing (China), October 7-11; also, at the *ESA Symposium on Environmental Modeling for Space-Based Applications*, ESTEC (The Netherlands), September 18-20; *ESA SP-392*, 213-223.

James Stephen Pridgeon (1990). The Goodwill Constellation: Seattle 1990 Goodwill Games Sculpture in Space. In: David W. Reed, Ed. Spirit of Enterprise: The International 1990 Rolex Awards. Buri, Berne, 236-238.

JS Pridgeon, PD Maley, & DD Lang (1990). A Free Flying Tether Experiment & Space Structure for ISY. Paper *IAF-90-049*.

L.A. Teichman (1968). The Fabrication and Testing of PAGEOS I. NASA *TN D-4596*, Washington (DC).

G. Williams (1987). Inflatables for Lightweight Satellite Application. L'Garde paper, Tustin (CA).

A. Wilson (1981). A History of Balloon Satellites. *JBIS* **34**[], 10-22.

C.V. Woerner & C.W. Coffee, Jr. (1964). Comparison of Ground Tests and Orbital Launch Results for the Explorer IX and Explorer XIX Satellites. NASA *TN D-2466*, Washington (DC).

A.R. Woods (1986). OURS Brochure. The OURS Project, Embrach, Switzerland. (Available on request to the authors.)

A.R. Woods (1992). The Cosmic Dancer Project. Paper presented at the *First European Space Art Symposium,* Montreux (Switzerland), 23-24 March.

Arthur Woods (1997). SEEDS -- Synergizing Earth's Evolutionary Development Spacewards. Paper *IAA-97-IAA-8.2.04* presented at the *48th International Astronautical Congress*, Turin (Italy).

Arthur R. Woods & Marco C. Bernasconi (1990). The OUR-Space Peace Sculpture: Further Developments in a Global Artwork for Space. Paper *IAA-90-652*; also (with a slightly modified title): *Leonardo* **24**[05], 601-606.