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PHOTOGRAPHIC INTERPRETATION REPORT

ANALYSIS OF LUNA-9 PHOTOGRAPHY

NPIC/R-5022/66
JULY 1966

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PHOTOGRAPHIC INTERPRETATION REPORT

ANALYSIS OF LUNA-9 PHOTOGRAPHY

JULY 1966

NATIONAL PHOTOGRAPHIC INTERPRETATION CENTER

INTRODUCTION

This report contains the results of an analysis of Luna-9 photography as requested in CIA/FMSAC requirement C-DS6-83,440. The object was to provide information about the facsimile photographic system, the spacecraft, and the lunar surface independent of previously published Soviet and U.S. data. The derived NPIC results corroborate the data published in the references at the end of this report. The agreement between the NPIC data and that data from the other sources validates the assumptions upon which the NPIC results are based. The primary working materials consisted of reproduced contact prints [redacted] of the moon, ground photography of a Luna-9 display at the Fair of Permanent Achievement, Moscow, and the Soviet motion picture T-6376.

25X1D

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GEOMETRIC ANALYSIS

1. Angular Fields of View

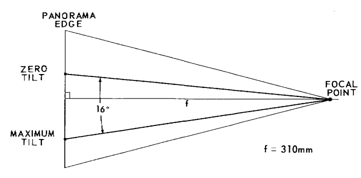
a. Azimuthal: Because the horizon image did not 25X1D continuously appear [redacted] (See Figures 1-4), the azimuthal angular field of view could not be determined by matching conjugate imagery. However, the available horizon image approximated a sine curve $y = C\sin\Theta$ which is characteristic of the rotational motion of a rigid body on a flat surface. With an origin at the point of zero tilt (See Paragraph 2a), the constant (C) was computed from measurements of y values along the small axis of the format and angular values along the longer format dimension. The following sine curves were approximated assuming that the horizon was flat.

25X1D [redacted]
$y = 0.290 \sin\theta$
$y = 0.335 \sin\theta$
$y = 0.413 \sin\theta$
$y = 0.400 \sin\theta$

The sine curve traces of the horizon images with apparent maximum and minimums indicate a 360 degree azimuthal angular field of view.

b. Vertical: The vertical angular field of view (28° 48'±2°) was determined by averaging the values obtained by two different solutions. The plus or minus 2-degree tolerance reflects a judgment rather than a precise figure.

25X1D (1) Utilizing the [redacted] on February 4, an effective focal length was graphically determined by adjusting a 16 degree tilt-angle overlay (See Paragraph 2a and Sketch A) to the points of zero and maximum tilt which provided a focal point. The focal length was measured directly on the constructed graphic.



Sketch A

By applying the derived focal length to the format size, the vertical angular field of view was computed to be approximately 28°30'.

(2) Employing ground photography, the true ground dimension of the "photometric" device and its distance from the camera station were computed (See Paragraph 5). An effective "blow-up" focal length for the facsimile panorama was computed from the following equation:

$$\frac{f}{D} = \frac{d2}{d1}$$

where f = focal length of panorama (303mm)

D = distance from camera station to device on panorama but determined from ground photography

d2 = dimension of device as measured on panorama

d1 = true dimension of device as determined from ground photography

The derived focal length together with the format size provided a vertical angular field of view of approximately 29°06'.

2. Tilt of Facsimile Scanner Rotation Axis

a. Relative to lunar horizon: The tilt angle is defined as the angle between the scanner rotation axis and a normal to the assumed flat terrain. To obtain the points of maximum slope (inflection points), tangent lines were graphically constructed at various points on the horizon and the tilt angle was measured directly. The tilt values are mean values with an accuracy of plus or minus 1.5 degrees.

25X1D

	RANGE (Degrees)	TILT (Degrees)
[redacted]	15 - 17	16
	16 - 19	17.5
	21 - 24	22.5
	21 - 24	22.5

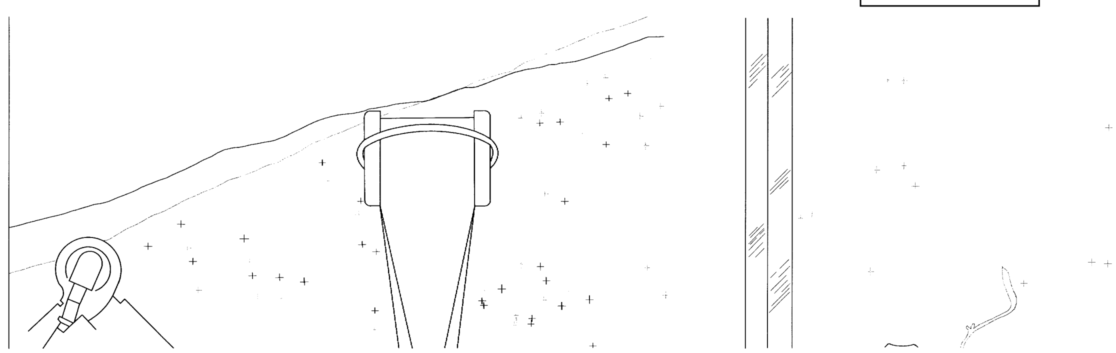


FIGURE 5. PLOTTED MOVEMENT OF OBJECTS [redacted] 25X1D

25X1

25X1

The relative displacement of conjugate imagery (See Figure 5) showed that the spacecraft moved between the 25X1D [redacted] To isolate the axis of capsule movement, traces of conjugate imagery from 25X1D [redacted] were plotted on an established base using capsule components (mirrors, antennas, feet) as references, assuming that the relative position of the components remained fixed. The displacement of the imagery and the near intersection of the different horizon images indicate that the movement was a rotation about an axis located in an area approximately 35 degrees to the right of the capsule foot displaying the prominent protuberance. The axis of rotation was approximately the same for both movements and the second movement produced the greater amount of rotation. No evidence of movement 25X1D [redacted] could be found. The difficulty in exactly locating the axis of rotation was that a scale change 25X1D [redacted] hindered overlay traces. Therefore, image displacement could not be definitely attributed to the scale change or actual capsule rotation. Variations in the image quality of 25X1D [redacted] considerably reduced the number of traceable images. The 25X1D [redacted] precluded comparative traces in those areas.

b. Relative to direction of sunlight: The tilt of the scanner axis relative to the direction of sunlight was determined by using the declination of the sun, the previously derived tilt of the scanner axis relative to the lunar horizon (See Paragraph 2a), and the angle between the azimuth of the sun's ray and the azimuth of the inclined scanner rotation axis. The angle of the sun above the local horizon was derived by computing and combining the selenographic coordinates of the sun with the known coordinates of the Luna-9 capsule. The selenographic coordinates of the sun at a time T_{ϕ} (Universal Time of a point on the panorama where the shadows indicate the point was looking directly into the sun) were obtained by interpolation from the American Ephemeris and Nautical Almanac (See Figure 6). The selenographic latitude and longitude of the capsule were reported in a Soviet Communique of [redacted] The Law of Cosines was used to determine the angle subtended at the moon's center between the vectors extended to the sun and capsule. The sun angle is the complement of the subtended angle (See Sketch B).

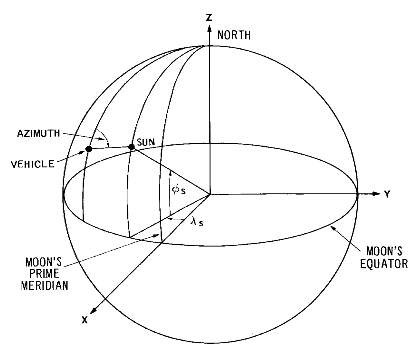
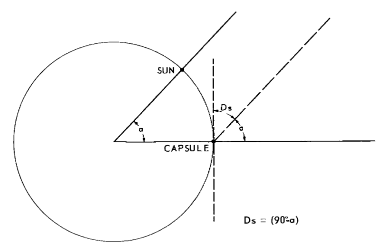


FIGURE 6. SELENOGRAPHIC COORDINATE SYSTEM. [redacted]



Sketch B

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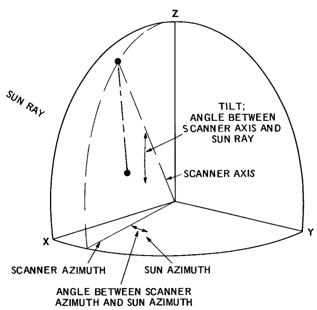
[redacted]

25X1

[redacted]

25X1

The Law of Sines was used to compute the azimuth of the scanner axis at the time T_{ϕ}. Knowing that the azimuth toward which the scanner rotation axis is inclined is approximately N 80°E, the angle between the scanner rotation axis and the sun's ray was computed using direction cosines (See Sketch C).



Sketch C

25X1D

Panorama	Tilt	Sun Angle	Azimuth
	67°	07°27'	92°26'
	59°	14°09'	93°18'
	42°30'	26°29'	95°12'
	29°	41°01'	98°13'

3. Mirror Data

The three dihedral mirrors mounted on the capsule image six areas of the lunar surface. Each mirror consists of two plane surfaces intersecting at a 90-degree angle. Mirrors one and two (See Figure 7) are of similar size, are mounted on the outer edge of the capsule, and are offset by 180 degrees. Mirror three which is smaller than the other two is located closer to the scanner turret. By printing the panorama negatives in reverse, the mirror images were correlated to the conjugate lunar surface images. Because the capsule was tilted, the imaged areas

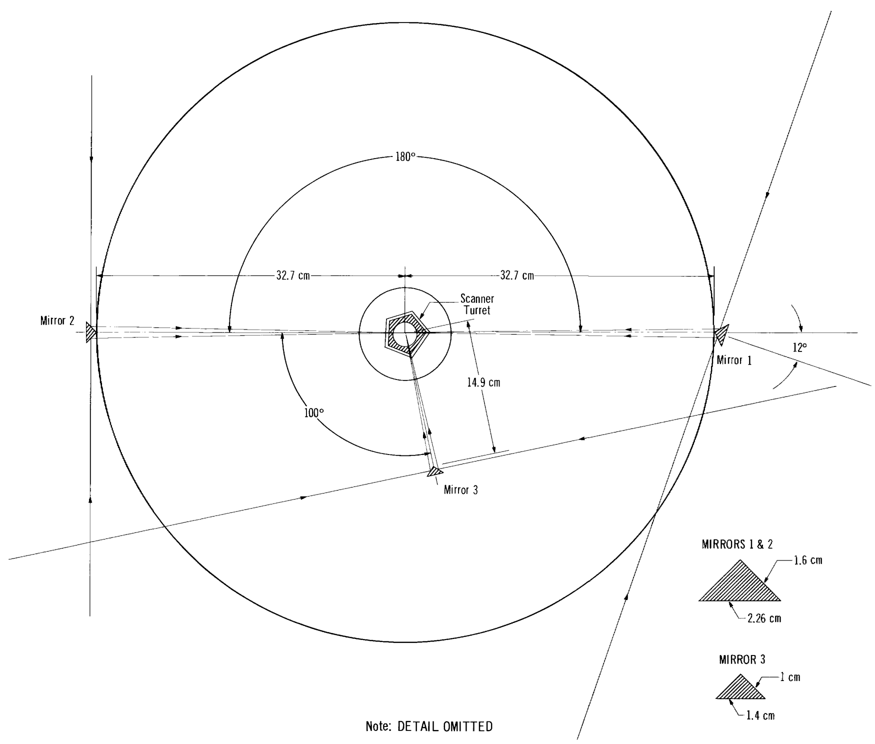


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FIGURE 7. MIRROR DIAGRAM.

vary in size and in distance from the capsule. Plots of images from the right face of mirror two and the left face of mirror one intersect at a point on the lunar surface approximately six feet from the capsule. By using the distance between the mirrors and the distance to the point of intersection, the orientation of the mirrors was determined to within plus or minus 1.5 degrees. Mirror two was rotated approximately 2 degrees counter-clockwise and mirror one was rotated approximately 12 degrees clockwise about the vertical axis. Rotation about a vertical axis was also indicated by the unequal imaging of the mirror faces in the panorama. The faces of mirror three were oriented at equal angles to the optical axis of the scanner based on the equal imaging of the mirror faces in the panorama. The faces of mirror one were not oriented at equal angles to the optical axis based on the unequal imaging of the faces in the panorama. The resolution of the panorama did not permit detection of the 2 degree rotation of mirror two. Mirrors one and two each occupy approximately 3.7 degrees of the panorama and mirror three occupies approximately 5.6 degrees. Stereoscopic viewing was possible with the corrected mirror images but the quality of the stereo image was at best poor.

4. Capsule Dimensions

Approximate dimensions of the Luna-9 capsule with the petals closed and protective covering in place were obtained from motion picture film T-6376. The height of an average man was used as a basic scale factor. That the man and capsule are equidistant from the camera station and that both are in a vertical plane were assumed. The interior orientation of the taking camera, the camera attitude relative to a vertical datum, and an estimate of the difference in distance from the capsule to the man in a direction parallel to the optical axis were obtained. Using a mensuration base established by the above method, the maximum diameter of the capsule was computed to be 3 feet.

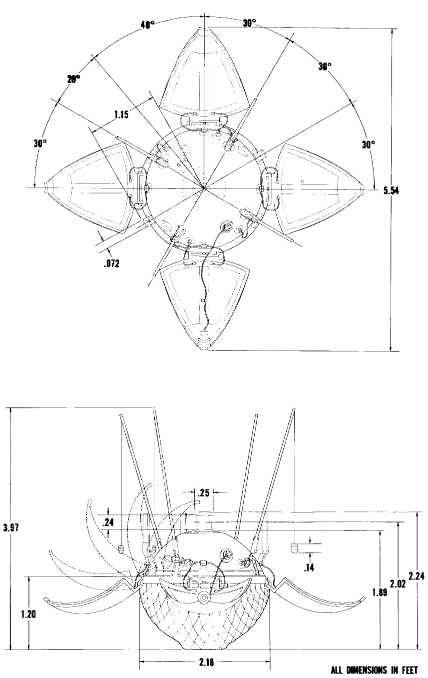


FIGURE 8. LUNA-9 CAPSULE

Employing ground photography of a Luna-9 display (Fair of Permanent Achievement, Moscow), the height of an average man was again used as a scale factor. Additional assumptions were that the Luna-9 capsule is positioned in the middle of the display and that the distance from the man imaged in the background to the camera is twice that of the capsule to the camera. Photo B-18 shows clearly that Luna-9 is in the center of the display. The primary photographs A-10 and A-12 were taken on opposite sides of the capsule. Image space distances (capsule diameters, heights of support poles, and distances between antenna end points) in both photographs agree to within an average error of plus or minus 5 percent. Since the scale and focal length remain constant between the two photos, the distance from the exposure station to the capsule is equal for both pictures. Therefore, a vertical plane through the capsule normal to the "air base" between the exposures stations bisects that "air base". The diameter of the Luna-9 capsule may then be ratioed directly at 1/2 the scale of the average man. The capsule diameter (See Figure 8) with petals unfolded and no protective covering was computed to be 2.18 feet (664.1 millimeters).

An article in the Soviet publication Aviation and Space (Issue 3, 1966, page 9) states that the camera is 60 centimeters (1.97') above the surface. It is unknown if this height refers to the scanner turret and accounts for the tilt of the capsule, but the Soviet figures and those computed from ground photography are very close. Based on this agreement and the satisfactory scale agreements between the various sources, the dimension 2.18 25X1 was selected as a base for computing all other dimensions. All Luna-9 capsule dimensions were then computed using graphical and ratio techniques.

5. Sizes and Distances of Objects on Lunar Surface

The derived capsule dimensions enabled estimates to be made of selected lunar surface features by monoscopic methods. The approach involved some of the same photogrammetric techniques used in high oblique aerial photography. Given focal length, height, and orientation, then the ground coordinates or size of any object may be computed.

Mensuration of the Luna-9 capsule provides a basic height of 2.02' to ℄ of scanner axis. Since Luna-9 is in a tilted position, this dimension represents a slant range rather than a height. The true height may then be computed for each scan depending on the amount of tilt.

The effective focal length of Luna-9 may be computed from the scale formula $s = f/h$. The photo distance of the photometric device was measured on the panorama, its ground distance was computed from ground photography, and the distance from the device to the exposure station was known. To solve monoscopically, it is also necessary to make use of the angular field of view which was determined previously.

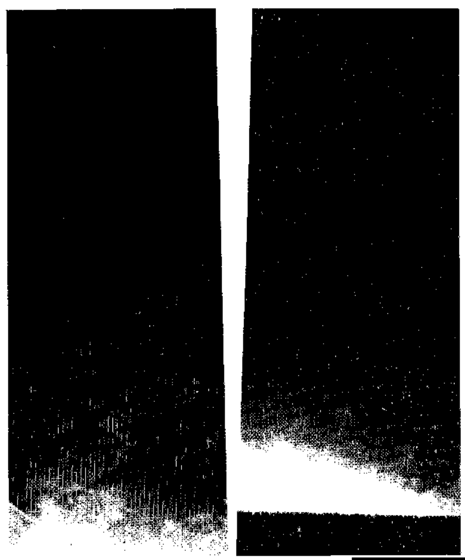


FIGURE 10. STEREO PAIR. [redacted]

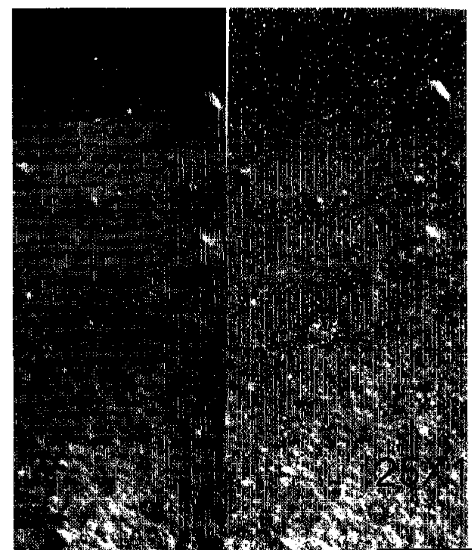


FIGURE 11. STEREO PAIR. [redacted] 25X1

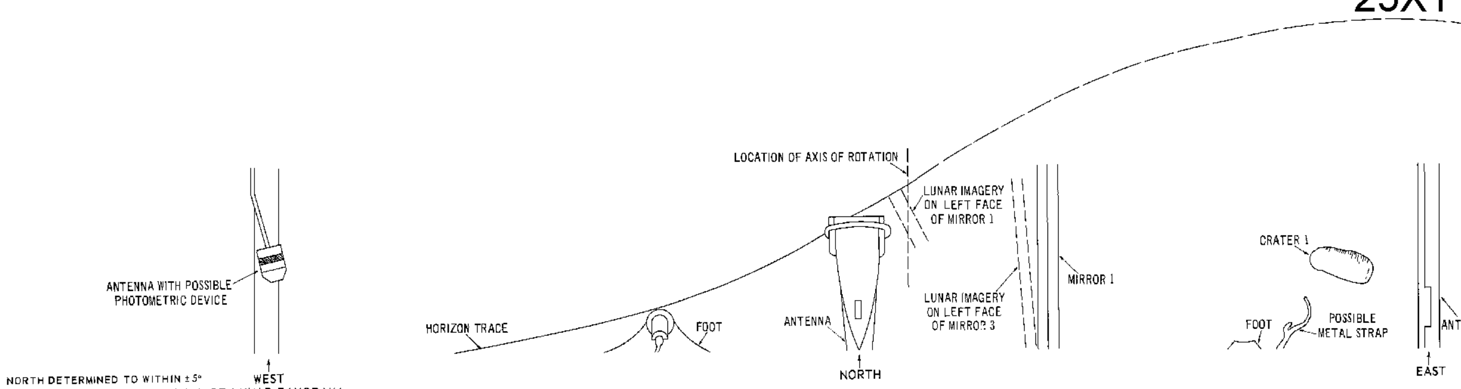


FIGURE 9. GRAPHIC PORTRAYAL OF LUNAR PANORAMA.

The dimensions for selected bits of lunar topography were computed monoscopically and are approximations only (See Figure 9).

Object	Distance from Capsule (Feet)	Size (Inches)
Crater 1	2 3/4	6-9 diam
Rock 1	7-8	6
Rock 2	23	7-8
Rock 3	23	7-8

STEREO BASELINE

Two stereo pairs (See Figures 10 and 11) were included to demonstrate the stereo viewing capability of the
25X1D [redacted] The pairs were selected from the
25X1D [redacted] capsule, a stereo base was approximated by using the scanner height and the change in the tilt of the scanner axis caused by the rotation. The maximum stereo base for azimuths at N 10°W or S 10°E was computed to be approximately 2.04 inches. At azimuths of N 20°W and N 20°E, the stereo base was computed to be 2.00 and 1.76 inches, respectively.

DIMENSIONS OF LUNA-9 SPACECRAFT

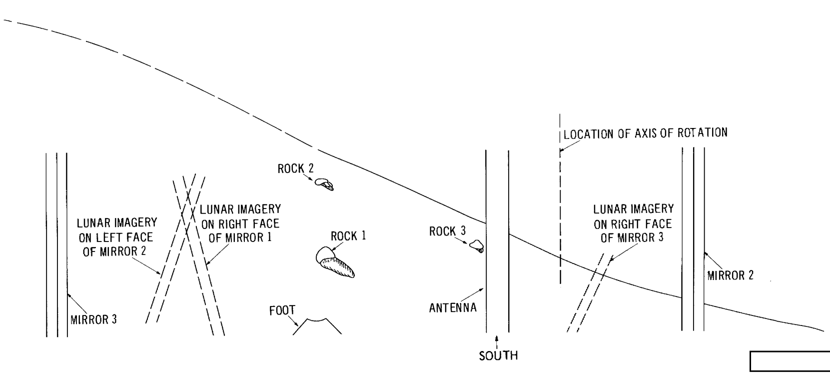
Dimensions of the Luna-9 spacecraft (See Figure 12) were obtained from both the Soviet motion picture T-6376 and photography of a Luna-9 display at the Fair of Permanent Achievement, Moscow. Because of superior imagery, the "Fair" photography was used as the primary source of detail. The detail of the movie film was such that only an overall length could be determined in addition to several dimensions to verify those obtained from the "Fair" photography. The difference in the overall length as derived from the "Fair" photography and from the movie film was less than 3.5 percent. An average of the two values established the overall length of the spacecraft as 12.16 feet. Employing the motion picture photography, the spacecraft length was obtained graphically by using the height of an average man as a scalar, two ellipses from the spacecraft to establish correct angular relationships, and an approximation of the difference in the distance from the man to the spacecraft in a direction parallel to the optical axis (See Figure 13). Utilizing the "Fair" photography, the overall spacecraft length was computed in two sections. The front section was ratioed from selected photographs using the capsule diameter with the protective covering in place as a known dimension. The rear section was graphically constructed based on a derived scalar and two derived angular values (See Figure 14). The scalar was the dimension of the black band around the spacecraft just below the covered capsule and was obtained by ratios. The angular values were obtained by determining ellipses from the spacecraft.

The basic construction technique was to construct an arbitrary object space line (center line of the Luna-9 spacecraft). The eccentricity of the two ellipses (images of true circles) with minor axes lying along the object space line was computed according to

$$\sin^{-1} e = \frac{\text{image distance of minor axis}}{\text{image distance of major axis}}$$

The angle (90°- e) was constructed from two arbitrarily spaced points on the object space line. The angles were extended to intersect at the camera lens.

A transparent overlay containing several points of the photograph was constructed. The points representing the top and bottom of the format, the principal point (approximated on cropped photography), two scale points, and the centers of the two ellipses were connected by a line denoted as the image space line. A line was constructed perpendicular to the image space line passing through the principal point and therefore passing through the focal point. The resulting image space system is then positioned so that the rays from the ellipses each pass through their respective transferred point on the overlay, and the optical axis passes through the focal point. The image space line is then located so that the tilt, angular field of view, and focal length are correctly determined. Projecting the images of the scale points onto the object space line determined the scale. Other dimensions were determined by projecting the images onto the "scaled" object space line.



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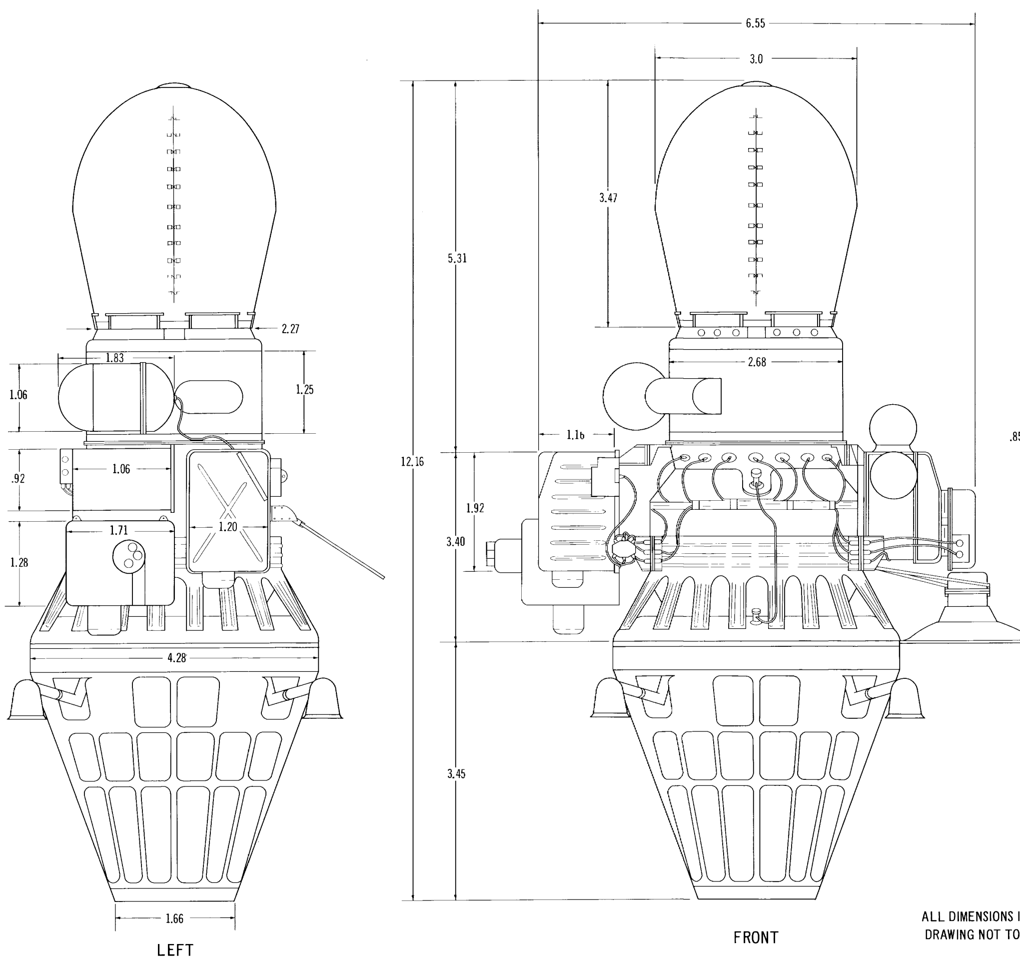

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FIGURE 12. LUNA-9 SPACECRAFT.

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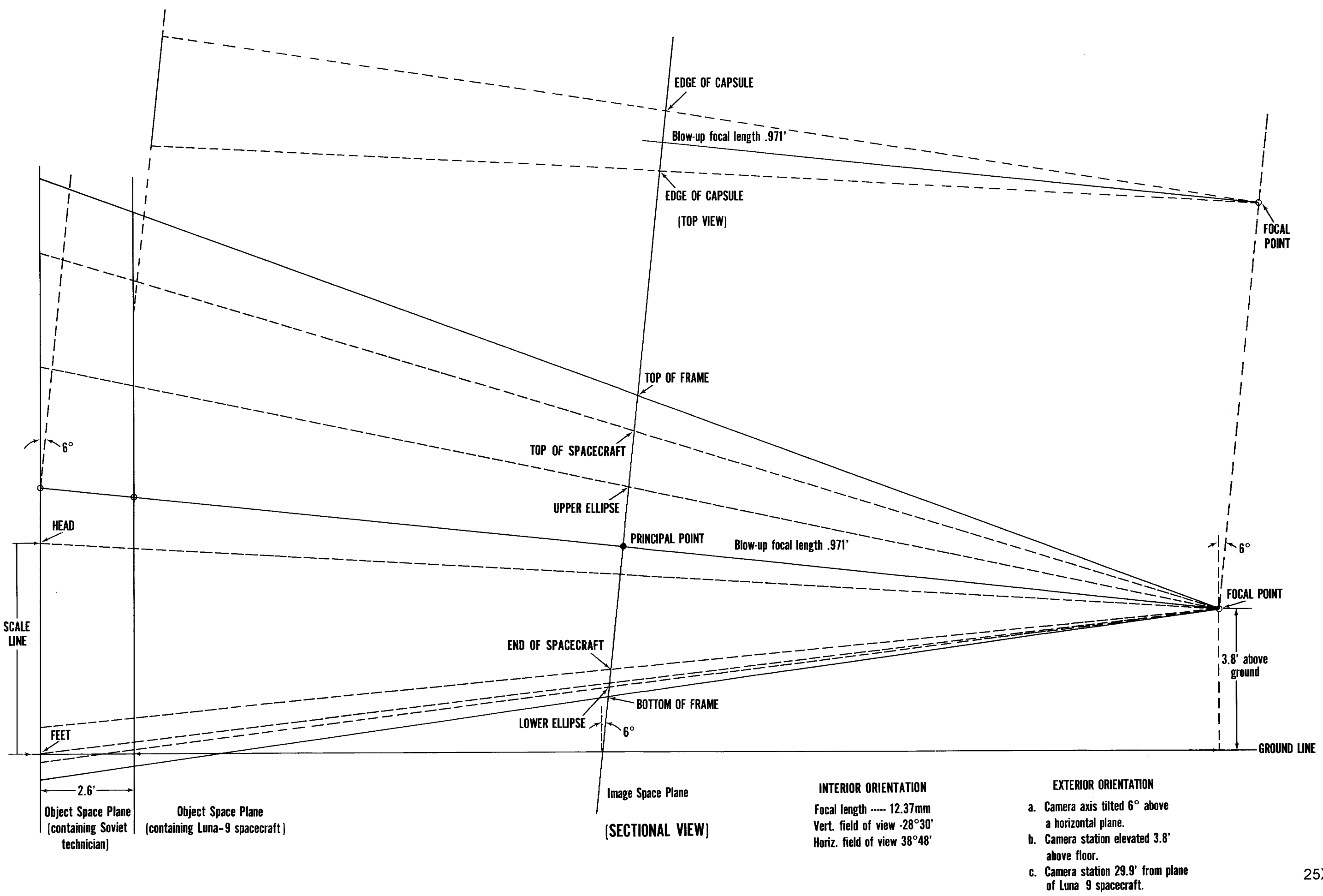

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FIGURE 13. GRAPHICAL CONSTRUCTION OF LUNA-9 SPACECRAFT FROM MOVIE FILM.

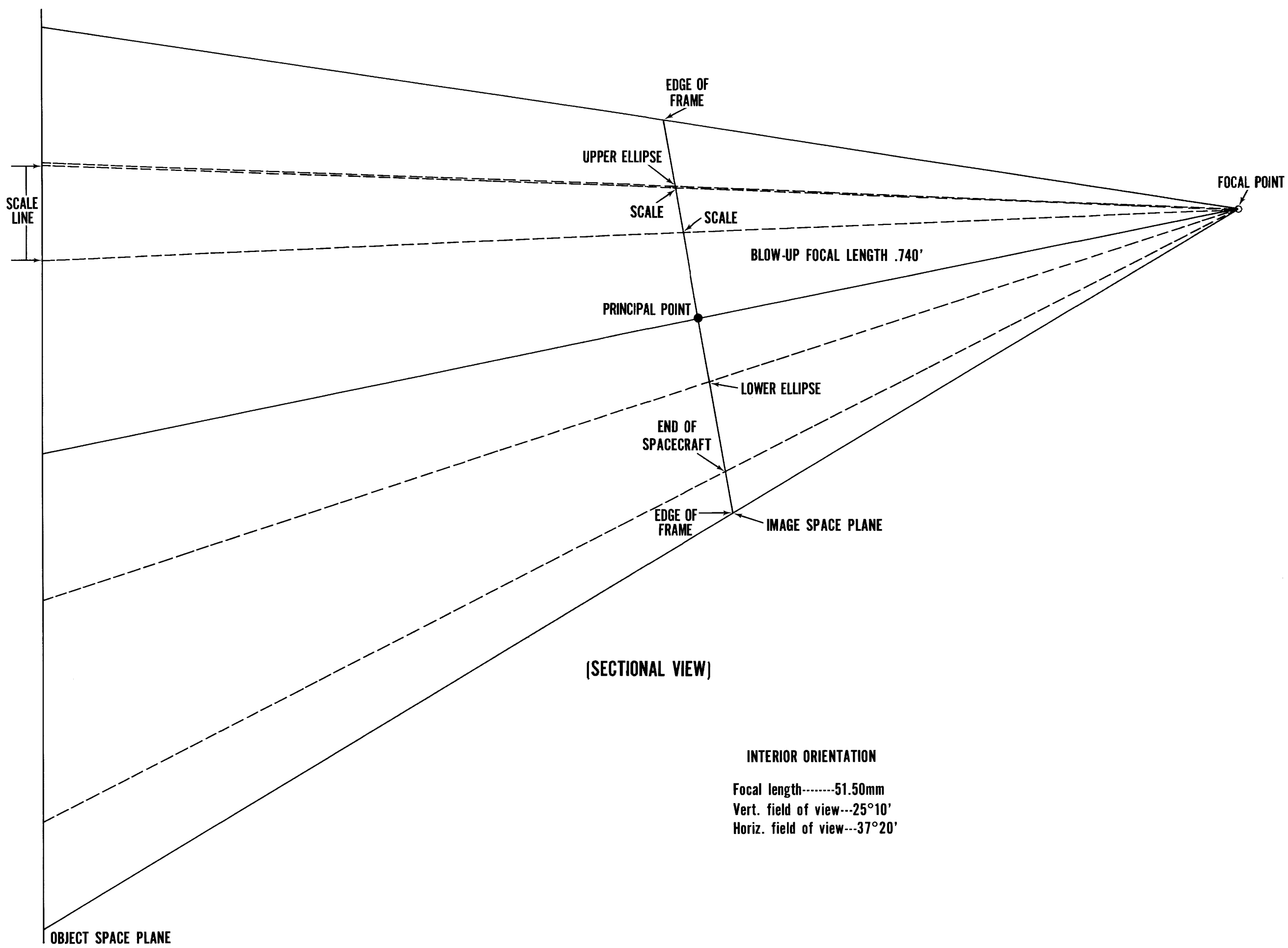

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FIGURE 14. GRAPHICAL CONSTRUCTION OF PART OF LUNA-9 SPACECRAFT FROM GROUND PHOTOGRAPHY.

REFERENCES

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3. Soviet Film T-6376 ("Starry Road") (Secret)

4. JPL Technical Report 32-877, Digital Video-Data Handling (Unclassified)

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REQUIREMENT

CIA/FMSAC. C-DS6-83,440

NPIC PROJECT

22292/66