A GRAPHICS APPROACH IN THE DESIGN OF THE DUAL AIR DENSITY EXPLORER SATELLITES

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SUMMARY

A computer program has been developed to generate a graphics display of the Dual Air Density (DAD) Explorer satellites which aids in the engineering and scientific design. The program displays a two-dimensional view of both spacecraft and their surface features from any direction. The graphics have been an indispensable tool in the design, analysis, and understanding of the critical locations of the various surface features for both satellites.

INTRODUCTION

The Dual Air Density Explorer Program will launch, in late 1975, two spherical satellites to measure the density and composition of the Earth's upper atmosphere. The two satellites will be covered with a number of perforations, solar cells, and other surface features. The locations of the uniformly distributed perforations relative to other surface features are important in order to maximize the experiment measurement accuracy. A graphics package has been incorporated into a perforation design program to aid in the analysis of the perforation pattern. This paper describes the graphics program which generates two-dimensional views of both satellites.

DUAL AIR DENSITY EXPLORER PROGRAM

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The basic objective of the Dual Air Density Explorer Program is to expand man's knowledge of the Earth's upper atmosphere by measuring the density, composition, and vertical structure of the atmosphere on a global scale. Two spacecraft (fig. 1) will be launched in November 1975 by a single Scout vehicle into the same polar orbital plane. The two satellites will have perigees of 350 km and 700 km and apogees of 1500 km. Perforations uniformly cover each sphere surface so that the same amount of atmospheric constituents enters the hollow sphere regardless of satellite orientation. The sphere enclosure itself is an integral part of a highly sensitive mass spectrometer system which is located inside the satellite. Thus, the mass spectrometer measurements are independent of satellite orientation -- which eliminates the need for an attitude control system. Also, in-flight calibration of the mass spectrometer system will be performed using drag data and on-board gas standards.

Lower Satellite

The lower satellite is a rigid .76 m (30 in.) sphere .001 m thick made of 6061 aluminum (fig. 2). Its main surface features are 85 holes (either .016 m or .018 m diameter) and 36 solar cells (.152 m x .168 m rectangles whose surfaces are curved concentric with the sphere surface). The center locations of the holes and solar cells are based on a symmetric 122 point pattern of a dodecahedron. Certain holes and solar cells, however, are displaced slightly from the pattern to accommodate the physical size of the solar cells and other surface geometry factors. Other surface features are four antenna pods (.05 m diameter plates), four antennas (flexible rods .53 m long), and an instrument package backplate (a cylinder of .138 m diameter extending .018 m above the sphere surface).

Upper Satellite

The upper satellite is a 3.66 m (12 ft) inflatable sphere (fig. 3) similar to the Langley Research Center Air Density Explorer inflatable drag satellites. It is constructed with 40 gores. Each gore has an identical perforation pattern of 80 holes (.028 m diameter), located at the center of 80 equal areas. The satellite hole pattern is modified by placing 20 solar cells (.254 m x .203 m flat plate rectangles) uniformly on the sphere (at the vertices of a dodecahedron) and eliminating those holes which fall within the view of the solar cells. The resulting hole pattern consists of approximately 2380 holes. The ring of holes closest to one pole have been moved out of the line of sight of an instrument package backplate, which is not included in the graphics.

GRAPHICS PROGRAM

Graphics Objective and Uses

The objective of the graphics is to display a two-dimensional view of the spacecraft and their surface features as viewed from any direction. The graphics are used to:

- visually verify relative locations and dimensions of the various surface features

- identify areas of close proximity between features

- aid in the design, analysis, and understanding of the critical locations of the features

- produce recognizable pictures of the spacecraft.

Graphics Approach

Initially, an equatorial coordinate system is set up with position on the surface of the spherical satellite represented by α (right ascension) and δ (declination). The right ascension is the distance measured along an arbitrary reference plane (equatorial plane) from an arbitrary reference point (vernal equinox). The declination is the distance measured perpendicular to the equatorial plane.

A two-dimensional picture of the satellite and its surface features is calculated for any given view. A particular surface feature is drawn by representing its various edges or facets as a set of data points (α,δ) that are plotted as a group. For example, the edge of a solar cell is drawn in the following fashion.

The location and dimensions of the solar cell are used to determine the coordinates of the solar cell's edge (α,δ) in the equatorial coordinate system. The coordinates of the given view vector are also calculated in this coordinate system. The view vector coordinates are used as the basis of a new equatorial coordinate system, with the new vernal equinox aligned along the view vector (fig. 4). The solar cell edge coordinates are first rotated into the new coordinate system and then transformed into a rectangular coordinate system, whose Z axis is aligned along the view vector. The X-Y plane defines the plane of the two-dimensional picture. The X-Y coordinates of the solar cell edge, with positive Z coordinates, are then plotted directly (fig. 4). (Negative Z coordinates correspond to features on the "back side" of the spacecraft.)

The remaining edges and other facets of the solar cell (grid lines on the upper face) are drawn in this manner. The process is repeated for the other surface features (holes, solar cells, etc.). For pictures of the spacecraft viewed from another direction, the coordinates of the new view vector are calculated and the method repeated. The equations describing the calculation of the coordinates of the view vector and a point on the sphere surface in the new equatorial coordinate system and rectangular coordinate system are given in the Appendix.

RESULTS

A graphics picture of the lower .76 m satellite is shown in figure 5. The view vector is located at the vernal equinox ($\alpha = 0$, $\delta = 0$). The individual holes are numbered as an aid in identifying their relative location with respect to the solar cells. The grid lines on the solar cells depict the strings of individual chips on each cell. Also, the thickness of the cells is graphically drawn (originally used to identify the "shadow" effect of the solar cells on the holes with respect to the velocity vector). Also shown are the four antenna pods and antennas.

A picture of the upper 3.66 m satellite is shown in figure 6 with the view vector at the vernal equinox ($\alpha = 0$, $\delta = 0$). The alignment of the hole pattern along the length of each gore is readily apparent. Holes that lie within the field of view of each solar cell have been eliminated. As can be seen, both figures give a recognizable picture of the two spacecraft and their surface features.

As an aid in understanding how specific hole locations affected the hole uniformity design, the graphics was originally used to focus on particular orientations. While an actual description of the hole uniformity design is beyond the scope of this paper, some of the views generated by the graphics as the satellite rotates about a spin axis are shown in figure 7 for the lower satellite and figure 8 for the upper satellite. The view vectors vary along a plane inclined 45° to the satellite equatorial plane. The right ascension and declination of the view vectors are given in the upper right hand corner of each picture. The figures represent how a spinning satellite would appear to an observer over a quarter rotation.

CONCLUSION

Both sets of figures give recognizable views of the spacecraft and their surface features as viewed from any direction. The graphics was an invaluable aid in verifying the relative locations and dimensions of the various surface features, identifying areas of close proximity between surface features, and understanding the critical locations of the hole patterns to maintain the uniformity criteria.

APPENDIX

The coordinates of the view vector (α_v, δ_v) are calculated from

$$\sin \delta_v = \sin i \sin \theta \tag{1}$$

$$\cos (\alpha_v - \Omega) = \cos \theta / \cos \delta_v \tag{2}$$

where i = inclination of spin plane relative to the equator

θ = angle measured along spin plane from the equator

Ω = ascending node, or distance along equator from vernal equinox ($\alpha = 0$) to intersection of spin plane with equator

The inclination (ψ) of the new equatorial plane is calculated from

$$\cos \psi = \cos \delta_v \sin \alpha_v / \sin \alpha_x \tag{3}$$

$$\cos \alpha = \cos \delta_v \cos \alpha_v \tag{4}$$

where α_x is the angle from the vernal equinox to the view vector.

The coordinates of a location on the sphere surface in the new equatorial system (α', δ') are calculated from

$$\sin \delta' = \cos \psi \sin \delta - \sin \psi \cos \delta \sin \alpha \tag{5}$$

$$\tan (\alpha' + \alpha_x) = (\sin \psi \sin \delta + \cos \psi \cos \delta \sin \alpha) / \cos \alpha \cos \delta \tag{6}$$

where α, δ are coordinates of location in old equatorial system

The coordinates of a location on the sphere in a rectangular coordinate system (with Z axis aligned along view vector, X axis aligned along new equatorial plane, and Y axis aligned perpendicular to both) are calculated from

$$X = r \sin \alpha' \cos \delta' \tag{7}$$

$$Y = r \sin \delta' \tag{8}$$

$$Z = r \cos \alpha' \cos \delta' \tag{9}$$

where r is the distance from the sphere center to the point on the sphere surface.

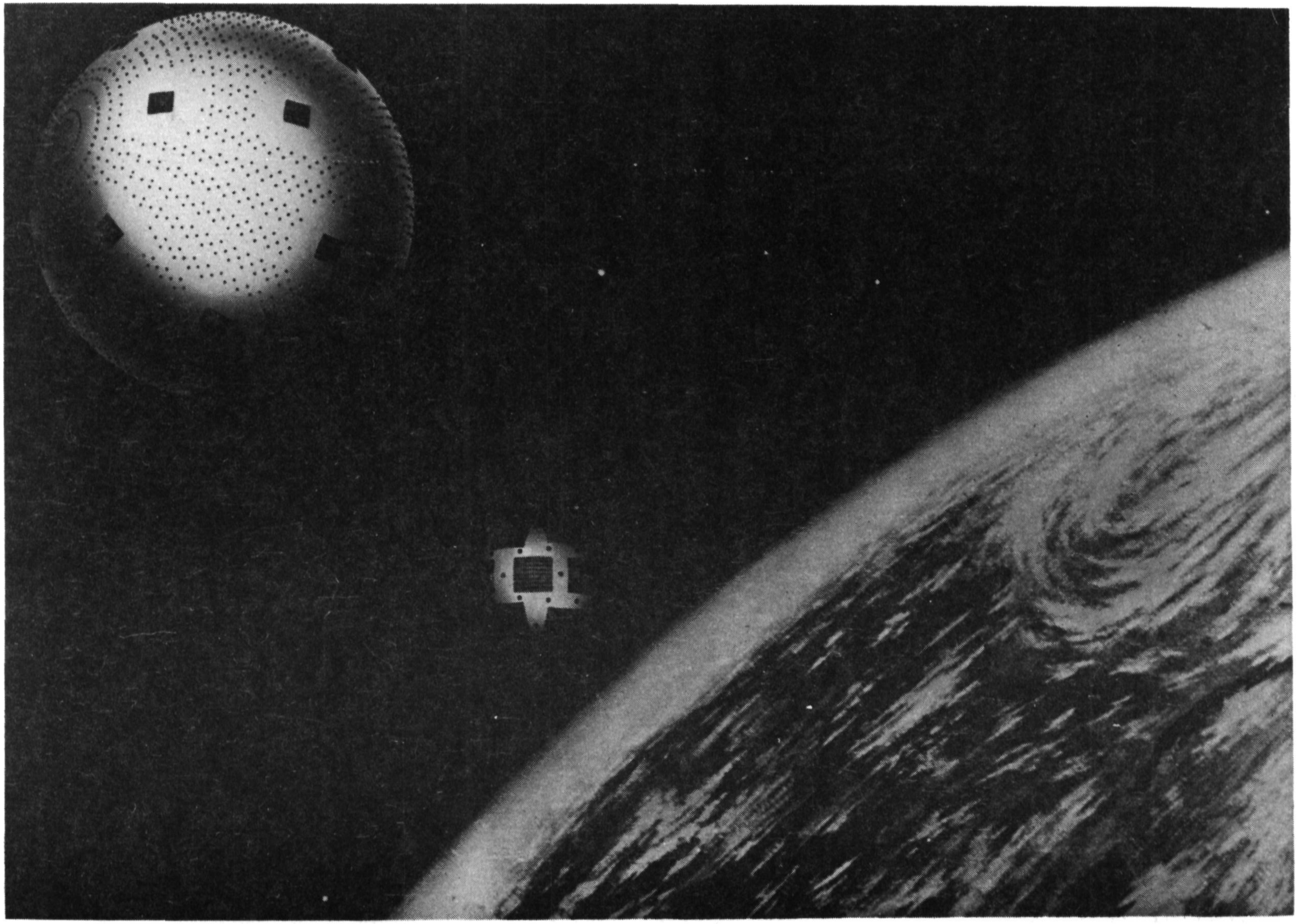


Figure 1.- Schematic concept of Dual Air Density Explorer satellites.

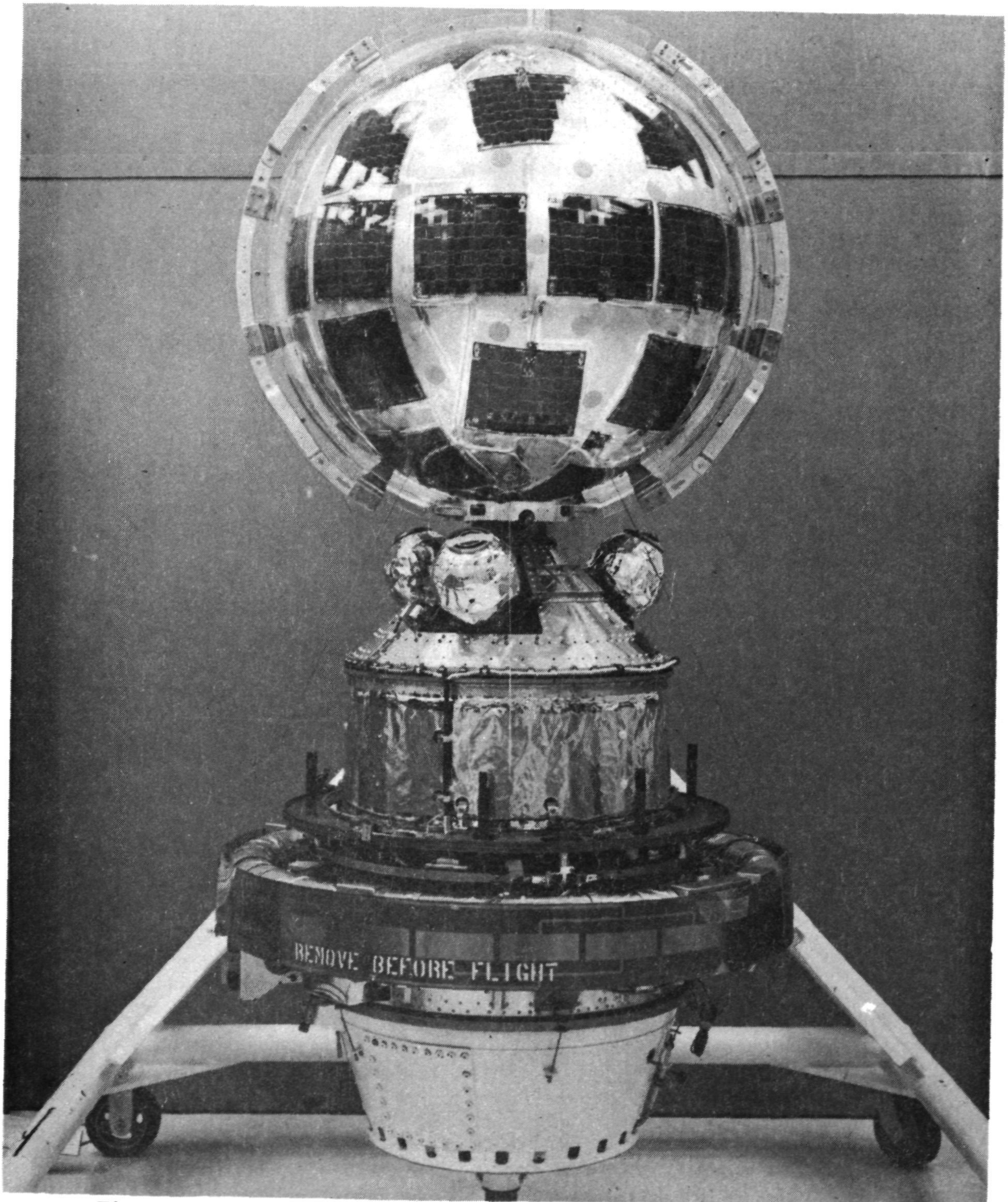


Figure 2.- Lower satellite in launch configuration showing the .76 m satellite, orbit booster package, 3.66 m satellite storage cannister, and inflation ring.

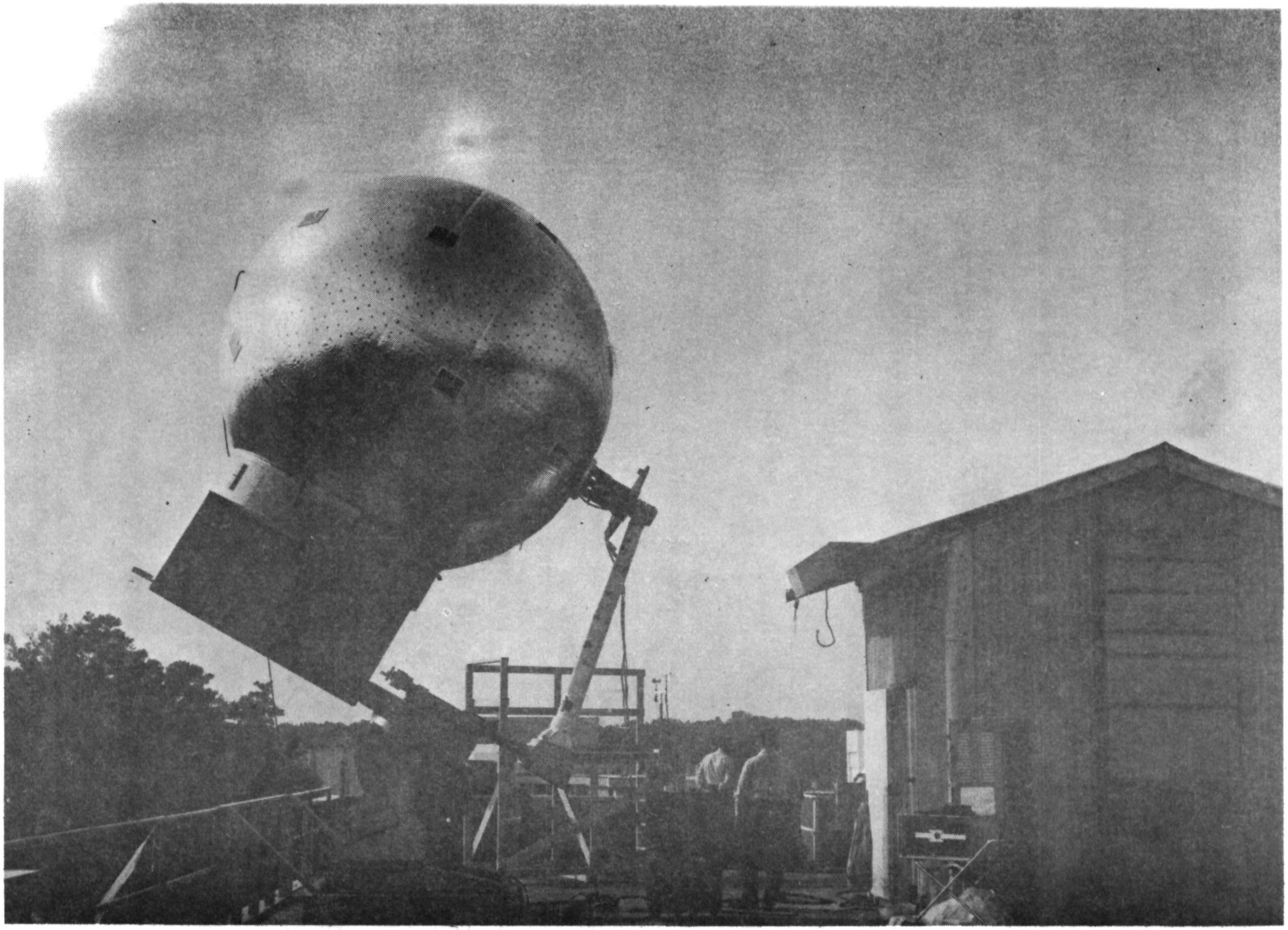
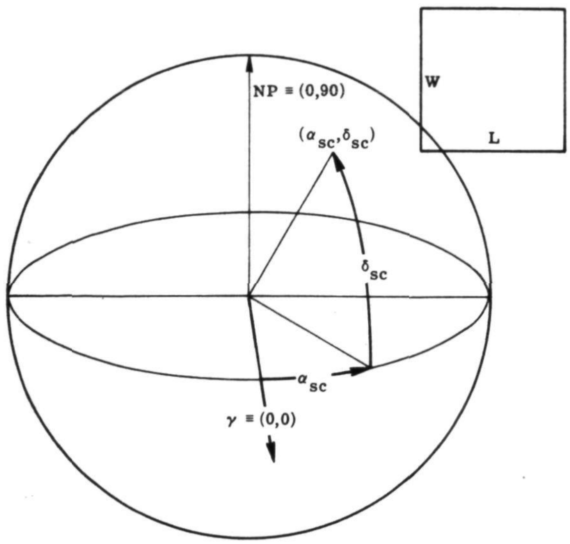
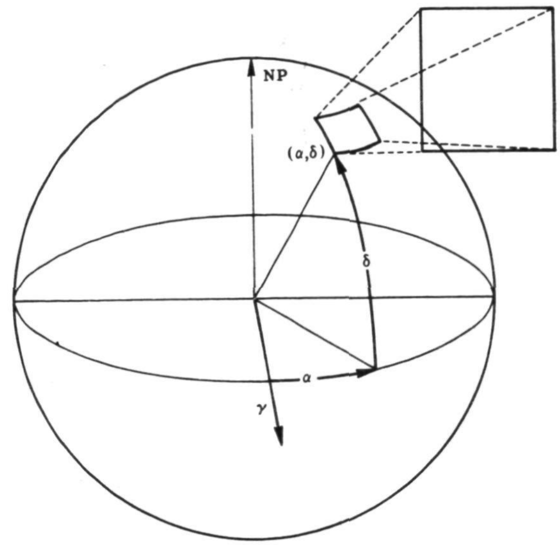


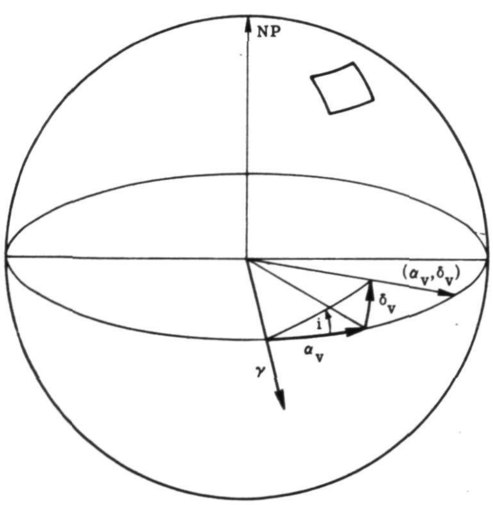
Figure 3.- Upper satellite fully inflated during antenna pattern test.



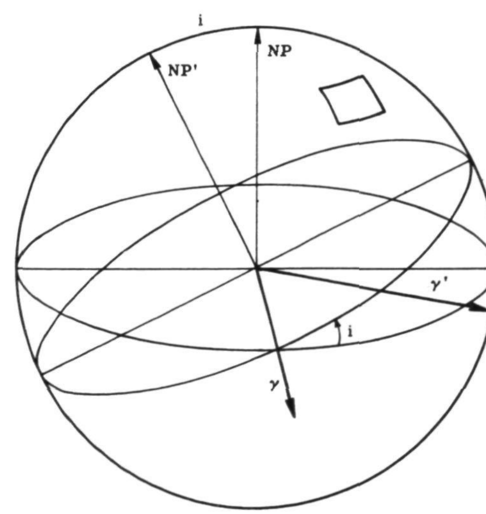
From the location of the center of each solar cell (α_{sc}, δ_{sc}) and dimensions (L, W), . . .



calculate the equatorial coordinates of edge of solar cell (α, δ).

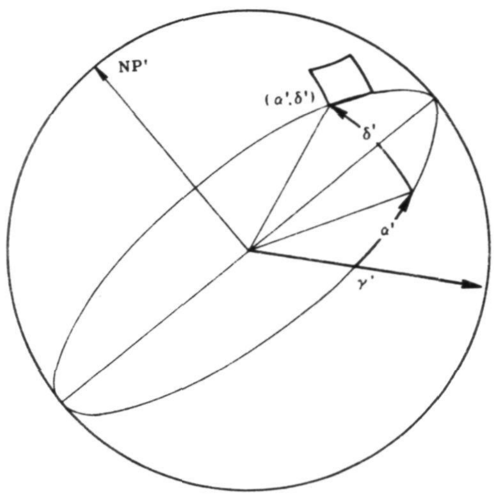


From the coordinates of the view vector (α_v, δ_v), . . .

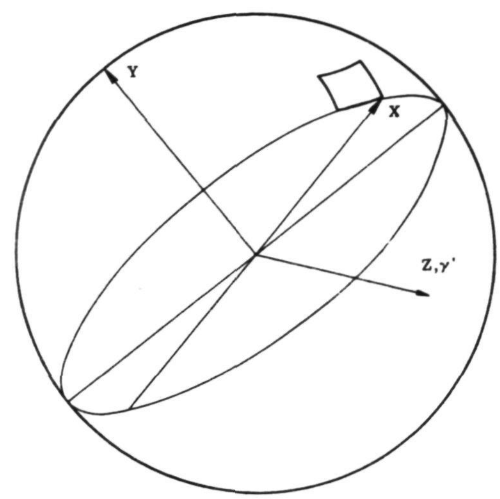


rotate into a new equatorial coordinate system (with view vector at γ'), and . . .

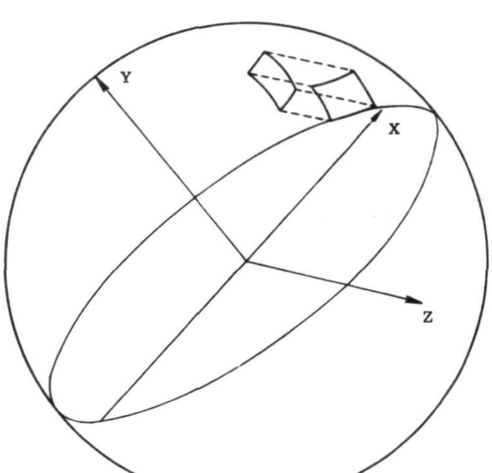
Figure 4.- Schematic diagrams describing graphics method.



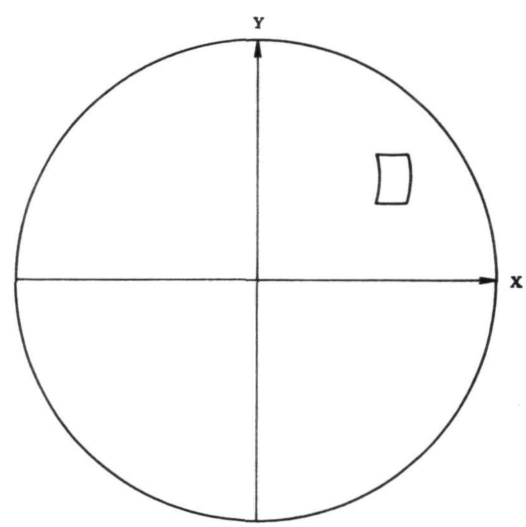
calculate new equatorial coordinates of edge of solar cell (α', δ').



Transform from the new equatorial coordinate system into an XYZ rectangular coordinate system (with Z axis at γ'), and . . .



calculate rectangular coordinates of edge of solar cell (XYZ).



Plot directly the XY coordinates of edge of solar cell.

Figure 4.- Concluded.

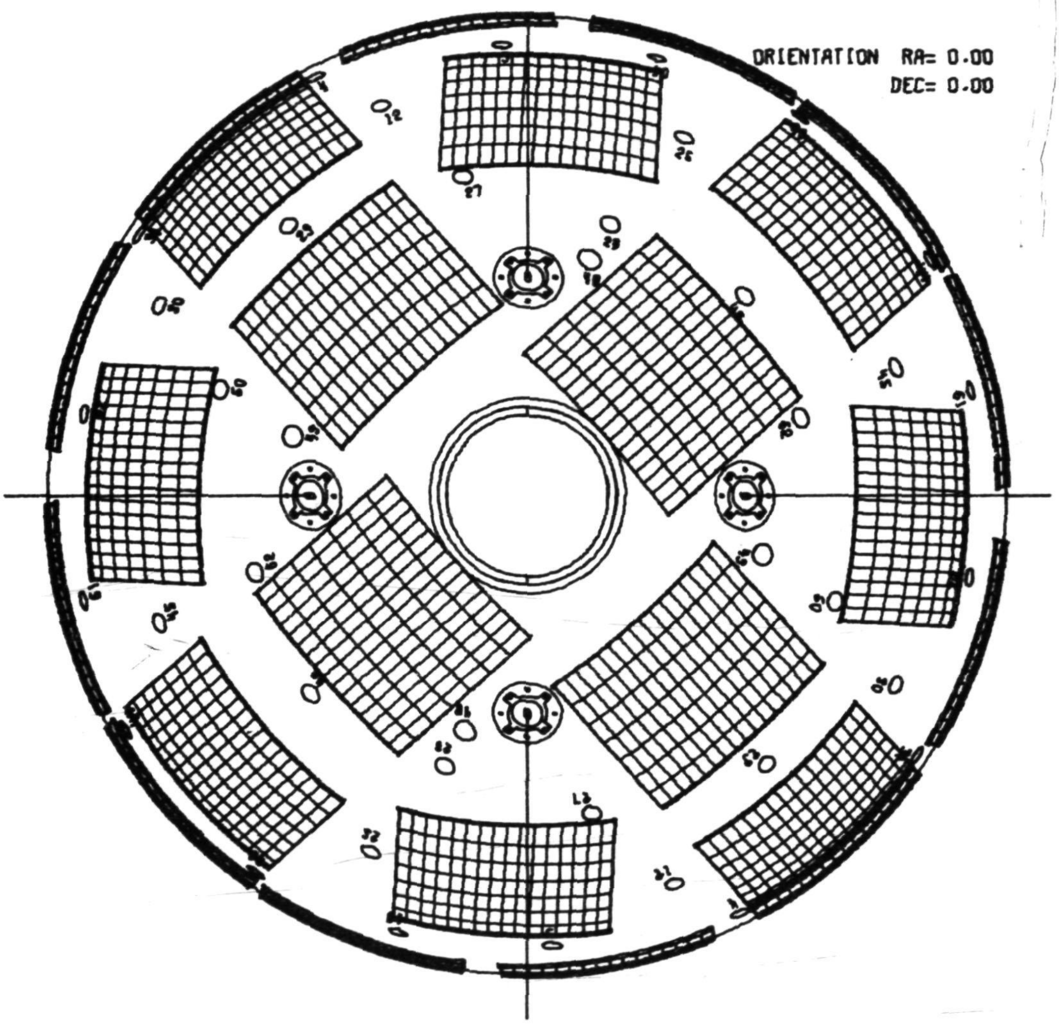


Figure 5.- Graphics plot of lower satellite showing holes, solar cells, antenna pods, antennas, and instrument package backplate.

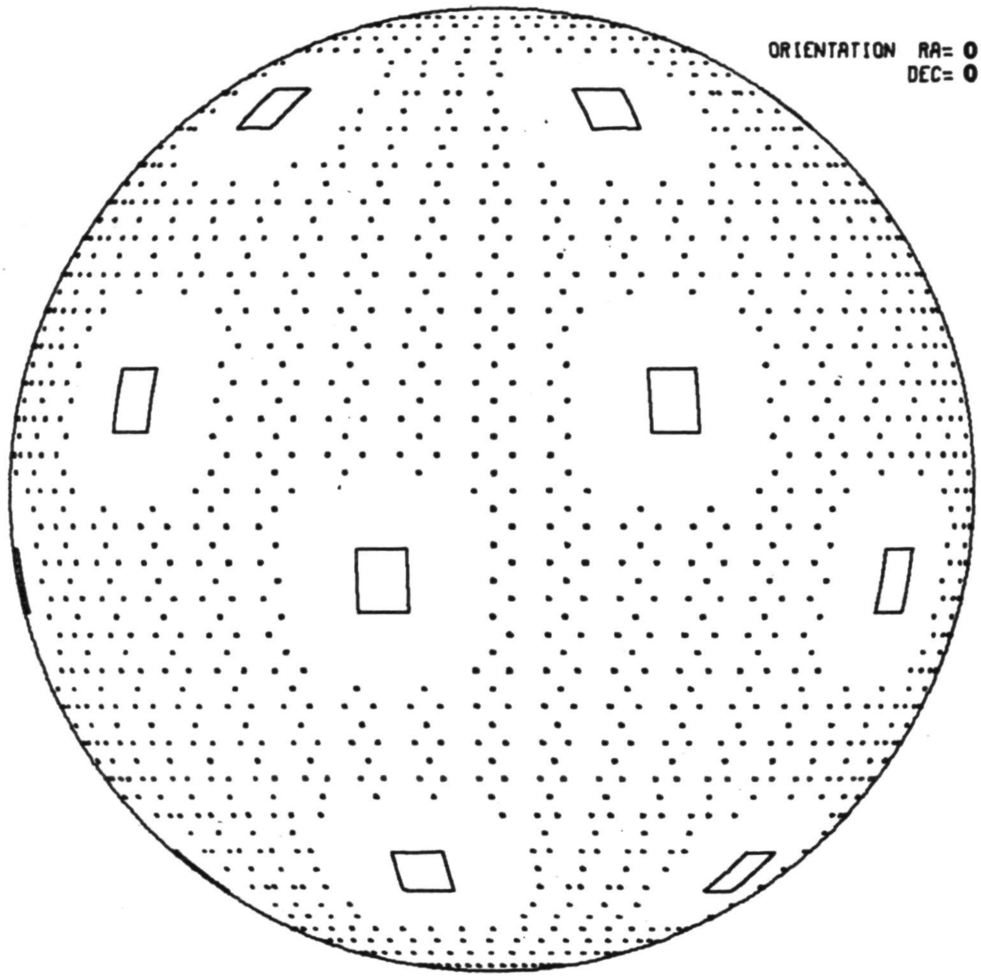


Figure 6.- Graphics plot of upper satellite showing holes and solar cells.

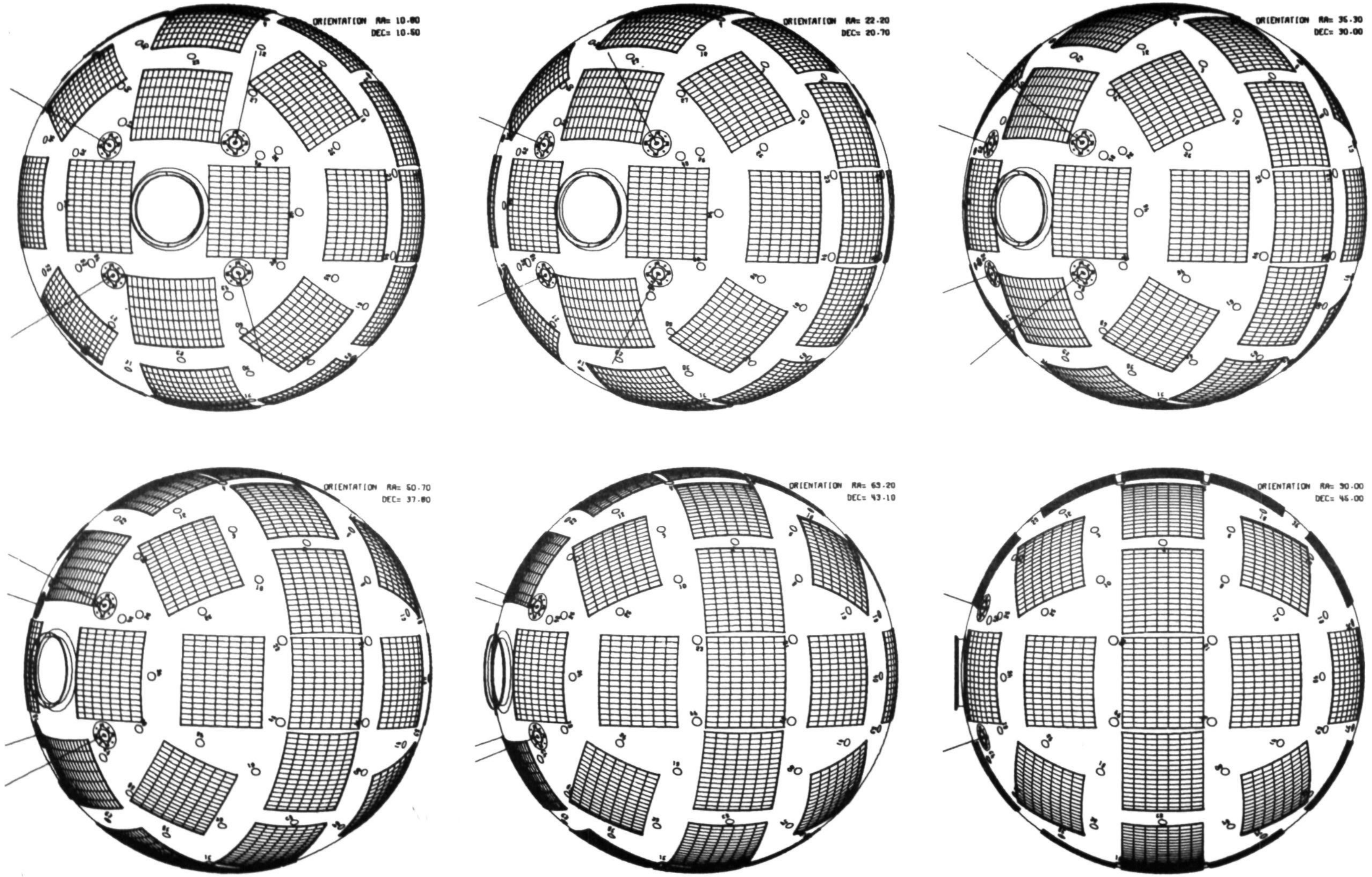


Figure 7.- Graphics plots of lower satellite over quarter rotation about a spin axis inclined 45° to the equator.

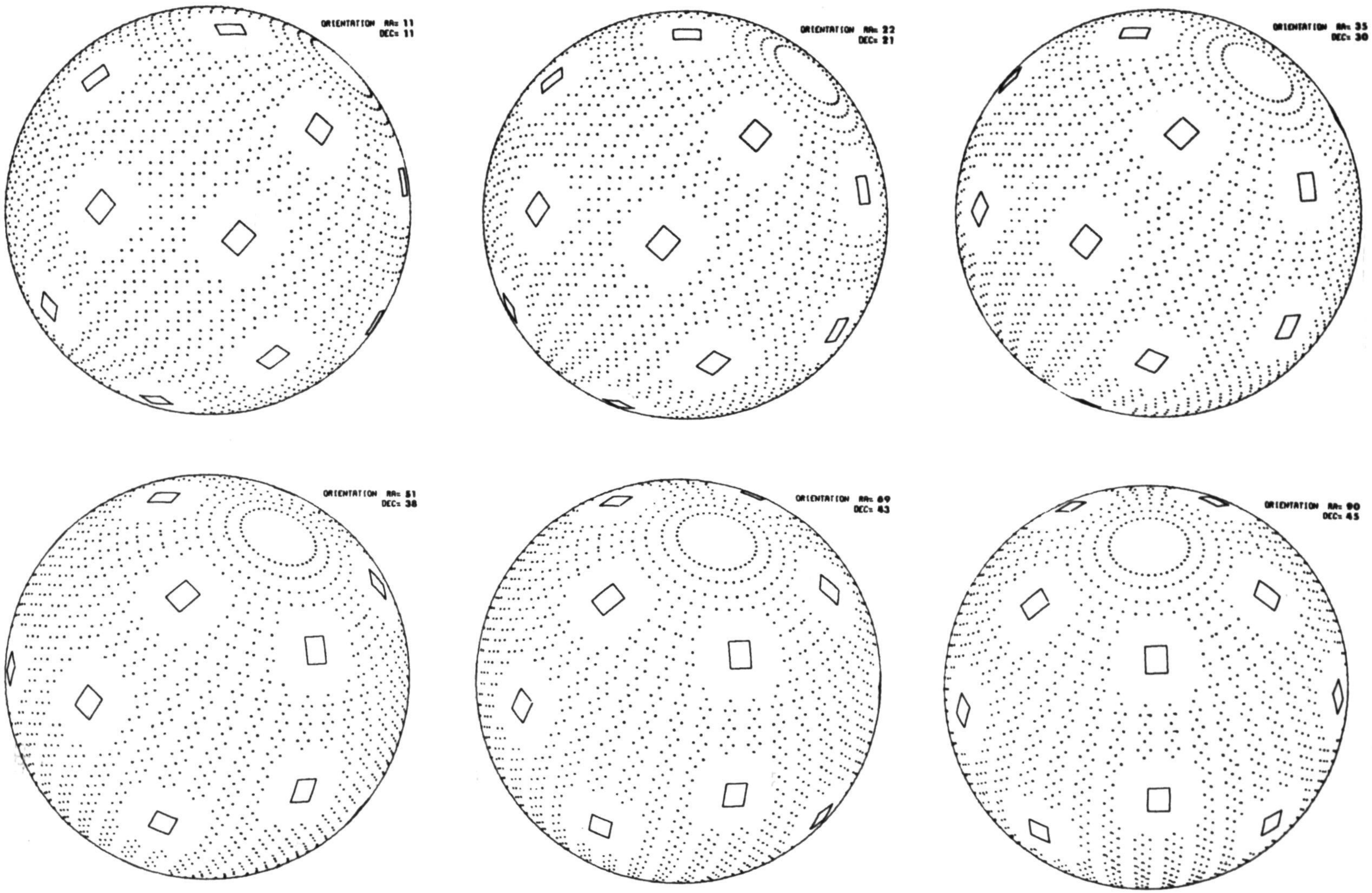


Figure 8.- Graphics plots of upper satellite over quarter rotation about a spin axis inclined 45° to the equator.