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MIT/IL
Apollo Guidance and Navigation
System Test Group Memo #896 (Z)

TO: G. P. Edmonds, Jr.

FROM: J. A. Hand

DATE: 31 October, 1966

SUBJECT: The LM Alignment Optical Telescope : A Functional Review

REFERENCE: KIC Document #LA65-204, Indoctrination Manual, LEM Alignment Optical Telescope, (Rev. A, May 1965)

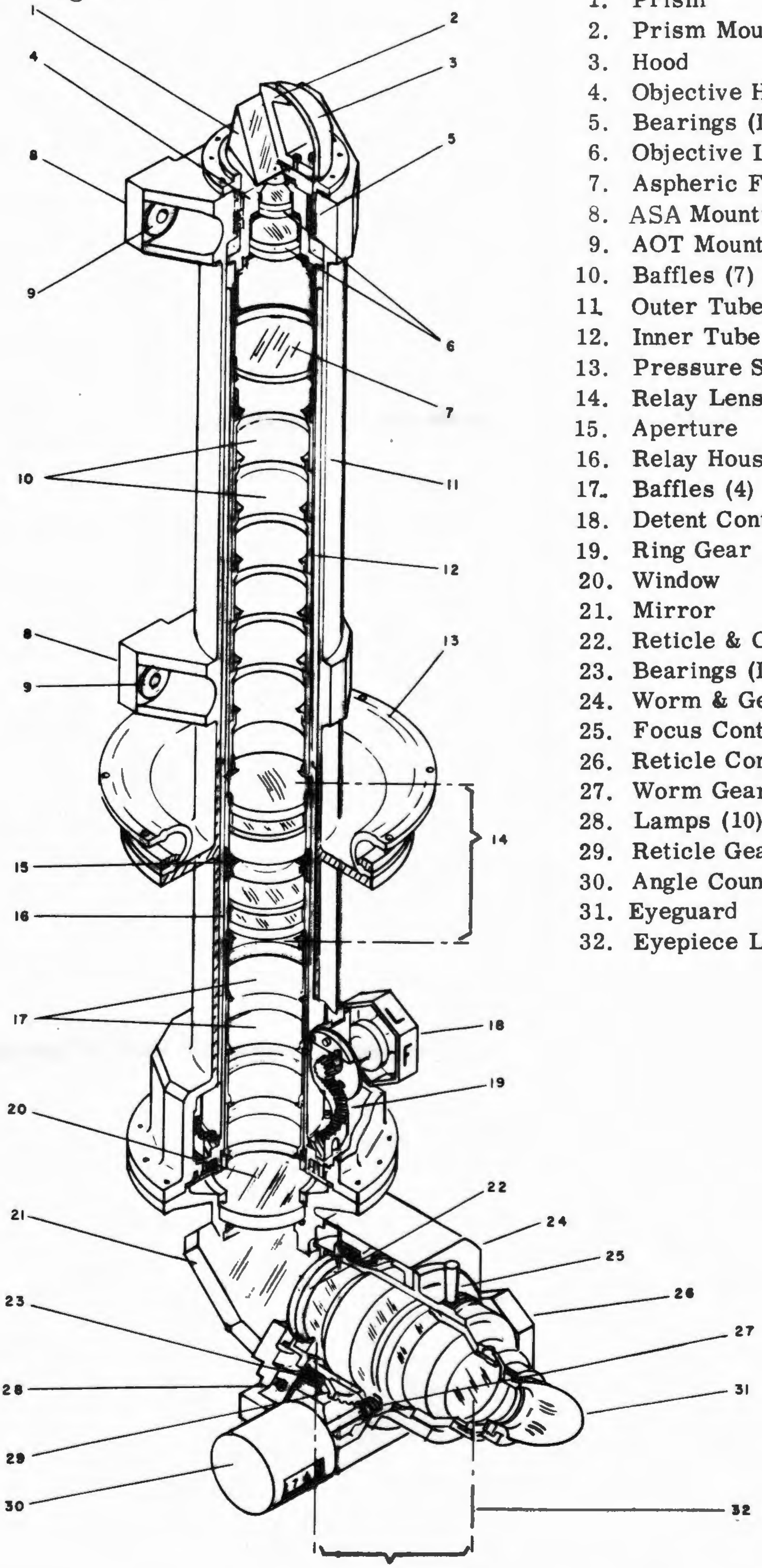
ABSTRACT

With the approach of the first integrated post-installation tests on the Lunar Module G&N System and the first flights of the spacecraft, it may prove useful to review the functions of the Alignment Optical Telescope (reference #1). In the present paper it is assumed that the reader is familiar with the mechanical design and mounting of the instrument (Exhibit #1).

DISCUSSION

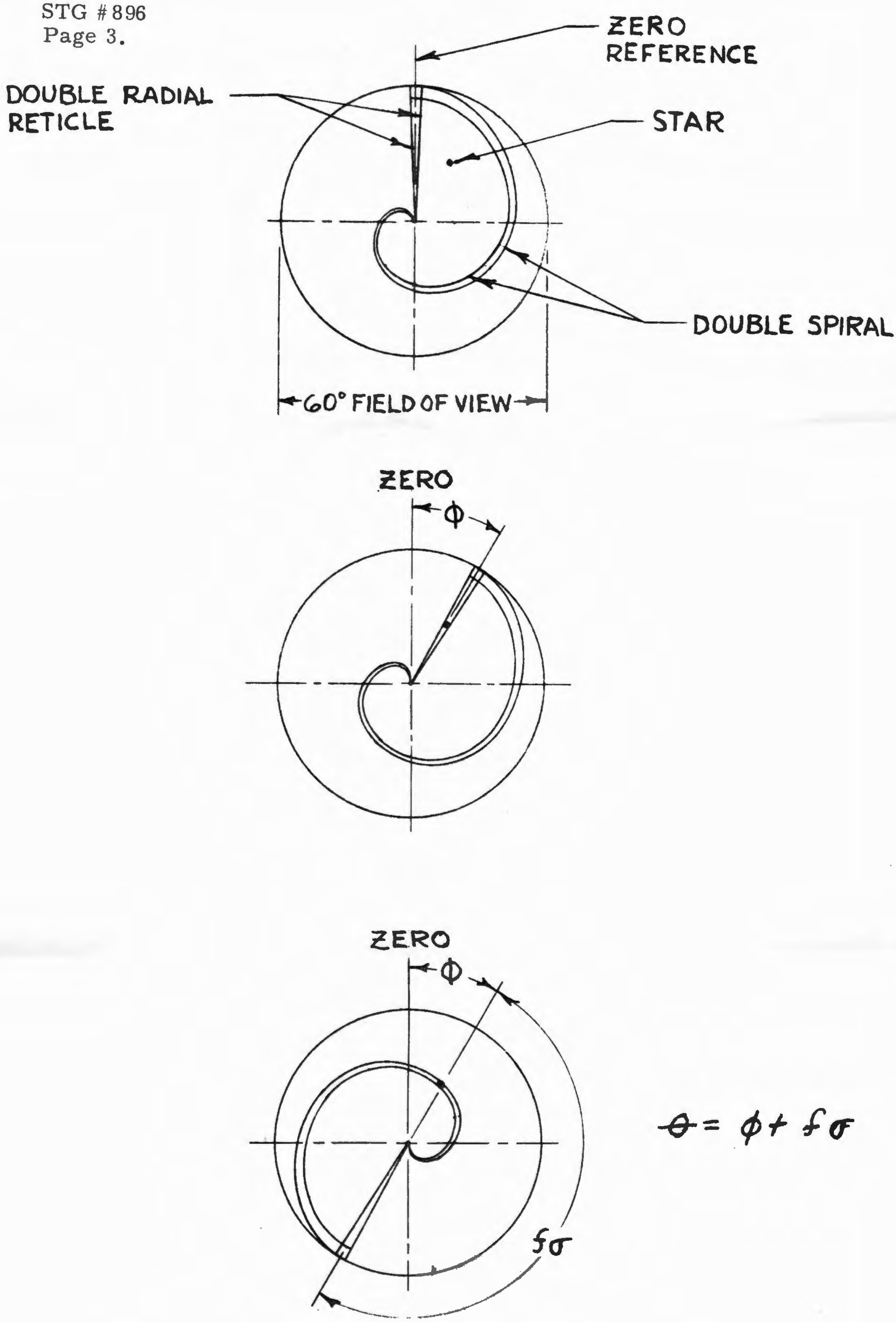
The primary reason for the AOT is to provide a means wherewith the inertial platform may be referenced to, and subsequently erected with respect to, the inertial framework via star sightings. To accomplish this, the AOT is precisely aligned mechanically with respect to the IMU through the Navigation Base and is designed such that it functions as a sextant.

The unity powered, 60 degree field-of-view periscope operates as a sextant in the following manner. A specially constructed reticle comprised of a shaft orientation line and an Archimedian spiral provides the capability for sequentially measuring angles, analagous to shaft and trunnion, to a navigational star. It may be seen from Exhibit #2 that this reticle, when rotated about the optical centerline (reticle center) to superposition of a target star on its double shaft orientation line, provides a direct measure of shaft angle. The angle turned through (Ø in the exhibit) can be read directly from a counter geared to the reticle and then inserted into the computer through the DSKY.



1. Prism
2. Prism Mount
3. Hood
4. Objective Housing
5. Bearings (Duplex)
6. Objective Lenses
7. Aspheric Field Lens
8. ASA Mounting Surfaces (2)
9. AOT Mounting Surfaces (2)
10. Baffles (7)
11. Outer Tube
12. Inner Tube
13. Pressure Seal
14. Relay Lenses
15. Aperture
16. Relay Housing (Relay Half)
17. Baffles (4)
18. Detent Control
19. Ring Gear
20. Window
21. Mirror
22. Reticle & Cover
23. Bearings (Duplex)
24. Worm & Gear Hsg.
25. Focus Control
26. Reticle Control
27. Worm Gear
28. Lamps (10)
29. Reticle Gear
30. Angle Counter
31. Eyeguard
32. Eyepiece Lenses

Exhibit #1 - Alignment Optical Telescope
Cutaway View



$$\theta = \phi + f\sigma$$

Exhibit 2 **AOT Reticle (Functional Diagram)**

After depressing the "mark" button to designate time when the shaft orientation line and star are aligned, and after inserting this counter reading into the computer, subsequent reticle rotation until the star is aligned with the Archimedian spiral provides an angular measure, f (σ), which is directly proportional to trunnion angle. That is, the radius from the center of the reticle to the spiral is a function of reticle rotation from its zero position and it is also a function of the included angle between the optical centerline and the star (trunnion angle).

To illustrate the measurement of trunnion angle, consider the following mathematical expressions:

$$r = a\gamma \quad \text{(for an Archimedian spiral)} \qquad \text{eq. 1}$$

where:

r = the radius of the line from the center of AOT reticle to the spiral

a = a proportionality constant

γ = reticle rotation as measured from the counter zero position

Now, the radius of the AOT field-of-view is 30 degrees and the spiral "tracks" out into the field this amount as the reticle is rotated through 360 degrees. Hence, the proportionality constant "a" in the above equation is $30^\circ/360^\circ$, or 1/12. Also, it may be noted that for any given viewing position, a trunnion angle up to 30 degrees can be measured. Parenthetically, the reticle measurements are not precise at the center and at the outer edge of the field of view since the shaft orientation line and the spiral cross at these points thus yielding ambiguity (counter measure is 0 or 360° and trunnion angle is 0 or 30°). The computer can negate this effect by sign logic.

In equation #1 γ is reticle rotation, or:

$$\gamma = \phi - \theta \qquad \text{eq. 2}$$

where:

θ = total reticle rotation from the zero position until the star is aligned with the spiral

ϕ = reticle rotation until the star is aligned with the shaft orientation line.

From the above equations and discussion it may be seen that in determining trunnion angle from the counter values for the spiral and shaft line measurements, the computer solves the basic equation:

$$\sigma = \frac{360 - (\phi - \theta)}{12} \qquad \text{eq. 3}$$

where: σ = trunnion angle.

The above measurements and computations are performed while the LM is situated on the moon for purposes of IMU alignment or re-alignment. In flight it is desireable to re-align the IMU.
The preceding AOT measurements require reticle rotations and alignments which might prove difficult under conditions of apparent target movements resulting from spacecraft motions. However, the AOT has two orthogonal lines on its reticle which permit star sightings without reticle rotation.

As shown in exhibit #3, a navigational star will appear to move back and forth across the orthagonal lines of the reticle when the spacecraft is in a limit-cycle mode of operation. By supplying a time mark to the computer each time the star crosses a reticle line, and by indication of the fixed AOT counter setting, the intersection of the two reticle lines define the line-of-sight to the star. Sequential sightings on two stars in the same manner provide definition of an inertial plane to which the IMU can be referenced.

AOT TERMS

A few terms used in conjunction with the AOT are somewhat unusual and thus deserve definition.

Detent Calibration

The AOT has three forward-looking positions known as detent positions. When the AOT is in the "F" position, as indicated on the detent control knob, the center of the field-of-view lies in the NAV Base X-Z plane, inclined approximately 45^{o} from the Y-Z plane. The detent control knob permits rotation of the field-of-view about the longitudinal instrument axis either 60 degrees left or right of this position as measured in the X-Z plane. These detent positions (L & R on the control knob) allow for additional viewing coverage of the celestial hemisphere. A fourth position allows for moving the head prism under a protective hood when the instrument is not in use.

By way of definition, then, detent calibration is the process whereby the optical centerline of the AOT (indicated at one end by the reticle center) is referenced, in terms of azimuth and elevation, to the instrument mounting plane, or datum plane.

Prior to making a sighting, the operator informs the computer, via a code into the DSKY, which detent position is being used. Stored in the computer are the azimuth and elevation coordinates of the optical centerline for each detent position as measured with respect to the common AOT-IMU datum plane. All AOT sightings are then made with respect to the center of the reticle as previously described.

An important aspect of detent calibration is that there is a different set of data for each instrument. Hence, if ever an AOT must be interchanged for any G&N System, so must be the detent calibration information stored in the computer (i. e. in erasable memory).

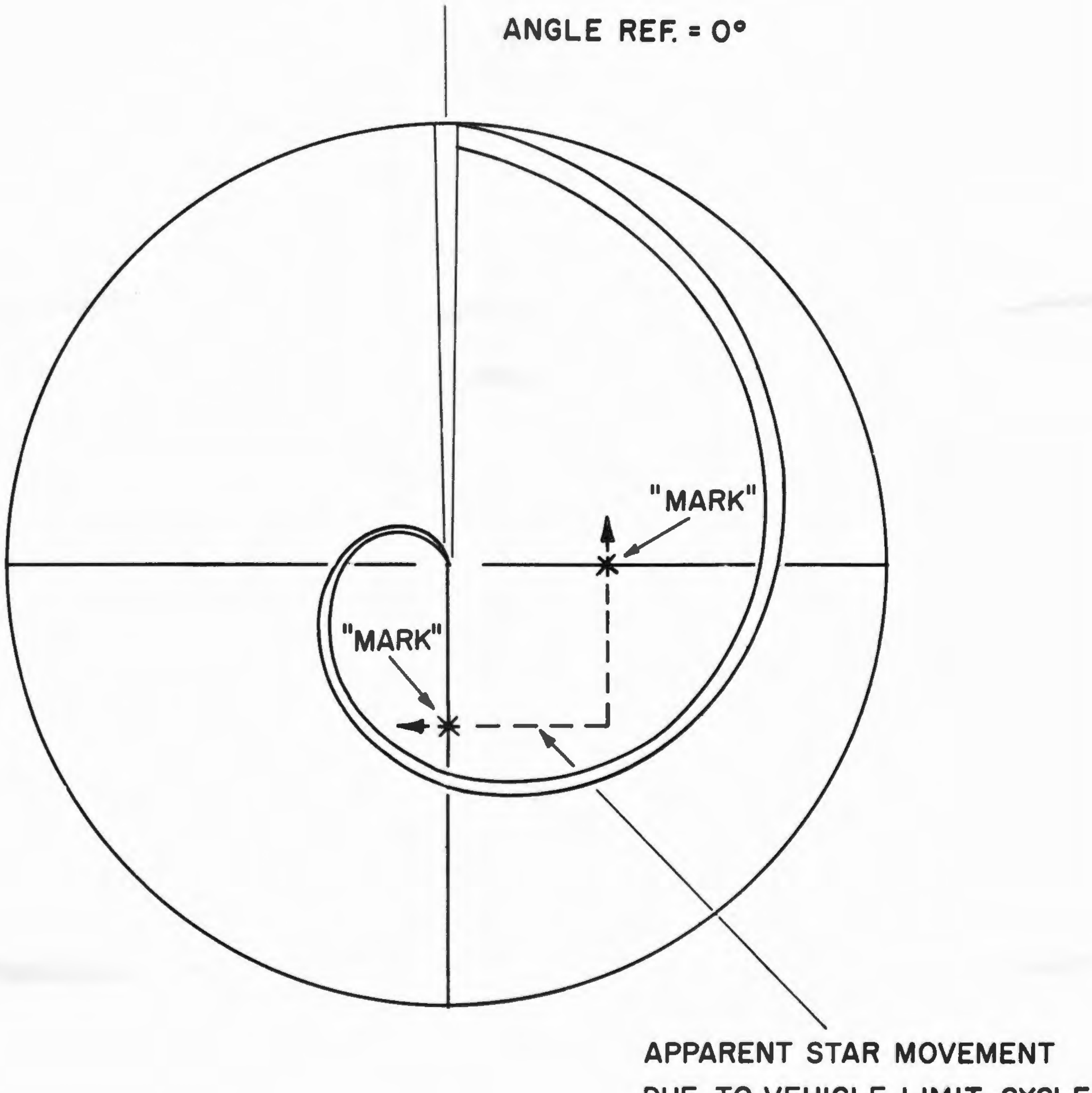


Exhibit #3 -AOT RETICLE WITH ORTHOGONAL LINES
(FUNCTIONAL DIAGRAM)

Field-of-View Rotation

When sighting through an AOT set in the forward detent position, the image seen is erect, non-inverted and non-reverted. However, when moving to the left detent, a line which was coincident with the horizontal reticle in the forward position will appear to be tilted left approximately 60 degrees. Similarly, the line will appear to tilt right 60 degrees when the right detent is used.

The reason the field tilts for left or right detents is that the head prism, which functions as a mirror in the instrument, changes the angle of its mirror face (hypoteneuse) with respect to the fixed, 45 degrees mirror at the lower end of the AOT. While the field rotation may be inconvenient for pre-flight testing, it is considered inconsequential for in-flight instrument usage since star sightings can be made from any orientation and pattern recognition is readily accomplished in the 60 degree field-of-view.

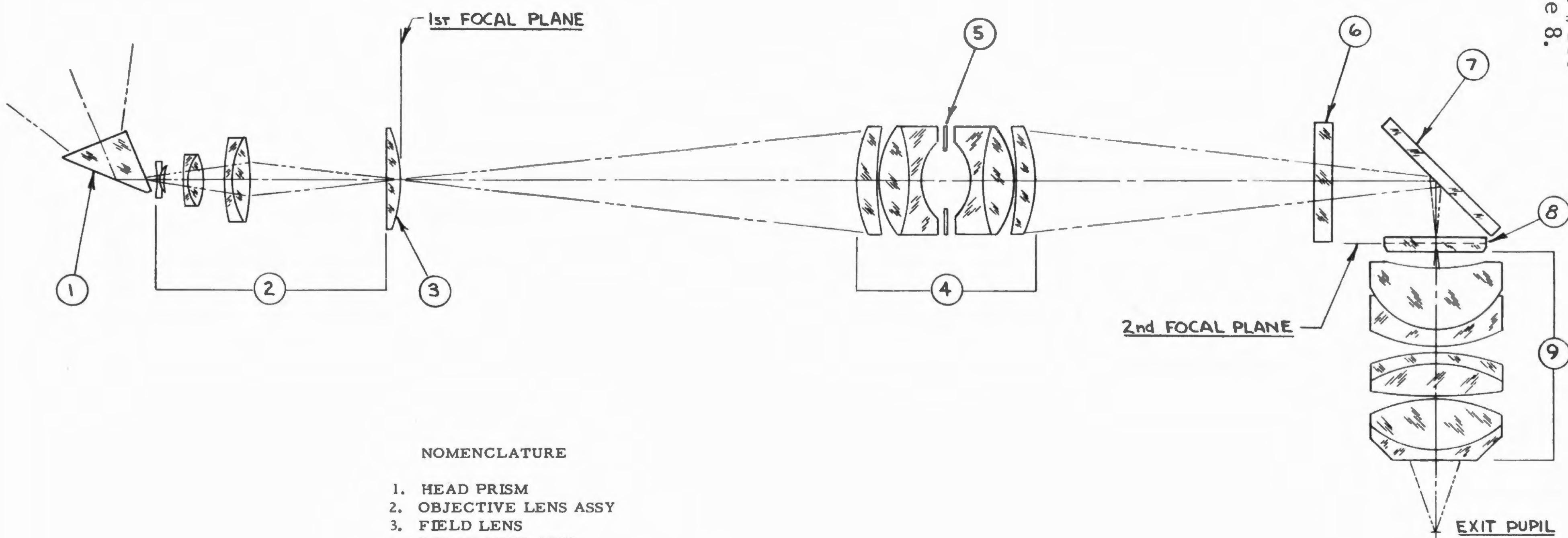
"Field Drop"

The center of the AOT reticle describes a line of constant latitude when rotation to any detent position is implemented. Thus, a point image at the reticle center would appear to have "dropped" in the field-of-view if it were not carried around to impinge on this line of constant latitude. For example, a horizontal line represented by the tooling bar commonly used in instrument testing represents a great circle when seen from the AOT. Thus, the targets mounted on the bar without compensation for this effect will appear to have "dropped" for left and right detent positions. This will not affect measurements made with the AOT reticle.

Power Match

Exhibit #4 illustrates the AOT optical system. As shown in the exhibit, the instrument has two focal planes, one just behind the aspheric field lens and one at the reticle. If an image enters the AOT at an angle such that it is radially displaced from the optical centerline at the first focal plane then it must be relayed to the reticle plane such that it is radially displaced an equivalent amount from the reticle center.

The process by which the AOT is calibrated such that radial displacements from the optical centerline for the first and second focal planes is called power match. Therefore, at the system test level, any AOT sighting which is made at a point in the field, other than the reticle center, includes two types of errors as a minimum, i. e., power match error and detent calibration error. Conversely, measurements made at the reticle center include only detent calibration error. Thus, the latter is rightly termed a detent calibration test while the former is termed an AOT functional accuracy test.



NOMENCLATURE

1. HEAD PRISM
2. OBJECTIVE LENS ASSY
3. FIELD LENS
4. RELAY LENS ASSY
5. APERTURE
6. TELESCOPE WINDOW
7. BERYLLIUM MIRROR
8. RETICLE
9. EYEPIECE LENS ASSY

Exhibit #4 - AOT Optical System

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