SSC99-I-7

The Starshine Satellite
From Concept to Delivery in Four Months

Bill Braun, Chris Butkiewicz, Ilene Sokolsky, and John Vasquez
Naval Research Laboratory
Washington, DC 20375

Gil Moore
Starshine Project Director
Monument, CO 80132

Abstract

Engineers at the Naval Research Laboratory's Naval Center for Space Technology (NCST) designed, built, and tested the Starshine satellite to meet Space Shuttle Hitchhiker Payload specifications. In a period of only four months after being provided the project requirements from the Starshine project director, Starshine was ready for delivery to the NASA Goddard Space Flight Center (GSFC) for STS 96. GSFC integrated the satellite with its Hitchhiker canister and installed it in the cargo bay of Space Shuttle Orbiter Discovery at the Kennedy Space Center. On May 27, 1999, Starshine went into orbit with Orbiter Discovery. On June 5, 1999, Starshine was deployed from the Hitchhiker canister into low Earth orbit.

This paper describes the features of the design, analysis, and testing of the Starshine satellite that permitted its delivery in such a short time. The paper also describes the design and production of the spacecraft's 878 mirrors and the polishing of those mirrors by 25,030 students in 18 countries, as well as the post-polishing protective coating of the finished mirrors. It will also describe the deployment of the satellite and early results of the tracking observations.

Introduction

Project Starshine provides a hands-on opportunity for students to participate in the construction and tracking of a satellite. Student observers will record the position of the satellite and provide this information to the project's website. These measurements will be used to determine the satellite's orbit. Changes in Starshine's orbit will be used to calculate the density of Earth's upper atmosphere and examine how the density of the upper atmosphere varies with solar activity.

Starshine consists of a small, passive satellite with no moving parts or electrical components. The spherical satellite, shown in Figure 1, is constructed primarily of aluminum with A-286 alloy steel fasteners. Starshine has an outer diameter of 18.7 inches, a height of 20.5 inches, and a weight of 86.5 pounds. Vent holes in the structure ensure that the sphere vents during ascent. The exterior of Starshine is covered with 878 aluminum mirrors. Starshine was mounted in a NASA Hitchhiker Canister using the Hitchhiker Ejection System (HES) Marman band interface.

Starshine Structure

The satellite structure, depicted in Figure 2, consists of the following hardware:

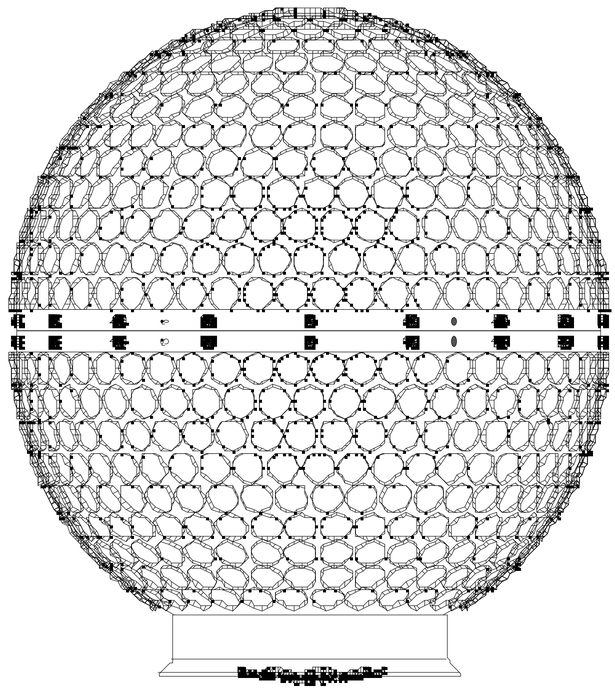

Figure 1 Starshine Satellite

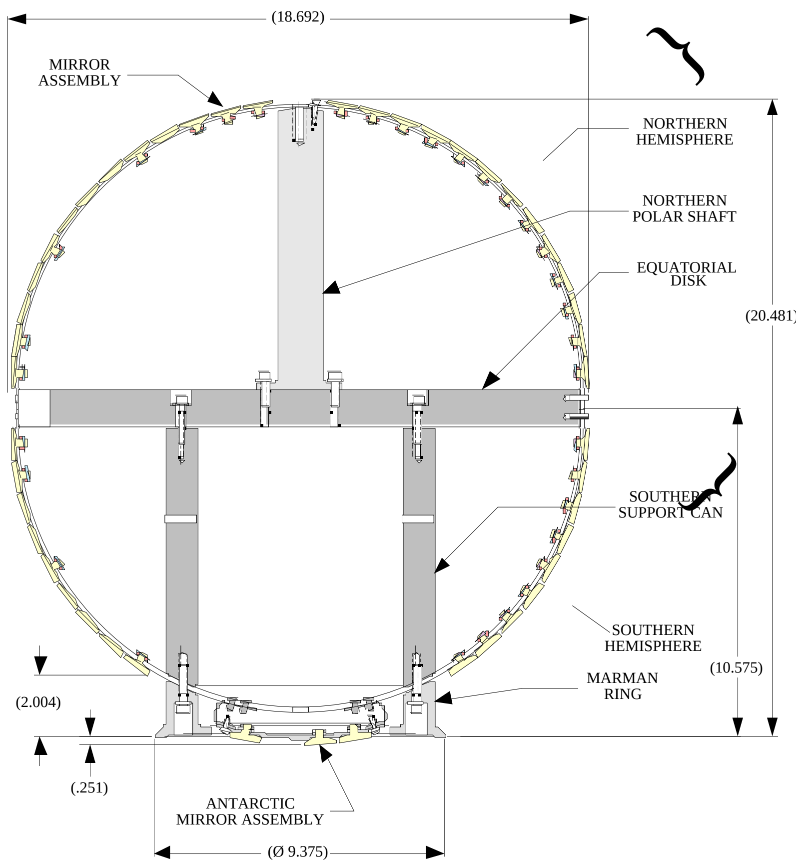

Figure 2 Starshine Structural Assembly

Hemispherical Domes

Two spin-formed aluminum hemispherical domes are used as the Northern and Southern hemispheres of the Starshine satellite (with an internal diameter of 18 inches and a wall thickness of .10 inches). The Northern hemisphere is drilled for mounting 499 mirrors onto its surface, while the Southern hemisphere is drilled for 399 mirrors. The dome material is 6061-T4 aluminum. The inside of the domes are painted black to increase internal thermal radiation heat transfer within the satellite. This provides a more even temperature distribution over the domes when the satellite is inside the Hitchhiker canister and while in orbit.

Equatorial Disk

A 1.2 inch thick 6061-T6 aluminum plate joins the two hemispheres together. The disk also transfers load from the shells to the Southern Support Can. The Equatorial Disk was designed to be heavier than structurally necessary in order to increase Starshine’s weight to the design requirement of 86 pounds.

Northern Polar Shaft

The 6061-T6 aluminum shaft enables the lifting of the assembled satellite and provides a load path to compress the HES spring.

Southern Support Can

This 6061-T6 cylinder provides a load path from the Equatorial Disk into the Marman clamp interface ring. Like the Equatorial Disk, the Southern Support Canister was designed to be heavier than structurally necessary in order to increase Starshine’s weight to the design requirement of 86 pounds.

Marman Ring

A 6061-T6 aluminum ring was designed to be compatible with the HES and provides the interface surface between Starshine and the Hitchhiker canister.

Antarctic Bracket

A 6061-T6 aluminum bracket is attached under the Marman clamp to provide extra mirror mounting surface area. Thirteen mirrors are installed onto this bracket.

Mirror Design, Production and Coating

At the beginning of the Starshine program, optical engineers at Utah State University's Space Dynamics Laboratory performed astronomical brightness studies to determine the minimum size of a mirror required to reflect sunlight from a satellite in a 350 km orbit to observers on the ground. The reflection from a mirror needed to be detectable by the naked eye at an elevation angle of 20 degrees or higher, under good atmospheric viewing conditions and a solar depression angle of 9 degrees or more. They found that a one inch diameter (25mm) mirror, ground and polished to a flatness of better than five wavelengths of visible light, would reflect sufficient sunlight to have an equivalent stellar magnitude of +1 (twice as bright as Polaris) under these conditions. An aluminum mirror of this diameter was designed with a basic shape and mounting post configuration that would avoid thermally induced warping of the front surface of the mirror when secured to an aluminum shell with an epoxy bonding compound filled with glass microbeads. Based on this design, faculty members of the Bridgerland Applied Technology Center in Logan, Utah programmed CNC lathes, and a group of high school and adult students in the machining program at that institution produced 2,400 mirror blanks for distribution to students worldwide by project volunteers.

Optical engineers at the White Sands Missile Range in New Mexico adapted a method they had developed for polishing aluminum mirrors to a flatness of 1/4 wavelength of visible light. The method developed fit the expected capabilities of elementary, middle, and high school students and the relaxed requirements of the Starshine project. Self-contained mirror polishing kits, containing two mirror blanks each, were prepared by project volunteers and mailed to 1050 schools around the world. Nearly 1800 mirrors were polished by 25,030 students in some 700 schools in 18 countries. Half the mirrors were retained for mounting in the schools' trophy cases and half were returned to the project, together with signature sheets to be scanned into a compact disk. The CD was later installed inside the satellite. Engineers and technicians at the Optics and Photonics Facilities of Hill Air Force Base in Utah inspected these mirrors. They corrected those that did not meet specifications and then coated all of the mirrors with a monomolecular layer of fresh aluminum, followed by a half-wave layer of silicon dioxide. The silicon dioxide increases the scratch resistance of the mirrors, allowing handling of the mirrors. The coating also maintains the mirror’s brilliance by preventing the oxidation of the aluminum. The finished mirrors were then shipped to the NCST for installation on the satellite.

Subsequent worst-case thermal studies by NASA resulted in predicted temperature ranges for the spacecraft, while still mounted in the orbiter cargo bay, of –40° C to +118° C, thereby eliminating the bonding method from consideration for mounting the mirrors. The NCST then redesigned the mirror-mounting scheme to preserve the original objective of avoiding mounting-and-thermal-stress-induced mirror warping. This design change secures the mirrors to the satellite shell under the worst-case thermal conditions and vibration loading (18 g in the radial direction).

Mirror Attachment

Mirrors are attached to the hemispherical domes and the Antarctic bracket using a method designed to minimize induced stresses on the mirror surfaces. Figure 3 shows the mirror installation assembly. A mirror is inserted into one of the hemispherical domes or Antarctic bracket. An O-ring (Parker E515-80) is placed onto the mirror shaft. The O-ring acts as a spring to preload the mirror assembly. Spacers are next inserted onto the mirror shaft to obtain the required preload. A snap ring (MS16624-4025) is installed onto the mirror shaft to retain the mirror on the dome or bracket. Each mirror assembly preload is verified to be between 6 pounds and 20 pounds by pushing on the mirror stem with a force gauge. The preload prevents mirror chattering during launch. After final Quality Assurance inspection, each snap ring is staked with Hysol EA934NA epoxy.

NCST Effort Overview

NCST’s efforts on the Starshine project began four months before the satellite needed to be delivered to the NASA Goddard Space Flight Center for integration into the Hitchhiker Canister. In order to meet this delivery requirement, a core group of engineers began concurrent design, analysis, and fabrication efforts. Figure 4 depicts the Starshine Project Flow Plan.

Stock materials and fasteners as well as established operating procedures were used as much as possible to reduce procurement lead times and development times. The

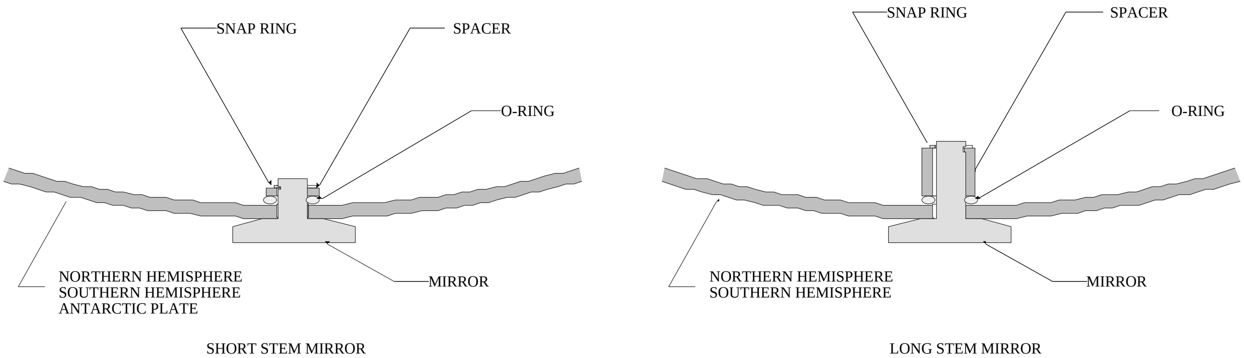

Figure 3 Starshine Mirror Installation Assembly

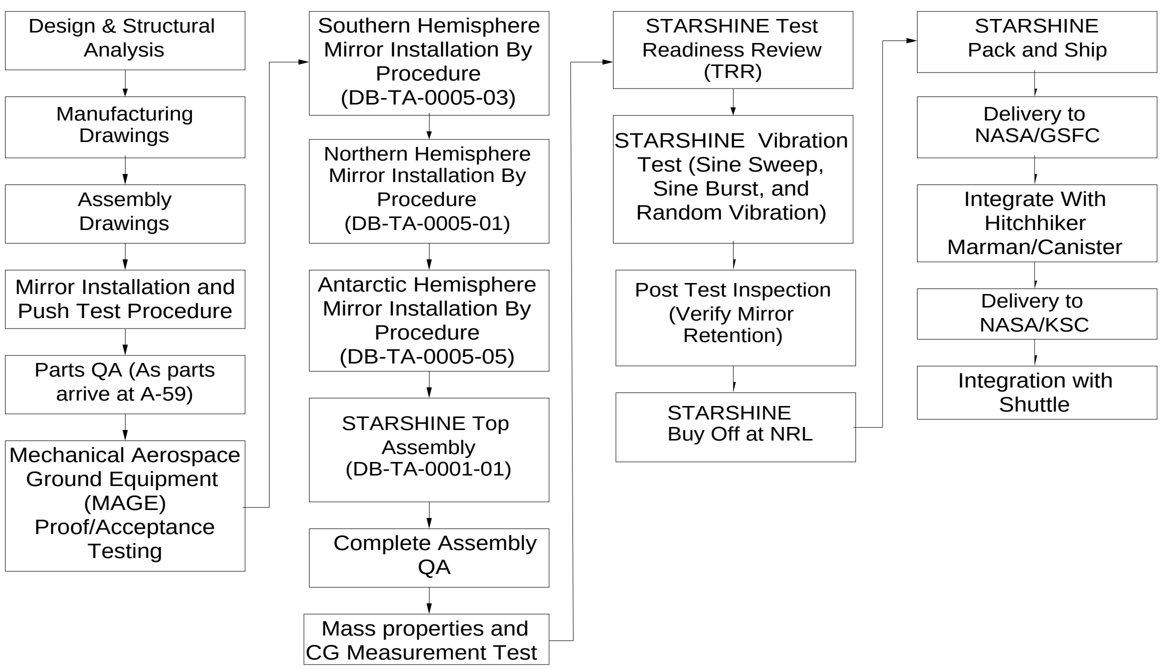

Figure 4 Project Starshine Flow Plan

hemispherical domes were sized to an existing mandrel in order to save fabrication time.

The polished mirrors were ready for delivery at the start of NCST's efforts. The innovative mounting technique was developed to accommodate the existing mirrors. The technique was simple enough to allow the installation of 878 mirrors in a timely manner. To validate the mirror installation procedure, push tests were conducted on test mirrors. This testing involved assembling mirrors onto an aluminum plate and pushing the mirror stem until a load of 100 pounds was achieved or the snap ring rolled out the mirror stem groove. Mirror push test results showed that the mirror assemblies could withstand more than 100 pounds of force before failure. The testing demonstrated a minimum margin of safety of 5.

All structural components of the Starshine satellite were designed and analyzed to a factor of safety greater than 1.25 on yield and 1.4 on ultimate material stress limits. A margin of safety was calculated for each structural part and was shown to be positive.

Materials were chosen to comply with MSFC-SPEC-522B for high resistance to stress corrosion cracking where possible. There were no material outgassing issues; all materials used on Starshine met the NASA outgassing requirement of less than 0.1% Collectable Volatile Condensable Materials and 1% Total Mass Loss. The Starshine Fracture Control Plan was implemented in accordance with "GSFC Fracture Control Plan" (731-0005-83B) and "NASA-STD-5003, Fracture Control Requirements for Payloads using the Space Shuttle, October 1996." No fracture critical parts were identified. "GSFC Fastener Integrity Requirements," (S-313-100), were employed to ensure that counterfeit fasteners were not used. Locking helical coils were used to preclude loosening of fasteners.

Testing of the Starshine satellite included sine sweep (structure frequency determination), random vibration (workmanship and flight qualification to Orbiter vibration levels), and sine burst (material strength) testing. These tests were conducted in three orthogonal axes.

A worst case fundamental frequency greater than 35 Hz was required. Sine sweep testing showed that the lowest fundamental frequency was approximately 243 Hz.

Starshine was subjected to 9.8 G_{RMS} random vibration from 20 Hz to 2000Hz and a sine burst of 18 g in each axis. A pre and post sine sweep of the satellite in each axis revealed no changes in the natural frequencies and no loose mirrors were observed.

Starshine Deployment

On May 27, 1999, Starshine was carried into space aboard Space Shuttle Orbiter Discovery during STS 96. On June 5, 1999, was deployed into its own nearly circular orbit with an initial altitude of 380 km and an inclination of 51.6 degrees. It is expected to remain in orbit for a period of approximately eight months, depending on solar activity and related fluctuations in upper atmospheric density. An international network of student observers has been established to measure and report Starshine's angular position at precise times, so that its orbit can be computed as it descends into the atmosphere. A display of its daily altitude is being presented on the Starshine website (http://www.azinet.com/starshine). Together with images of the sun, students can make a correlation between sunspot activity and the rate of decay of the satellite's orbit. This provides insight to the relationship between sunspot activity and the fluctuation of the Earth's atmospheric density.

Due to the fact that Starshine did not tumble as expected during its deployment from the Hitchhiker Ejection System, the rate of visible flashes produced by its mirrors is unexpectedly low. Instead of occurring at the rate of one flash every few seconds, the rate varies from once per fifteen seconds, to once or twice per pass across the sky, to none at all. Flash rate depends on the relative positions of the sun, the satellite, the observer, and the orientation of the mirrors on the satellite as the satellite sweeps across the sky. The flashes are as bright as predicted, but they are so far apart that tracking them is quite difficult. Therefore, Space Command radar tracking, supplemented by occasional flash location measurements from world wide visual observations, is initially being employed for determining the satellite's orbit. This situation is expected to improve in the latter phases of the mission as the satellite descends into the atmosphere. Aerodynamic forces, generated by the denser air, will torque the satellite. Starshine should then tumble at a faster rate and produce more flashes during a given pass. Opportunities for high-quality measurements of Starshine's position will increase as it approaches re-entry in late 1999 or early 2000. More student observations are also expected as schools in the Northern Hemisphere return for the fall term in August and September.

Conclusions and Future Plans

The design, manufacturing, integration, and deployment of Starshine have gone according to plan. Thousands of students from around the world have participated directly in a space experiment. Enthusiasm for the project on the part of the students and teachers has been outstanding. The brightness of the mirror flashes is slightly higher than predicted, however, tracking and data reporting has started slowly. This slow start is a result of two factors; low flash rate (due to the slow tumble rate) and closure of schools in the Northern Hemisphere for the summer time. It is anticipated that both the flash rate and the availability of observers will improve in the fall and early winter of 1999. The satellite will descend into denser air (causing tumbling of the satellite), and Northern Hemisphere students (who comprise the greatest number of participants) will be returning to school for the fall term.

Future plans for Starshine II include a solution to the spin rate problem. An internal mechanism for producing a known post-deploy spin rate will be proposed. Starshine II structural components will consist of the flight spare hardware stored at the NCST. Approximately 2,400 additional mirror blanks have been produced by Bridgerland Applied Technology Center students. Publicity surrounding the launch and deployment of Starshine has been extensive. Project officials are expecting a deluge of applications to participate in Starshine II. Mirror polishing kit components are presently being assembled by the National Aerospace Teachers Association. A procedure for selecting schools to receive the kits is being prepared by the Starshine Project Office. A request for assignment to a Shuttle Mission has been submitted to NASA. It is estimated that an opportunity to fly Starshine II will occur in the year 2000.

Acknowledgments

In addition to the supporters, students, and teachers, the authors of this paper wish to thank those people at the NCST who helped make Starshine a reality. Most especially we thank Ed Senasack, Mike Brown, Russell Starks, Charlie Bird, Lakyetta Rodgers, and Katie Hale.