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PLACEMENT OF RETROREFLECTORS ON THE LAGEOS SATELLITE

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16. ABSTRACT

A model is presented for placing a large number of equal size holes in the surface of a spherical satellite. This problem differs from the classical mathematical problem of packing the maximum number of equal nonoverlapping circles on a sphere in that no hole can intersect the assembly joint at the satellite equator. The model was used during the design of Lageos to analyze the influence of the satellite diameter and hole size on the number of holes that could be placed on the satellite. The retroreflector placement pattern used in constructing Lageos was produced by the model.

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INTRODUCTION

The Laser Geodynamic Satellite (Lageos), which looks like a cosmic golfball, is a 60 cm diameter sphere with retroreflectors embedded in its surface [1]. It is designed to provide a stable point in the sky to reflect pulses of laser light. Lageos was constructed from a cylindrical counterweight embedded in two hemispheres as shown by Figure 1. Figure 2 illustrates the retroreflector mounting concept. Drilling tolerances and structural integrity required that a minimum distance be maintained between retroreflector mounting holes.

During Lageos design, a need arose for a retroreflector placement model to obtain placement information for various sphere diameters and retroreflector mounting concepts. The design goal was to place the maximum number of retroreflectors while achieving a reasonable amount of symmetry. (Total symmetry occurs when the distance between the centers of any two adjacent retroreflectors is a constant.) No retroreflectors could be placed in the hemisphere joint and a minimum distance between adjacent mounting holes (Fig. 2) had to exist.

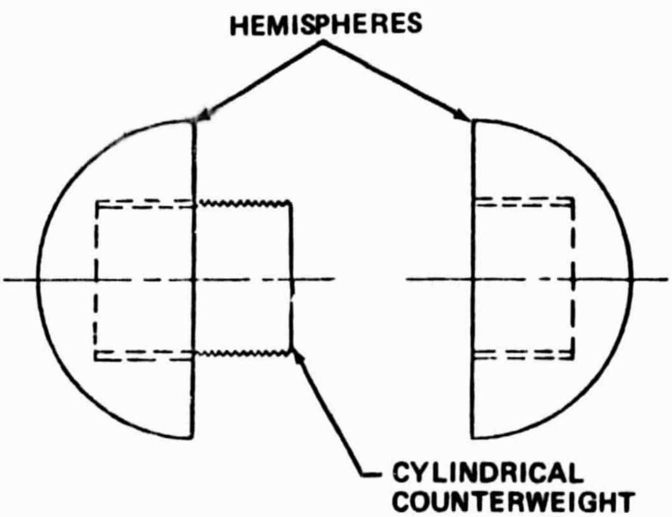

Figure 1. Retroreflector mounting concept.

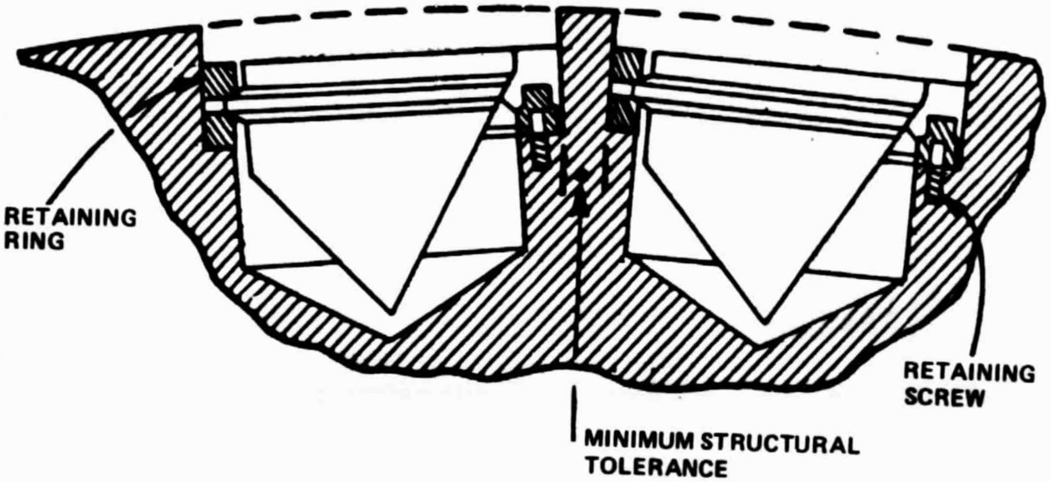

Figure 2. Lageos assemble.

A literature survey revealed that the retroreflector placement problem is very similar to the classical mathematics problem of packing the maximum number of equal nonoverlapping circles on a sphere. The retroreflector placement problem differs only in that no retroreflector mounting hole can intersect the joint between the two hemispheres. However, papers [2] on the classical problem provide only an upper bound on the maximum number of circles that can be placed on a sphere. No systematic procedure for placing the circles was found in the literature.

PLACEMENT MODELS

Three types of placement models were considered. The first type placed holes on the faces of a polyhedron inscribed in the sphere. The holes were then projected to the surface of the sphere. Dodecahedrons, icosahedrons, and other polyhedrons having equal faces were considered. These models were rejected because of the difficulty in avoiding the joint between the two hemispheres. The second type of model avoided this pitfall by dividing each hemisphere in a number of equal spherical polygons. This reduced the problem to one of placing the maximum number of holes within one spherical polygon. However, the total number of holes that can be placed on a hemisphere was found to be highly sensitive to the size and shape of the spherical polygon, for fixed sphere diameter and hole size. The problem of deciding which spherical polygon to use for the different sphere diameters and hole sizes under consideration became complex. This complexity was inconsistent with the need to quickly and easily evaluate a range of sphere diameters and retroreflector hole sizes.

The third type of model was selected because it satisfied this need. It places holes in rings about each hemisphere (Fig. 3). The desired minimum distance between holes in adjacent rings is achieved by control over the width of the rings. Note that absolute symmetry is achieved about the polar axis and between the two hemispheres. Only approximate symmetry is obtained about an axis in the equatorial plane. Total symmetry is difficult to obtain because no holes may be placed in the joint between the two hemispheres. Here, the joint is assumed to be in the equatorial plane of the sphere.

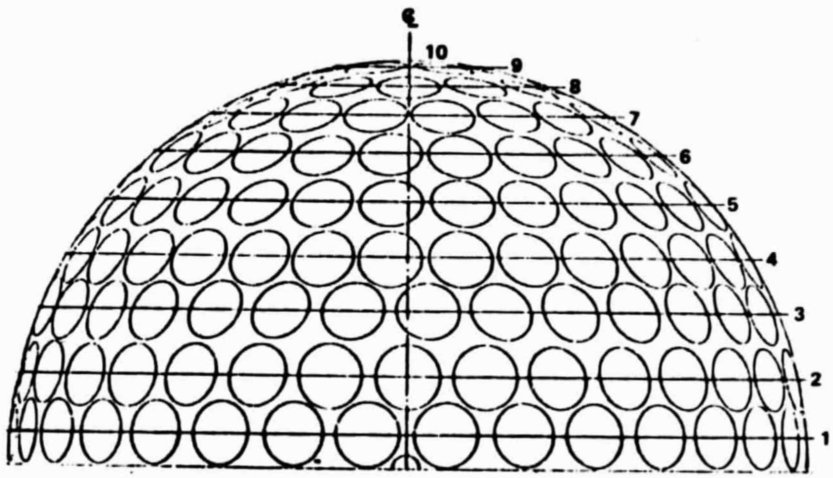

Figure 3. Retroreflector ring placement concept.

The effectiveness of the model was improved by a simple modification. The modification involved "meshing" rings which contain approximately the same number of holes. This concept can best be explained by an example. Suppose 40 holes can be placed in the first ring above the hemisphere joint and 39 holes can be placed in the second ring above the joint. The modified model places 39 holes in both rings. This allows the second ring to be placed closer or meshed with the first ring (Fig. 3). The two meshed rings require less surface area than the two unmeshed rings. Note that more than two rings can be meshed. Rings can be meshed until the ratio of holes placed per unit surface area reaches a point of diminishing returns. However, meshing more than two rings on Lageos was found to reduce symmetry more than it increased the number of holes placed.

The model efficiency was evaluated by comparing the number of holes placed by it with the theoretical upper bound on the maxin.um number of equivalent, equal, nonoverlapping circles that could be placed on a sphere having the same radius as the satellite. The theoretical upper bound equation was obtained from Reference 2. The number of holes placed by the model was on the average 85 percent of the computed upper bound. This percentage was considered acceptable in light of the constraint that no hole could be placed in the satellite hemisphere joint.

Hole placement symmetry was evaluated by considering the range of surface distances between adjacent holes. Generally, the range was between x and 2x where x is the distance between the closest two holes in the placement pattern. A typical case for a satellite diameter of 60 cm and a 4.76 cm hole diameter had a range of 0.42 to 0.91 cm between adjacent holes. This amount of variation in retroreflector symmetry was found to be acceptable.

CONCLUSIONS

The model proved to be an effective tool for assisting in the Lageos design. It was used to quickly produce efficient alternative retroreflector placement patterns for the different satellite diameters and retroreflector mounting concepts considered [1]. The retroreflector placement pattern used in manufacturing Lageos was produced by the model. The pattern contained 426 holes (4.76 cm in diameter) for the 60 cm diameter satellite. The ring placement concept made the task of drilling the holes easy to automate. The model could be potentially useful in the design of future spherical satellites and possibly assist in planning the placement of dimples on golf balls.

REFERENCES

1. Lageos Phase B Technical Report, NASA TMX-64915, Marshall Space Flight Center (February 1975).

2. Coxeter, H. S. M., "The Problem of Packing a Number of Equal Non-overlapping Circles on a Sphere," Transaction of The New York Academy of Science, Series II, Vol. 24, 1961, pp. 320-331.

APPROVAL

PLACEMENT OF RETROREFLECTORS ON THE LAGEOS SATELLITE

By John Edd Moore

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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