Low Cost Large Space Antennas

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ABSTRACT

The mobile communication community could significantly benefit from the availability of low-cost, large space-deployable antennas. A new class of space structures, called inflatable deployable structures, will become an option for this industry in the near future. This new technology recently made significant progress with respect to reducing the risk of flying large inflatable structures in space. This progress can be attributed to the successful space flight of the Inflatable Antenna Experiment in May of 1996, which prompted the initiation of the NASA portion of the joint NASA/DOD coordinated Space Inflatables Program, which will develop the technology to be used in future mobile communications antennas along with other users.

The NASA/DOD coordinated Space Inflatables Program was initiated in 1997 as a direct result of the Inflatable Antenna Experiment. The program adds a new NASA initiative to a substantial DOD program that involves developing a series of ground test hardware, starting with 3 meter diameter units and advancing the manufacturing techniques to fabricate a 25 meter ground demonstrator unit with surface accuracy exceeding the requirements for mobile communication applications. Simultaneously, the program will be advancing the state of the art in several important inflatable technology areas, such as developing rigidizable materials for struts and tori and investigating thin film technology issues, such as application of coatings, property measurement and materials processing and assembly techniques. A very important technology area being addressed by the program is deployment control techniques. The program will sponsor activities that will lead to understanding the effects of material strain energy release, residual air in the stowed structure, and the design of the launch restraint and release system needed to control deployment dynamics. Other technology areas directly applicable to developing inflatable mobile communication antennas in the near future are analytical performance prediction tools, configuration studies and miniaturizing the inflation systems.

LARGE ANTENNAS ARE NEEDED

Large space-deployable reflector antennas are needed for a variety of applications that require structures up to 30 meters in diameter for RF operation between 0.3 and 88 GHz. The classes of applications include **mobile communications, earth observation radiometry,** active microwave sensing, orbiting very long baseline interferometry (OVLBI) and DOD space-based passive and active sensors. A number of mobile communications system concepts are based on L-band, 1.5 GHz with aperture sizes from 10 to 20 meters and Ka-band, 20 to 30 GHz with apertures from 4 to 8 meters. Earth observation radiometry can utilize reflectors from 15 to 30 meters in diameter for operation somewhere between 1.4 and 60 GHz. Active microwave sensing is based on planar arrays up to possibly 3 by 16 meters for operation from 1 to 90 GHz. The next generation OVLBI after the VLBI Space Observatory Program (VSOP), which was recently launched, will need a reflector somewhere between 15 and 30 meters in diameter for RF operation between 2 l and 88 GHz. Current DOD concepts for space based radar are based on structures up to 25 meters in diameter for RF operation from 1.5 to 8.5 GHz.

USER CONCEPT SELECTION CRITERIA

Recent constraints on the availability of resources for these classes of applications within NASA, the Science Community, the commercial sector and even the DOD, have resulted in very stringent user application requirements. The real key is affordable antennas that are mechanically reliable with high mechanical packaging efficiency and aperture precision while maintaining low mass and long term dimensional stability. In addition to designing for these challenging criteria, meaningful demonstrations of such concept capabilities will have to be accomplished to attract any kind of serious user interest. This means that (a) low-cost and lightweight hardware can only be verified by actually building large flight-quality antennas, (b) deployment reliability can only be demonstrated with large flight-type hardware in a realistic service environment, (c) useable reflector surface precision will have to be validated in a realistic service environment and (d) mechanical packaging efficiency can only be validated with full scale, flight configured hardware.

NEW CLASS OF SPACE STRUCTURES

Fortunately for the users, a relatively new class of deployable space structures has recently emerged that has tremendous potential for accommodating the current user criteria. Even though large inflatable space structures have been around for over 40 years, i.e., Echo 1, series 1959-64, only recently have a very few organizations learned how to design and manufacture thin membrane structures with enough geometric precision to be seriously considered for specific classes of applications.

Significant technology achievements have been made by both L'Garde, Inc. of Tustin, California and Contraves of Zurich, Switzerland. L'Garde, Inc. has successfully built and flown a large number of small inflatable space structures over a period of 25 years. In this same time frame and in parallel, other concepts for much larger size inflatable structures for solar concentrators, reflector antennas and solar cell support structures were under development. The culmination of the latter effort was the NASA sponsored In-Space Technology Experiments Program (IN-STEP) Inflatable Antenna Experiment. Meanwhile, in the time frame of 1975 to 1985, Contraves developed concepts for large offset reflector antennas intended for mobile communications applications and other applications. A 10 by 12-meter proof of concept antenna reflector structure was designed, built and deployed on the ground. The surface accuracy of a few mm RMS for such a new and unique structure of this size was considered by many a major advancement of this technology. Other organizations which have demonstrated a technology capability for inflatable space structures include SRS, ILC Dover, Thiokol, and Aerospace Recovery Systems.

IAE

The NASA Office of Aeronautics and Space Technology initiated IN-STEP specifically to sponsor the verification and validation of new innovative and high payoff technologies in the space environment. The potential of this new class of space structures for a number of meaningful applications resulted in the selection of the L'Garde, Inc. inflatable deployable reflector antenna concept for an experiment.

The basic objective for the experiment was to validate and characterize the functional mechanical performance of a large inflatable low cost deployable reflector antenna structure in a real orbital operational environment. This objective when evaluated with respect to the L'Garde, Inc. technology data base for the inflatable antenna concept, their manufacturing facilities, and the capability of the Spartan spacecraft, resulted in the selection of a 14 meter diameter reflector structure with three 28 meter long struts. It is interesting to note that, this size structure is reasonably close to what is needed for several classes of application, in particular, mobile communications. The experiment requirements were to (a) develop a large low cost flight quality reflector antenna structure, (b) validate mechanical packaging efficiency, (c) demonstrate deployment reliability and (d) measure surface precision on orbit. The IAE was successfully flown on the Space Shuttle S'1'S-77 on May 29, 1996.

The overall experiment was successful. New, unique and low cost space structures technology was demonstrated on orbit by (a) building a large inflatable space antenna structure on the order of about $1,000,000, (b) demonstrating extremely efficient mechanical packaging by stowing a 14 by 28 meter inflatable structure in a container the size of an office desk, (c) manufacturing an offset membrane reflector structure with a surface precision on the order of a few mm RMS and (d) demonstrating the robustness of deployment for this new class of structure. The results of this experiment were used specifically to establish the technology database and were the basis of a technology road map for the continued development of this type of space structure.

MOBILE COMMUNICATIONS ANTENNA NEEDS

Current concepts for L-band mobile communications are based on using multiple beam offset reflector antennas in the size range of 8 to 20 meters in diameter. Some system concepts utilize numerous spacecraft, while all concepts are based on low cost antennas. In addition to the requirement for low cost, antenna **structures must also be lightweight with mechanical packaging techniques that will** enable the use of different size and shaped spacecraft. Without such physical capabilities the antenna stowed configuration could drive the spacecraft design and the size of the launch vehicle shroud, which have major inpact on system cost.

SPACE INFLATABLES PROGRAM

The program was created as the logical follow-on to the successful flight of the Inflatable Antenna Experiment that was launched in May 1996. The program is designed to be compatible with a large DOD investment in several different inflatable technology programs. The two largest elements of the DOD programs are a two year Large Inflatable Structure Program funded by the Phillips Laboratory and a Rigidified Inflatable& Materials Development Program, both of which are executed by L'Garde, Inc., Tustin, Ca. The NASA portion of the joint program is designed to leverage off, complement, broaden the scope and accelerate the DOD inflatable technology development program. The results of the joint program will significantly reduce the risk of using the inflatable technology for NASA, DOD and commercial missions such as mobile communications.

The technology investment strategy for the program was based on the inputs from the users. A Quality Function Deployment (QFD) analysis was conducted to determine where NASA money should be invested to maximize the leverage from the DOD program. As a result a robust two year program was created. The program will address all of the fundamental technological areas for inflatables and advance the technology to the point where 25 meter class apertures supported by large rigidizable structures can be baselined for long life space missions.

PROGRAM DESCRIPTION

The Program consists of 10 major activities as described in the following sections:

Deployment

The purpose of this research and development is to understand and characterize the **fundamental factors influencing deployment dynamics and therefore the reliability of inflatable structures** in space. Upon reaching the vacuum of space, the folded inflatable membranes are subject to the pressure of internal residual gas. The effect of this gas expansion in conjunction with strain energy release of flexible materials and thin films could lead to uncontrolled deployments. To address these phenomena several sub-scale drop tests will be performed to evaluate the newest predictive tools, packing methods and release and ejection mechanisms under simulated microgravity conditions. Thermal vacuum tests will provide additional information regarding different designs of vent valves, vent techniques and temperature effects on different deployment techniques.

Support Structures

The purpose of this research is to understand the whole new class of inflatable rigidizable structures in space. There are several different types of materials and rigidization techniques that are under consideration for applications.

The methods of rigidification under study are: gel impregnation, cold rigidization, UV curing, yielding of aluminum laminate and foam injection. Other advanced concepts such as gas curable epoxies and radiation curing will also be considered for far term applications. The materials that offer the most promise in the short term are gel and rigidified aluminum. An extensive material properties program will be implemented to establish the data base of stress/strain/temperature properties. Large struts, tori and beams will be constructed and tested in thermal vacuum chambers. Thermal vacuum tests will significantly improve the data base of the rigidification process with respect to temperature, pressure and different types of inflatant gases. The optimal ways of joining inflated members will be studied to arrive at designs of tube connectors, joints and saddles.

The support structures technology area is currently being substantially supported by the DOD.

Membranes

The success of inflatables in space in the long run depends on the properties of materials used. This task will investigate a number of candidate materials and their properties, such as stress/strain/temperature characteristics, non-linear modulus, creep, coefficient of thermal expansion, and radiation tolerance. The most promising materials will be tested for compatibility with fabrication and processing techniques, and deposition of optical coatings, flexible interconnects and electronic elements. A number of environmental tests will be conducted to allow more accurate performance predictions of the selected thin films. The films will be subject to accelerated tests of UV radiation, high energy electrons, low energy protons and combined effects. In addition, mid-LEO orbit AO-erosion life tests will be conducted. A comprehensive property data base will be created for selected materials to serve as a universal reference for future inflatable structures. Compatible adhesives for joining membranes and methods for forming doubly curved surfaces will also be investigated.

Analytical Tools

A significant contribution to faster, better, cheaper missions will come from extensive analytical modeling to shorten the design, test and fabrication cycle. This activity includes dynamic and static structural performance prediction, thermal models, reflector performance predictions and ground based simulation methods. It is important that all the existing specialized codes such as the Finite Element Analysis of Inflatable Membranes (FAIM), TRASYS and IMOS be made compatible with each other and work in tandem to allow the engineers several iterations of the preliminary design before any prototype hardware is built and tests are conducted, All codes will reflect the latest knowledge and refinements obtained from other tasks of the program.

Manufacturing and Assembly

This extremely important activity will be entirely funded by the DOD component of the program in the next two years. There will be synergism of the manufacturing tasks with the NASA sponsored work. The manufacturing tasks will depend to a great extent on the materials development results and the characteristics of the resulting products.

System Testing

This is a very important area of inflatable technology. Inflatables are a new class of structures that are very difficult and sometimes impossible to test on the ground. The sizes of the structures considered for proof of concept demonstrations are not compatible with ground facilities of aerospace companies. The testing itself imposes many new challenges: large vacuum tanks, large dynamic test facilities, methods of relating results of these tests to space conditions or conducting partial deployment tests on KC- 135 aircraft in simulated microgravity conditions, vent test techniques verification, support structure performance, surface measurement equipment and most of all deployment control technique verification.

Inflation Systems

One of the major benefits of the inflatable structures is their low launch volume and mass. While it is clear that thin membranes have low mass and can be packaged into a small container, the inflatable structural systems do not consist of membranes only. From the system point of view a significant part of the total mass is attributed to the inflation system. Consequently, a miniature inflation system is equally important. The inflation system is also a major contributor to the mechanical reliability of the structural system and a participant in control of the deployment. Studies will be conducted to determine if an inflation system with its cumbersome tanks and pressure regulation system could not be replaced by some other alternatives. One alternative is on-board gas generation, using chemical reaction between liquids or liquids and solids. Such a gas generation system would likely consist of a reaction chamber, liquid low pressure tank, and low pressure valving.

Interfaces

This technology area deals with the interfaces between the inflatable and the rest of the spacecraft. These include the mechanical and electrical interfaces that are involved with the launch, deployment and post deployment. This technology area is considered to be mission specific. Only a small portion of the funds will be invested hereto ensure there are no formidable problems with a spacecraft.

Active Shape Control

Active shape control can contribute to further dimensional precision of inflatable structures. Smart materials can be integrated into the structure to adjust the geometry either in real time through feedback control or before the rigidification takes place. This approach could compensate for many variables in materials, processes, fabrication, space effects or temperature. This technique will probably be required if the inflatables are to be used as high frequency antennas.

Requirements and Applications

This is a very important area of the inflatable technology development since the application requirements will focus and drive the program elements. One of the primary considerations of this task is to collect the user requirements. Based on these requirements conceptual designs will be developed for the primary customers of the technology. These conceptual designs will help focus the trade studies considering both inflatables and mechanically deployed structures and different approaches for achieving inflatable structure configurations. The trade studies, for example, will point out: the benefits and application limitations of gel rigidizables and aluminum rigidizables, and cover contamination requirements, range of radiation exposures, atomic oxygen environments, and lifetime performance. The trade studies will also contribute to investment decisions depending on relative importance of different aspects of the inflatable program.

CONCLUSION

The joint NASA/DOD Space Inflatables Program will develop inflatable structures technology to the point of demonstrating a ground based technology readiness level for 25 meter antenna structures within two years. It is expected that these antenna structures will have reflector surface precision on the order of 2 mm RMS and thus will make inflatables a viable technology for mobile communications.

However, before this inflatable technology will be ready for application to the commercial community it will have to be demonstrated by a long duration, operational, large size space antenna validation. It is expected that hardware development for such a demo will start in 1999 to accommodate a flight in the year 2001 time **frame. If such a demo is successful the commercial applications will follow.** Even though this timetable points out that we will not see inflatable mobile communication antennas in space before the year 2003, the high payoff of decreasing by orders of magnitude the cost, mass and launch volume of large space structures may be worth waiting for.

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