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PRELIMINARY DESIGN REVIEW REPORT (DRL Item MSM-S-137-2)

ACQUISITION OPTICS SUBSYSTEM

VOLUME I

25 SEPTEMBER 1967

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ACQUISITION OPTICS SUBSYSTEM

VOLUME I

25 SEPTEMBER 1967

Group-3

Subcontract No. 029B25000
(preliminary dated 3 Jan 67)

ITEK CORPORATION
LEXINGTON, MASSACHUSETTS 02173

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INTRODUCTION

This preliminary design review report is presented in accordance with the requirements of specifications MSM-S-137-2 dated 14 August 1967 and SCM-100A dated 12 September 1966 with the exceptions defined in Itek letters 9300-67-257 dated 8 August 1967 from Mr. A. L. Wright to Mr. J. E. Brogan and 9300-67-283 dated 15 September 1967 from Mr. W. N. Snouffer to Mr. J. E. Brogan. The report is organized in sections as tabulated in MSM-S-137-2.

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1.0 Acquisition Optics Design Compatibility with Specification

1.1 General Description of the Acquisition Optics

The Acquisition Optics Subsystem (AO) consists of a high power visual telescope used in conjunction with a precision pointing assembly for proper aiming of the telescope. The entire subsystem, consisting of two (2) identical sets of telescopes and pointing assemblies (a right-hand set and a left hand set) is mounted to the Lab Module section of the Manned Orbiting Laboratory (MOL) vehicle. The telescopes (Figure 1.1-1) are mounted within the Lab Module with the pointing assemblies (Figure 1.1-2),each consisting of a gimballed scanning mirror for pointing and a fixed folding mirror and window for directing the light from the scan mirror into the telescope, mounted externally on the Lab Module.

The purpose of the Acquisition Optics subsystem is to enable the astronauts to examine a series of targets in order to assess the amount of military relevent activity in the target zone. The astronaut will evaluate the activity in the target area, make a priority determination to assist in the selection of target areas for photographic coverage by the main optical system, fine correct the tracking rates stored for the target in the on-board computer, and generally obtain real time reconnaissance information concerning the target.

To fulfill the above objectives, the design of the AO was keyed to allowing the astronaut the maximum possible latitude in the use of the instrument. The scanner is able to point over a wide range in pitch (+70° to -40°) and in roll (+45° to -45°). A protective shroud covers the external elements when they are not in use. The zoom lens allows continuous magnification change from 127X to 63.5X and 31.75X to 15.88X. The insertion of a two-element low power group provides the two power ranges noted. Since the field of view at lowest magnification is 8 times that at highest magnification, the astronaut can select the amount of territory he wishes to have under surveillance at any one time. The apparent rotation of the scene is compensated by the use of a Pechan prism. A reticle is provided to aid in centering and tracking the targets in the field. Filters are provided for image contrast enhancement. The eyepiece focusing device allows the telescope to be used by any astronaut with just a simple focusing adjustment. The peripheral display, seen at the edge of the apparent field, will provide the astronaut with time sequence and identification data to facilitate the decision making process. The derotation mechanism, zoom lens, low power groups, and blanking shutter have backup override controls which minimize the possibility of a catastrophic failure mode. A sun sensor and blanking shutter mechanism are provided to protect the astronaut should the scanner inadvertently point to the sun. This shutter mechanism may also be closed when the scanner is in a slewing mode in order to prevent the astronaut from experiencing an unpleasant physiological phenomenon. To aid the user in recognizing target areas, the ability for the telescope to accept a cue image has also been built into the system.

In a typical operational sequence, the MOL system is launched for a 30 day mission with the AO in a stowed configuration. Upon Lab Module activation, the crew removes the launch locks from the scanner gimbals, the protective shroud door, the low power groups, and the zoom lens. A brief functional checkout would follow. A typical surveillance pass would adhere to the following sequence: (a) the computer commands the scanner to slew to a target, (b) the observer checks the weather and general cloud cover in the target area, (c) he then searches the entire target field for other areas of interest in the vicinity of the pre-programmed target - if a more interesting target appears, he has the ability to override the preprogrammed list and can command the main optics to photograph the new area, (d) he identifies and validates the target, e) he fine corrects the position accuracy and tracking rates and (f) he decides which target to photograph. Once the decision on photography is made, he may then concentrate on extracting as much real time information as he can for the remainder of the target pass. The scanner is then slewed on command to the next target.

Thus the Acquisition Optics subsystem performs two valuable tasks: examination of the field yields real-time reconnaissance data, and coupled with the main optical system it enhances the usefulness and quality of the reconnaissance photographs.

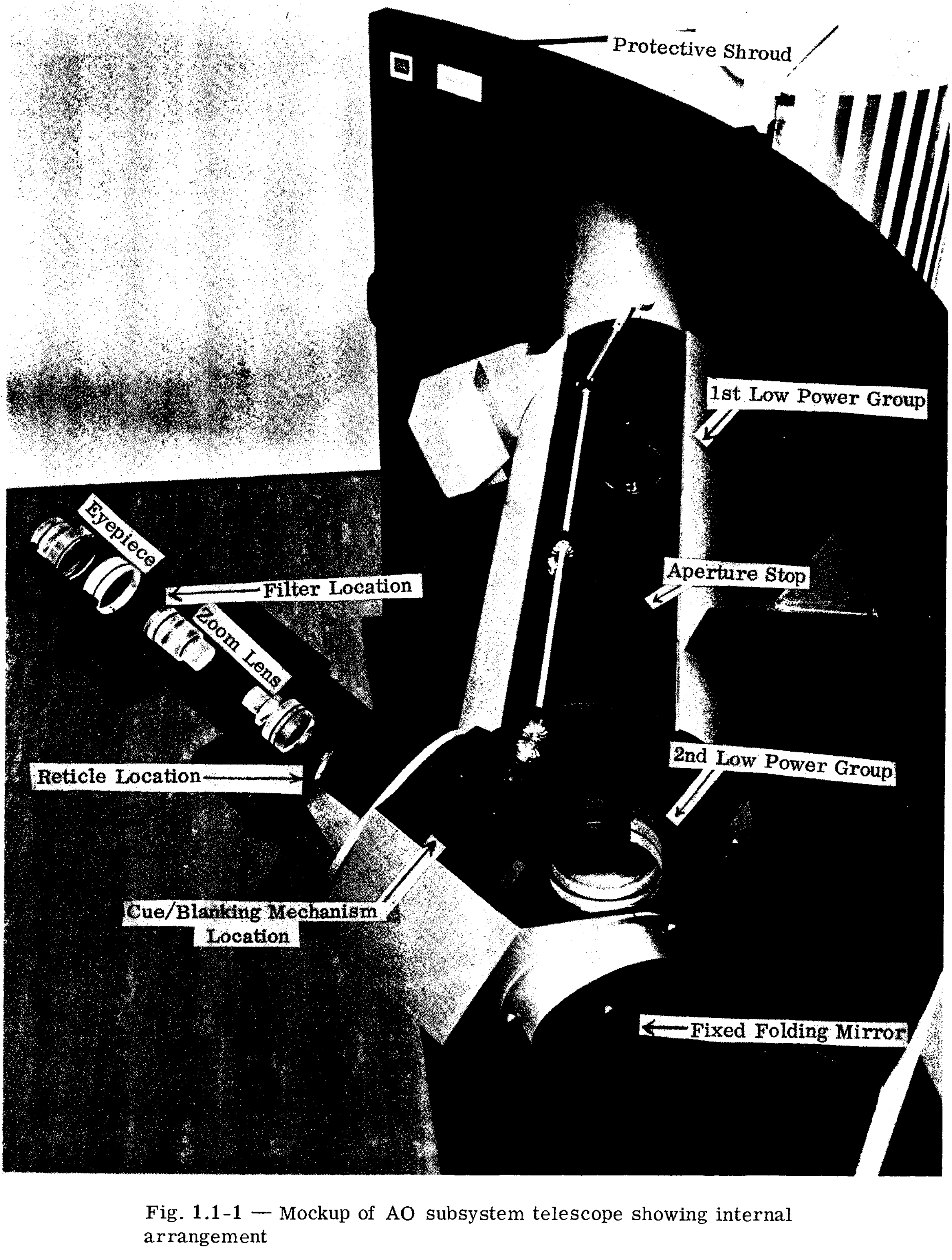


Fig. 1.1-1 — Mockup of AO subsystem telescope showing internal arrangement

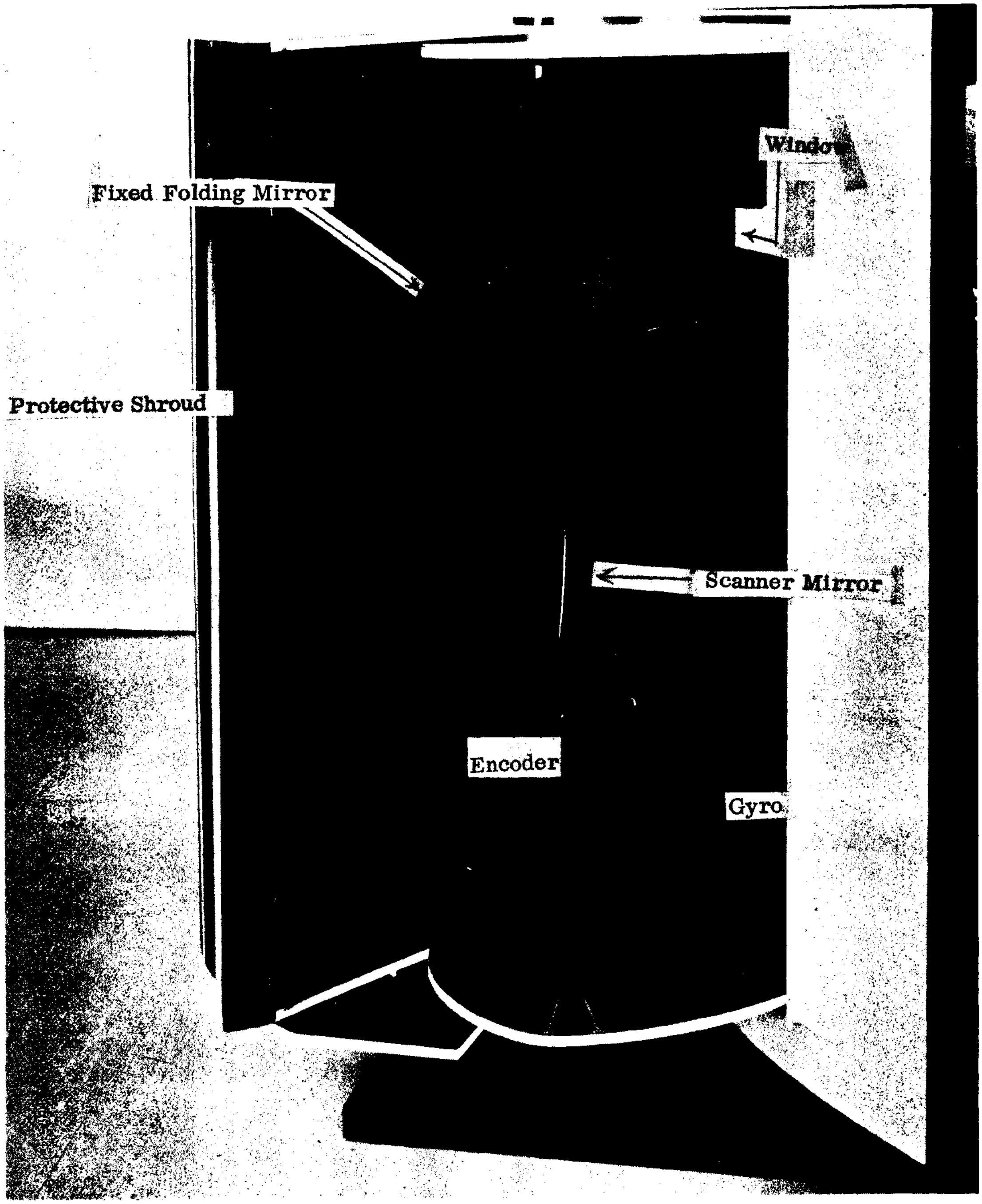


Fig. 1.1-2 — Mockup of external components of AO subsystem (protective cover open)

1.2 Compliance with Specification

1.2.1 Introduction

Section 1.2 of the Preliminary Design Review Report (PDRR) satisfies the following documentation requirements: (a) Design Review Reports MSM-S-137-2, items 2, 5, and 6, and (b) Performance Analysis Report, GE-MOL-S-124.

This section of the report examines the Acquisition Optics design and compares the design features with the specification requirements as set forth in Itek Specification No. 905850, Revision A, (Section 3.0). In those cases where the specification requirement is met, the analysis or drawing which verifies this fact is presented. In the event that the specification requirement is not met, the reason for the variation is stated, alternative design approaches are discussed, and a recommended course of action is described.

The general organization of this section is as follows: the specification, Itek No. 905850, Revision A,[*] which is the document presently governing the Acquisition Optics design, is presented in its entirety in Addendum 1.2-A, and each paragraph in this specification is then discussed in section 1.2.2. It should be noted that this is not a negotiated specification. Those portions of the specification where no exceptions were taken to the latest directed version of the design requirements (as expressed in EC-331B and SDR-137-4) are denoted by normal, Gothic-style print. Those portions where exceptions were taken are denoted by the words in italicized script. Also, portions which were deleted are shown by a - ( ) - symbol. The specification in Addendum 1.2-A, exactly as it is stated, contains the Acquisition Optics design criteria which are presently being implemented and form the basis for the PDR.

---

[*] All references to specification 905850 in the Preliminary Design Review Report refer specifically to Revision A of that specification contained in Addendum 1.2-A.

1.2.2 Specification Requirement/Design Feature Comparison

Referenced paragraph numbers of specification 905850 are shown in parentheses following each section title.

1.2.2.1 Performance (3.1)

The Acquisition Optics Configuration Drawing, 114400 clearly shows that the component possesses the capabilities described in the above referenced paragraph without exception. These capabilities are discussed and analyzed in detail in later sections of this report.

1.2.2.2 Optical Magnification and Field of View (3.1.1.1.1)

The final optical design release, contained in Section 3.6.1 of this report, includes a discussion which shows that the requirements listed in the referenced paragraph are fully satisfied.

1.2.2.3 Resolution (3.1.1.1.2)

The latest resolution estimate for the component is 3.3 feet ground resolved distance. This estimate was calculated in the following manner. The modulation transfer function (MTF) for the highest lens magnification was taken from the final lens design release, section 3.6.1. The preliminary manufacturing and alignment tolerance budget for the component, as estimated in paragraph 3.6.5, was used to degrade the lens MTF in order to produce a function which represents the completed system. This function was then intersected by the Schade visual resolution threshold function in order to estimate the resolution. Figure 1.2-1 shows the relationship between these functions and the parameters for which this calculation is valid. The requirements of the referenced paragraph are thus met without exception. The

FIGURE 1.2-1

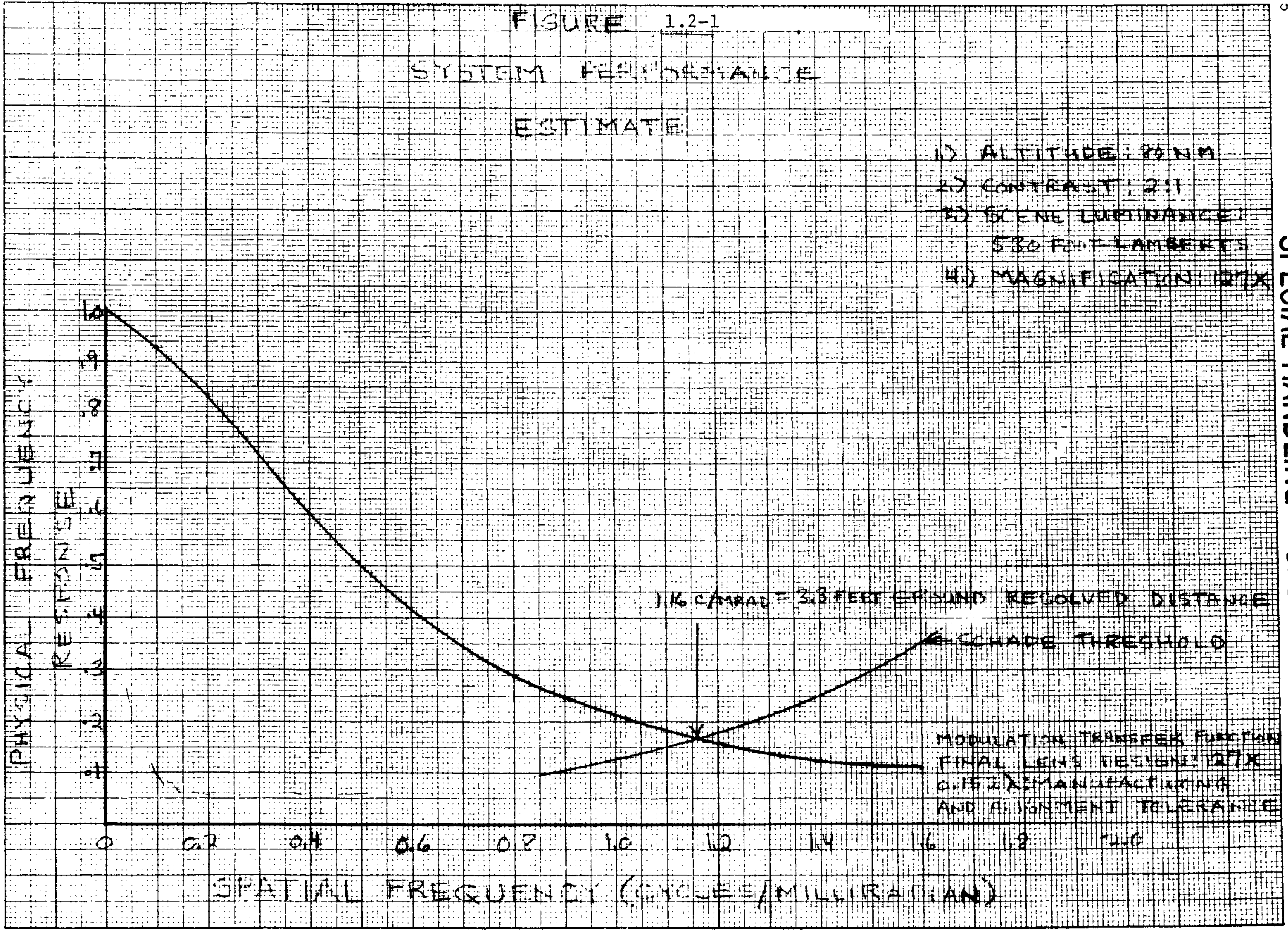
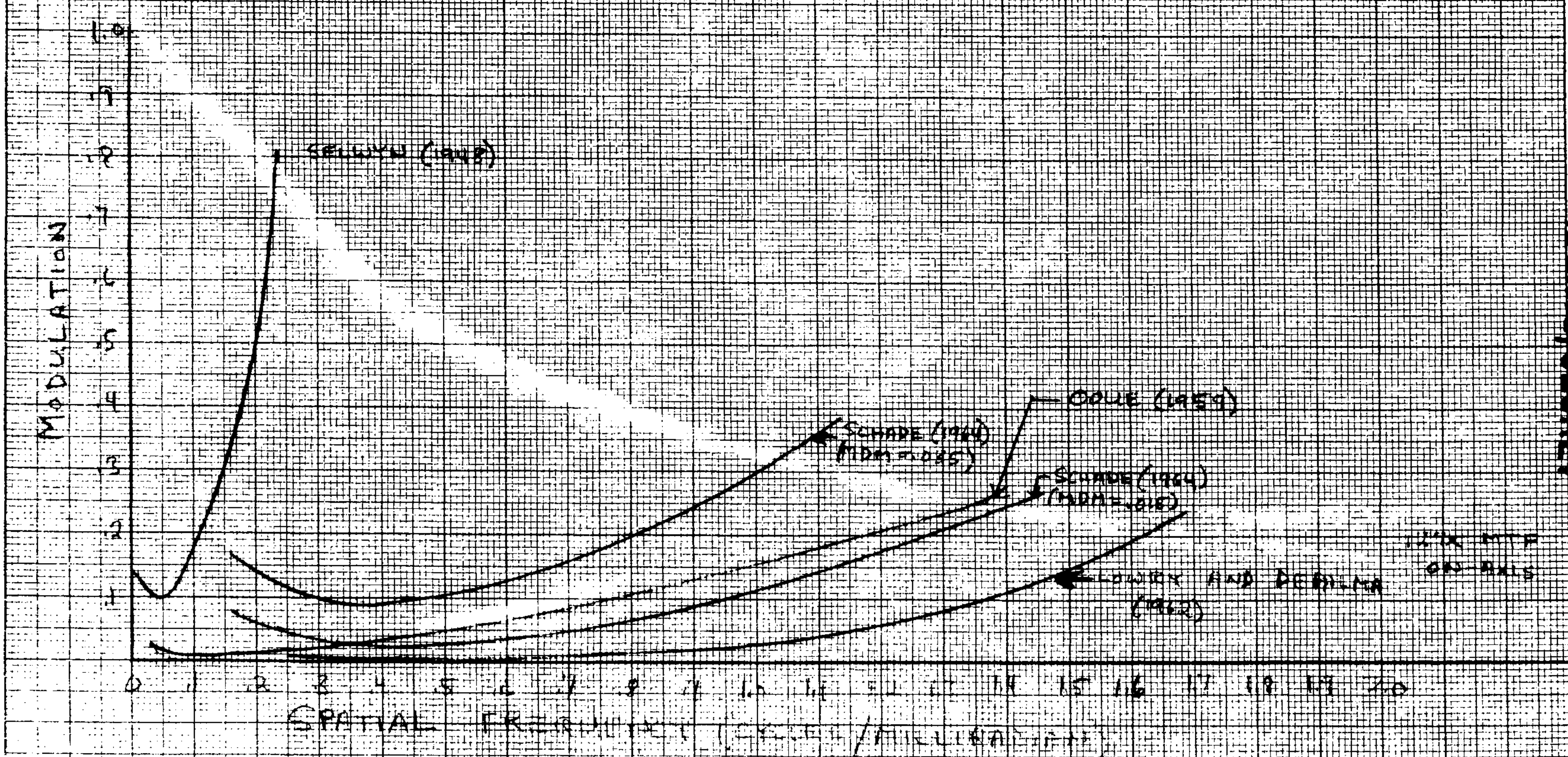

SYSTEM PERFORMANCE
ESTIMATE
1) ALTITUDE: 80 NM
2.) CONTRAST: 2:1
3) SCENE LUMINANCE:
530 FOOT-LAMBERTS
4.) MAGNIFICATION: 127X
1.16 C/MRAD = 3.3 FEET GROUND RESOLVED DISTANCE
← CHADE THRESHOLD
MODULATION TRANSFER FUNCTION
FINAL LENS DESIGN: 127X
0.15 Z X MANUFACTURING
AND ALIGNMENT TOLERANCE
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
PHYSICAL FREQUENCY RESPONSE
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
SPATIAL FREQUENCY (CYCLES/MILLIRADIAN)

FIGURE 1.2-2

LOW-CONTRAST VISUAL THRESHOLDS



justification for the use of the Schade threshold is as follows:

a. A literature search is being conducted (see Figure 1.2.-2 for a threshold summary) and the preliminary results indicate that the Schade threshold with a minimum detectable modulation of 0.015 apparently yields realistic estimates of system performance.

b. A discussion of this subject with experts in this field including Dr. S. Q. Duntley of the Visibility Laboratory on 14/15 June 1967 at SPO resulted in general concurrence to the use of this Schade threshold.

Completion of the literature study and an experimental verification of performance prediction will be concluded in the near future.

1.2.2.4 Scan Field (3.1.1.1.3)

In order to allow line of-sight (LOS) pointing within the total field limits stated in the referenced paragraph, the appropriate scanner gimbal angles for a 9° cant angle were calculated. The results of these computations are presented in section 3.5.4. Drawing 905842 shows that the computed gimbal angles were used in the design of the scanner gimbal assembly.

Figure 3.6.4-1 illustrates the fact there is no internal vignetting at the highest magnification. It is shown in subsequent design sections that there is no vignetting between the scan angles specified due to mirror and window sizes. However, further analysis is needed to determine if the scan mirror LOS intersects the LM contour. This analysis will soon be completed.

1.2.2.5 Scanner Orientation (3.1.1.1.4)

Compliance with the requirements of the reference paragraph cannot be determined at this time. The scanner gimbal axes orthogonality requirement of 0.5 arc minutes is well within the capability of theodolite alignment techniques (5 arc seconds). However, direction from

G. E. is required to establish, on the Mechanical Interface Control Drawing, the type of alignment means to be provided to satisfy the remainder of the requirements in the referenced paragraph. Once these alignment means are defined, an analysis will be conducted to determine the magnitude of the alignment adjustment capability which must be included in the design of the external AO hardware.

1. 2. 2. 6 Scanner Gimbal Acceleration (3. 1. 1. 1. 5)

The scanner gimbal acceleration provisions in the referenced paragraph are satisfied without exception. Section 3. 7. 5. 2 of this report discusses the scanner capabilities and shows that the requirements are met.

1. 2. 2 .7 Scanner Gimbal Torques (3. 1. 1. 1. 6)

The design requirements of the referenced paragraph have been satisfied. Analyses showing these points are contained in section 3. 7. 4. 2 of this report. Experimental verification of compliance will be demonstrated in the near future when bearing friction tests are run.

Experimental determination of the Power Spectral Density (PSD) of the random torque variation will be conducted. The degree to which the design goal is achieved will then be estimated.

1. 2. 2. 8 Scanner Gimbal Inertia (3. 1. 1. 1. 7)

The gimbal inertia requirements for the cross-roll and roll axes of no less than 0. 08 and 0. 36 slug-feet-squared respectively have not been satisfied. The actual values for the present design status are 0. 054 and 0. 21 slug-feet-squared for cross-roll and and roll respectively. Refer to section 3. 2 for a detailed discussion of this problem area.

1. 2. 2. 9 Scanner Structural Dynamics (3. 1. 1. 1. 8)

A preliminary scanner transmissibility analysis indicates that the provisions in the referenced paragraph will be met. The dynamic analysis, presented in section 3. 7. 3. 3, treated only the structural contributions to the frequency response curve and excluded gyro and torquer effects. In order to reaffirm the attainment of the specification requirements, tests will be conducted which include the gyros and torquers when these items are made available.

1.2.2.10 Scanner Gimbal Position Readout (3.1.1.1.9)

The requirements of the referenced paragraph will be met. Proof of this fact is presented in section 3.7.5.2 and in the purchase specifications for the encoder. (SK 114148 and SK 114149) Since the encoder manufacturer has agreed to the specification, the performance is expected to exceed the requirements in the referenced paragraph.

1.2.2.11 Gimbal Stops (3.1.1.1.10)

The design criteria in the referenced paragraph have been satisfied without exception. See section 3.7.4.3 of this report for a description of the stops.

1.2.2.12 Image Rotation Capability (3.1.1.1.11)

The requirements of the referenced paragraph are fully satisfied. Section 3.10.3.5 of this report discusses the electrical design of the derotation mechanism and shows that these requirements are met. Figure 3.6.1-1 shows an optical schematic layout of the rotation device.

1.2.2.13 Cue Insertion and Slew Blanking Provisions (3.1.1.1.12)

The cue insertion provisions of the reference paragraph are satisfied. The target image cue image switch occurs in 0.4 second. The cue insertion mechanism is a separate device from the blanking mechanism. See section 3.10.3.2.3 of this report for a detailed description of the cue mechanism design.

The slew blanking mechanism and solar blanking mechanism have been united into a single device. Since the reaction time for the solar blanking mechanism is more stringent (see specification paragraph 3.1.1.1.23) than 0.4 second time required by the slew blanking specification, this requirement is exceeded. The solar blanking time requirement, approximately 0.13 second has been used and the mechanism is designed to satisfy that requirement. Refer to section 3.10.3.2.2 for more details.

1.2.2.14 Telescope Design Approach (3.1.1.1.13)

The final lens design release, section 3.6.1, clearly demonstrates that the provisions in the referenced paragraph are met without exception.

1.2.2.15 Window (3.1.1.1.14)

The component includes a window to allow light to pass into the aperture of the telescope. This window is shown in Figure 3.6.1-5. A study was conducted to prove that the window can withstand the pressure differentials present across the lab module (LM) structure without impairing optical resolution (see section 3.6.10). The results of this study show that the window can withstand the pressure differentials of the orbital environment without degrading the performance thus meeting the requirements of the referenced paragraph without exception.

1.2.2.16 Aperture (3.1.1.1.15)

The final lens design release, section 3.6.1, and the telescope configuration drawing SK 114400 demonstrates that the provisions in the referenced paragraph are met without exception.

1.2.2.17 Eye Relief (3.1.1.1.16)

The final lens design release, section 3.6.1, shows that the eye relief requirements are fulfilled without exception. The eye relief is 0.77 inch and the eye relief variations during zoom and power change are 0.02 and 0.001 inch respectively.

1.2.2.18 Reticle (3.1.1.1.17)

Section 3.10.4.7 shows that the component contains a reticle with the required pattern scribed on its surface.

1.2.2.19 Optical Filters (3.1.1.1.18)

Section 3.10.4.6 shows the filter wheel with the four (4) sections for neutral density or spectral filters. Manual rotation of the wheel allows a crew member to select and insert the filter. The requirements of the referenced paragraph are, therefore, fulfilled. The types of filters to be inserted in the wheel are yet to be determined by the Contractor.

1.2.2.20 Focus (3.1.1.1.19)

A study was made to determine if a manual focus adjustment was required to refocus scenes corresponding to nadir distances between 70 nm and 230 nm. The result of the study was that the focus adjustment would not be required. This study also shows that the scene will remain in focus throughout the specified range of scan angles. The study results are contained in section 3.5.4.3.

1.2.2.21 Zoom Optics (3.1.1.1.20)

The final lens design release, section 3.6, shows the modulation transfer functions for the high and low power modes of operation, Figures 3.6.1-27 and 3.6.1-28. The specification requires that the resolution values for the various magnifications must be at least as good as a gradient which is simply the loss of resolution due to changing the magnification. In section 1.2.2.3, the resolution at the highest power is estimated to be 3.3 feet. From the Figures 3.6.1-27 and 3.6.1-28, it is seen that the transfer functions for the lower magnifications are all better than that for the highest magnification. Thus, the predicted resolution for these cases will be better than a prediction which is based on magnification change only. In other words, if the MTF's for all magnifications were equal, then the provisions of the referenced paragraph would be met exactly. Since the lower magnifications have better MTF's, the resolution estimates will be less than the values in the referenced specification paragraph, thus fulfilling the requirement without exception.

1.2.2.22 Zoom and Magnification Change (3.1.1.1.21)

The requirements of the referenced paragraph are met without exception. Section 3.10.4.3 contains a discussion of zoom lens electrical design and section 3.10.2.4 and 3.10.2.5 a discussion of the power changer design. That the specification requirements are satisfied is also shown in these sections.

1.2.2.23 Peripheral Display (3.1.1.1.22)

The requirements of the referenced paragraph are satisfied with one exception. The luminous output requirement of the lamps is unspecified in the specification. Therefore, complete conformance to the specification cannot be determined. Section 3.10.4.5 of this report contains a full description of the display and, shows compliance with the specification with the one exception stated above.

1.2.2.24 Solar Blanking (3.1.1.1.23)

The mechanism requirements of the referenced paragraph are satisfied by the slew/solar blanking device. See section 1.2.2.13 of this report for the discussion which justifies this conclusion. The sun sensor, which actuates the shutter, has yet to be designed. An optimization study which trades off considerations such as sensor location, weight, number of sensors for redundant coverage, etc. will be conducted. The result of this study will be a sun sensor design which fulfills the specification requirements.

1.2.2.25 Environmental Shroud (3.1.1.1.24)

The requirements of the referenced paragraph have been met with no exceptions. The exhaust impingement study (section 3.5.3.5) indicated that the shroud door would have to provide a positive seal. The design (section 3.9.4) incorporates a positive seal approach. The door opens fully in 10 seconds, thus exceeding the 25 seconds required by the specification. The shroud door fail-safe device, door position telemetry indication, and the redundant means to open the door in the event of a failure have been incorporated into the shroud design. Thus, section 3.9 demonstrates the achievement of the requirements in the referenced paragraph.

1.2.2.26 Pressure Integrity (3.1.1.1.25)

The specification requirements in the referenced paragraph will be implemented. Analysis to determine the optimum vent design is being conducted. The results and design detail to date are in Section 3.10.1.4 Further work is required before this item will be satisfied.

1.2.2.27 Launch Locks (3.1.1.1.26)

Launch locks are required for the scanner gimbals, low power groups, the zoom lens, and the shroud door (sections 3.7.4, 3.10.2.4, 3.10.4.2 and 3.9.4 respectively). In the detail design information sections for each of these assemblies, these locks are described and analyzed. The results of the analyses show that the requirements of the referenced section are met without exception.

1.2.2.28 Alignment (3.1.1.2.1)

No internal on-orbit alignment adjustments are required. The tracking mirror reflecting surface will be parallel to the cross-roll gimbal axis within 0.5 arc minutes. References defining the scanner axes to within 0.5 arc minutes will be provided as shown on the interface control drawing by mutual agreement. The provisions of the referenced paragraph are satisfied.

1.2.2.29 Target Image (3.1.1.2.2)

Figure SK 114400, the A0 assembly drawing shows a monocular eyepiece, thus fulfilling the design requirement.

1.2.2.30 Eyepiece Apparent Field of View (3.1.1.2.3)

The final lens design release, section 3.6.1, shows that the apparent field of view is constant for all possible magnifications, thus fulfilling the requirement.

1.2.2.31 Manual Overrides (3.1.1.2.4)

The specification requirements for the override controls have been met with one exception. Section 1.2.2.44.3 indicates that the controls must be designed for use by a gloved hand. Until the gloved hand criteria are made available to Itek Corporation, compliance with this requirement cannot be ascertained.

1.2.2.31.1 Cue Insertion and Blanking Mechanism/s (3.1.1.2.4.1)

The override control requirements in the referenced paragraph have been satisfied. See section 3.10.3.2 for design details.

1.2.2.31.2 Zoom Mechanism (3.1.1.2.4.2)

The zoom mechanism override control has been incorporated into the design of this subassembly. The requirements in the referenced paragraph are satisfied without exception. See section 3.10.4.2 for the detailed design.

1.2.2.31.3 Magnification (Power) Change Mechanism (3.1.1.2.4.3)

The override requirement for the power change mechanism is satisfied as shown in section 3.10.2.4 of this report.

1.2.2.31.4 Derotation Mechanism (3.1.1.2.4.4)

The requirement of the referenced paragraph is satisfied. Refer to paragraph 3.10.3.2 for design details.

1.2.2.32 Scanner Gimbal Drive (3.1.1.2.5)

The requirements of the specification are fully satisfied by the use of two independent stator windings in each torquer. Section 3.7.5 describes the scanner gimbal drive and shows in detail that these requirements are met.

1.2.2.33 Scanner Gimbal Encoders (3.1.1.2.6)

The requirements of the referenced paragraph, governing the encoder operational criteria, are satisfied without exception. This is shown in section 3.7.5 and the encoder specifications in SK 114148 and SK 114149.

1.2.2.34 Scanner Gimbal Mounted Gyro Assembly (3.1.1.2.7)

The gimbal-mounted gyro assembly was packaged with the scanner design, satisfying the requirements of the referenced paragraph. However, changes to drawing 47D404663 received on 19 September 1967, which include dimension and center of gravity shifts, require a redesign which is currently being analyzed.

1.2.2.35 Instrumentation (3.1.1.2.8)

The requirements in the referenced paragraph have been met without exception. The thermal instrumentation for the various parts of the AO is discussed in Addendum 1.2-E at the end of this section.

1.2.2.36 Telemetry Input Signal Requirements (3.1.1.2.9)

The requirements in the referenced paragraph have not been implemented pending the outcome of the uncertainty as to the voltage of the logic bus. The encoder will operate from +4.0 volts, but the telemetry requirements are based on a 5.0 volt logic bus. Therefore, either the telemetry signals should be referenced to 4.0 volts or the encoder should operate from 5.0 volts. The specification requirements cannot be met until this question is settled by G.E.

1.2.2.37 Optical Transmission Losses (3.1.1.2.10)

The requirements of this paragraph have been satisfied. Refer to section 3.6.6 for a detailed analysis of reflection and absorption losses in the telescope. The analysis shows that the transmission at the edge of the field is less than 1% smaller than it is at the center of the field and at the 1/2 field position the transmissions are approximately equal. The axial system transmission at the high magnification is 35%.

1.2.2.38 Field Breaks (3.1.1.2.11)

The field breaks are described in sections 3.10.1.3 and 3.10.2.3. The locations are approximately 27 inches from the window for the first break and 29 inches further for the second break. This fulfills the requirement in the referenced paragraph.

1.2.2.39 Reliability (3.1.2.1)

The requirements of the referenced paragraph are met with one possible exception. Section 3.4 of this report contains the reliability analysis of the component.

The exception noted above is as follows: since the luminous output of the lamps in the peripheral display has yet to be determined, the MTBF for the lamps cannot be calculated. Therefore, the attainment of the MTBF requirement in the referenced paragraph cannot be proven. This analysis will be performed when the required display lamp luminance output is determined by G.E.

1.2.2.40 Maintainability (3.1.2.2)

The optical assembly is designed for ease of maintenance. The maintainability program described in Addendum 1.2-D demonstrates that all the maintainability requirements in the referenced paragraph are fulfilled.

1.2.2.41 Useful Life (3.1.2.3)

The reliability estimate in section 3.4 shows that the life and duty cycles contained in the referenced paragraph are achievable and, therefore, this requirement is satisfied with one exception. The luminous output of the peripheral display lamps has not been specified, and therefore, compliance with the specification cannot be determined for this one case.

1.2.2.42 Environmental (3.1.2.4)

The design criteria in the referenced paragraph are being utilized in the structural and environmental control design for the subassemblies in this component. The design details are presented throughout section 3.0.

1.2.2.43 Transportability (3.1.2.5)

The requirements of the referenced paragraph are fully satisfied. The design requirements for the shipping containers have been evaluated by a container manufacturer, Container Research, Inc., and although they are felt to be stringent, the manufacturer states that they are achievable.

1.2.2.44 Human Engineering Considerations (3.1.2.6)

1.2.2.44.1 Field Flatness (3.1.2.6.1)

The degree to which this design goal is achieved may be assessed from the study results presented in section 3.6.12.

1.2.2.44.2 Exit Pupil and Eye Relief (3.1.2.6.2)

The "AO Human Engineering Procedure" contained in Addendum 1.2-B outlines the human factors program being utilized in the design of the AO. With this as a basis, the degree to which this design goal is achieved can be assessed.

1.2.2.44.3 Controls and Displays (3.1.2.6.3)

Using the "AO Human Engineering Procedure" document (see Addendum 1.2-B) as a basis, all the manual controls in AO have been designed. These include the cue/slew/solar blanking mechanisms, filter wheel, focus adjustment and the override controls for the zoom, Pechan prism and low power groups. This fulfills one requirement in the referenced paragraph. Since the "Human Engineering Procedure" was written before the "gloved hand" requirement was known, the control designs have not incorporated this feature. When the details of the gloved hand control operation are made known to Itek Corporation, the manual control designs will be reviewed to assess the impact of this requirement and the designs will be updated accordingly.

The ability to perceive the location of the control and the orientation of the particular device in order to utilize the control, in an ambient light level of 0.1 foot candles has not been determined. A human factors analysis of this problem and a recommended design approach for its solution will be conducted in the near future.

1.2.2.45 Safety (3.1.2.7)

The safety criteria set down in the referenced document will be met by the AO design. The "Safety Engineering Requirements" document, contained in Addendum 1.2-C sets forth the procedures which will ensure that the AO design is totally safe for use by a human being. This specification requirement is met without exception.

1.2.2.46 Interface Requirements (3.2.1)

Refer to section 2.0 for a detailed discussion of the interface compliance with the specification.

1.2.2.47 Component Identification (3.2.2)

1.2.2.47.1 Government Furnished Property List (3.2.2.1)

There is no requirement in the referenced paragraph.

1.2.2.47.2 Contractor Furnished Property List (3.2.2.2)

The scanner design is predicated on the assumption that the contractor-furnished items will be supplied and the design is ready to accept them. Procedures are also being written for the care and handling of these items prior to their inclusion in the finished component. This requirement is satisfied.

1.2.2.47.3 Special Approval Components (3.2.2.3)

The specification requirement is satisfied. Refer to section 8.0 for a list of the Special Approval components.

1.2.2.48 General Design Features (3.3.1)

The Acquisition Optics Configuration Drawing, Figure SK 114400, clearly demonstrates that this component possesses all the design features required by the referenced paragraph.

1.2.2.49 Weight (3.3.1.1)

The current AO weight estimate is in section 3.2 of this report. This weight establishes the baseline in lieu of a requirement in the specification.

1.2.2.50 Power (3.3.1.2)

The latest AO power budget is contained in section 3.3 of this report. This power establishes the baseline in lieu of a requirement in the specification.

1.2.2.51 Selection of Specifications and Standards (3.3.2)

The requirements of the referenced paragraph are being satisfied without exception.

1.2.2.52 Materials, Parts and Processes (3.3.3)

The discussion in section 5.12.9 of this report shows that the specification criteria from the referenced paragraph are being satisfied without exception.

1.2.2.53 Standard and Commercial Parts (3.3.4)

The discussion in section 5.12.8 of this report shows that the requirements in the referenced paragraph are being implemented without exception.

1.2.2.54 Moisture and Fungus Resistance (3.3.5)

The requirements in the referenced paragraph are being implemented without exception. It will be shown that there are no materials in the AO design which could provide nutrients for a fungus growth as required by MIL-STD-454. Also, all surfaces in the AO will resist detrimental moisture effects through use of the materials, coatings and processes specified in MIL-S-5002.

1.2.2.55 Corrosion of Metal Parts (3.3.6)

The discussion in section 5.0 of this report shows that the requirements in the referenced paragraph are being implemented without exception. Refer to section 5.12.1 for a discussion of electrolytic corrosion control. Section 5.12.2 contains the stress corrosion control criteria. Section 5.12.3 details the protective treatment plan for the AO.

1.2.2.56 Interchanegeability and Replaceability (3.3.7)

The discussion in section 5.12.10 of this report shows that the requirements in the referenced paragraph are being implemented as much as is feasible. Cant angle and shroud requirements preclude interchangeable scanners. Interchangeable systems is also an impossibility after final alignment. The interchangeability and replaceability requirements are being carried out to the highest possible subassembly level.

1.2.2.57 Workmanship (3.3.8)

The workmanship standards in the referenced paragraph are being implemented. Refer to section 5.12.5 for a detailed discussion.

1.2.2.58 Electromagnetic Interference (3.3.9)

The provisions of the referenced paragraph are met. The "Electromagnetic Compatibility Control Plan" referenced in section 7.0 of this report details the procedures which will be followed in order to ensure electromagnetic compatibility with the rest of the system.

1.2.2.59 Identification and Marking (3.3.10)

The discussion in section 5.12.6 of this report shows that the requirements of the referenced paragraph are being implemented without exception.

1.2.2.60 Storage (3.3.11)

The discussion in section 5.12.7 of this report shows that the requirements of the referenced paragraph are being implemented. The AO will perform as required after two year's storage in the specified environment.

1.2.2.61 Cleanliness (3.3.12)

The component will be assembled in a Class 10,000 clean room or shall be capable of being cleaned for use in a Class 10,000 area. See section 5.12.4 of this report for further details.

1.2.2.62 Allowable Acoustic Noise (3.3.13)

The requirements of the referenced paragraph will be implemented. Analysis of this problem will be conducted and the results will be applied to the design of those subassemblies which are sources of acoustic noise.

ADDENDUM 1.2-A

Acquisition Optics
System Design Specification
Project 9300

Specification No. 905850
Revision A
29 August 1967

Description of Document

This specification details the latest design and performance requirements for the Acquisition Optics subsystem. It is an amalgamation of the negotiated version of the specification (EC-331B; 3010-67-092/F), the Subcontractor Direction Record document (SDR No. 137-4; 9300-67-X187), and the changes which are still to be negotiated. These changes, which the project wishes to implement, are denoted by the italicized print. Deletions of requirements contained in the negotiated documents are denoted by a -()- symbol.

This specification is the source of the design and performance requirements for the Acquisition Optics sybsystem and will be implemented accordingly.

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1.0 Scope

This part of this specification establishes the requirements for performance, design, test, and qualification of one mission-design-series of equipment identified as optical assembly. This component is used to observe selected areas of the earth's surface from an orbiting vehicle in sufficient detail to detect activity of military interest. This equipment requires pre-aiming by means of computer direction and final aiming and tracking corrections by the operating observer.

2.0 Applicable Documents

The following documents, of exact issue shown, form a part of this specification to the extent specified herein. In the event of conflict between documents referenced here and the detailed content of Section 3, 4, & 10, the detailed requirement of Section 3, 4, & 10 shall be the superseding requirement. Any conflict between a document listed in this section and a lower tier referenced document shall be resolved in favor of the listed document.

Specifications

Military

MIL-A-8421B 5 May 1960	Air Transportability Requirements, Specification For
MIL-C-26482C Amend 1, Supp. 1A 20 Feb. 1963	Connectors, Electric, Circular, Miniature, Quick Disconnect
MIL-E-25366C 27 Feb. 1961	Electrical & Electronic Equip. & Systems, Guided Missiles

MIL-E-5400H	Electronic Equipment, Aircraft, General Specification For
MIL-F-7179B Amend 1 29 July 1965	Finishes, Coatings, General Specification for
MIL-H-27894A 9 Jan. 1963	Human Engineering Requirements for Aerospace Systems & Equipment
MIL-S-38130 10 Sept. 1963	Safety Engineering of Systems
MIL-S-5002A Int. Amd. 1 *11* 24 Dec. 1963	Surface Treatments & Metallic Coatings For Metal Surfaces

General Electric Company

DR 1100A March 1967 AN 1 Thru 4	Environmental Criteria and Component Test Requirements Specification - MOL
DR 1110A 28 Feb. 1967	Selected Ave Parts List
DR 1112 Add. 1 18 April 1966	Selected Processes for use in the MOL Mission Module, General Spec for
DR 1113 18 April 1966	Selected Structural Parts for Use in the MOL Mission Module, General Spec for

DR 1115 Nov. 1966	Selected Materials for use in the MOL Lab. and Specification for the MOL AGE/AAE
DP 1690 11 Nov. 1966	Electromagnetic Compatibility Requirements for MOL Program
S-30000 18 Sept. 1964	Design Requirements for Electronic Modules
S-30001 17 June 1963	Module, Electronic, Metal Frame-Assembly, Instruction for
S-30002 12 June 1963	Modules, Electronic, Encapsulated -Cordwood-Assembly Instruction for
S-30029 24 March 1965	Soldering Criteria for Microelectronic Devices.
S-30042 31 March 1966	Engineering and Quality Standard Electronic Equipment.

Standards

Federal

FED-STD-209 16 Dec. 1963	Clean Room & Work Station Requirements, Controlled Environments
FED-STD-595 Change 2 19 Feb. 1962	Colors

Military

MIL-STD-130B Chg. 1 7 Feb. 1964	Identification Marking of U.S. Military Property
MIL-STD-143A Chg. 1 14 May 1963	Specs, & Stds., Order of Precedence
MIL-STD-150A Chg. 2 28 Jan. 1963	Photographic Lens
MIL-STD-195 Chg. 1 20 Oct. 1965	Marking of Connections for Electronic Assembly
MIL-STD-202C Chg. 2 27 May 1965	Test Methods for Electronic & Electrical Component Parts
MIL-STD-454A 5 Jan. 1965	General Requirements for Electronic Equip.
MIL-STD-795 Chg. 1 26 Aug. 1964	Colors
MIL-STD-803A 1 Dec. 1964	Human Eng Des Crit For Aero & Equip. Part 11-Aero Sys Facil & Fac Equip

MS-33586A 16 Dec. 1958	Metals, Definition of Dissimilar

Drawings

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GE 711-00120	Temperature Envelope

Bulletins

ANA Bulletin 400, Rev. U 15 May 1964	Electronic Equipment, Aircraft & Guided Missiles, Applicable Documents
SP-63-470 Vol. 1	Farada
SSD Exhibit 63-3 24 June 1963	Engineering for Transportability
MIL-HDBK-217A	Reliability Stress & Failure Rate Data for Electronic Equipment
MIL-HDBK-141 5 Oct. 1962	Military Standardization Handbook Optical Design

Technical Order

WADC-TR52-321	Anthropometry of Flying Personnel
	DOD Index of Specifications and Standards
PIR No. 7223-MOL-278	Special Subsystem Design Load Factors

3.0 Requirements

3.1 Performance

The optical assembly consists of a scanner, folding mirror, and shroud externally mounted to an orbiting vehicle, an optical window in the vehicle skin, and an internally mounted telescope. The assembly in conjunction with on-board computer and/or crew initiated command & control provides acquisition and tracking of selected targets. A means for actuation of magnification, image rotation, and focus shall be provided. The telescope allows insertion of externally provided image cue projection and provides means for switching between scanner and cue images. The image switching mechanism or a separate mechanism also provides blanking of the target image on command. The optical assembly design incorporates spectral and/or neutral density filters. -()-

3.1.1 Functional Characteristics

3.1.1.1 Primary Performance Characteristics

3.1.1.1.1 Optical Magnification and Field-of-view

Two ranges of optical magnifications shall be provided. In the high range, magnification shall be continuously variable from the maximum which shall be 127x plus or minus 5x to at least one half of maximum magnification. The maximum magnification in the high range shall provide a real field of view 0.5 plus or minus 0.03 degrees in diameter. -()- The exit pupil diameter at maximum magnification shall be no less than 2.0 mm. The minimum magnification in the low range shall be no greater than 16x plus or minus 1x and shall provide a real field of view of no less than 4 degrees. The exit pupil diameter in this case shall be at least 4 mm. *For all magnifications, a portion of the field of view will be obscured by the display described in paragraph 3.1.1.1.22.* A continuous zoom between minimum magnification and twice minimum magnification shall be provided.

3.1.1.1.2 Resolution

The on-axis resolving power of the acquisition optics shall enable a flight crew member -()- to resolve a 3-bar target corresponding to that specified in MIL-STD-150A, of *1.65* foot wide white bars oriented in any direction with *1.65* foot spacing on a black background *(3.3* foot per line pair*)*. This

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acquisition optics resolution shall be obtainable when

A. The apparent contrast ratio of the 3-bar target, as seen by the acquisition optics aperture is 2 to 1.
B. The apparent scene brightness, as seen by the acquisition optics aperture, is 530 foot-lamberts.
C. The line-of-sight range to the target is 80 N. mi.
D. The required resolution shall be obtained at maximum magnification

3.1.1.1.3 Scan Field

The scanner shall permit LOS pointing within a total field of view of plus 70 deg. forward to minus 40 deg. aft in cross roll, and plus or minus 45 deg. in roll, referenced to the orbiting vehicle coordinates. There shall be no vignetting or obscuration between plus 40 degrees and plus 10 degrees in pitch, at roll angles within plus or minus 35 degrees cross track at the highest magnification, referenced to the orbiting vehicle coordinates. See Figure 1.

3.1.1.1.4 Scanner Orientation

The scanner roll and cross roll gimbal axes shall be orthogonal within plus or minus 0.5 arc min. The scanner shall be designed to allow installation so that the optical axis between the scanner and the folding mirror is parallel to the vehicle roll axis. The scanner roll axis shall be capable of being aligned such that,

A. It is 9 degrees plus or minus 3 arc minutes from the vehicle roll axis in the pitch roll plane
B. It lies in the vehicle roll pitch plane within plus or minus 1.0 arc minutes.

Means shall be provided to permit measurement of the actual scanner roll axis alignment -()- to an external reference. The direction of cant for scanners can be opposite to each other, the direction chosen to be compatible with envelope and obscuration constraints. See Figure 2.

3.1.1.1.5 Scanner Gimbal Acceleration

The scanner shall be capable of roll accelerations of at least

2 rad/ sec. sq. and simultaneous cross roll acceleration of at least 1 rad/sec. sq. The full roll acceleration capability shall be attainable in LOS scan range of plus or minus 40 degrees (with respect to the vehicle coordinates) a fall off in acceleration capability of 10% shall be tolerated in the remainder of the roll scan range defined in paragraph 3.1.1.1.3. The full cross roll acceleration capability shall be attainable in the cross roll range defined in paragraph 3.1.1.1.3.

3.1.1.1.6 Scanner Gimbal Torques

The mean value of the running friction torque for either gimbal shall be no greater than 2 in-oz. Starting friction torque shall be no greater than 1.5 times the mean value of running friction torque for each gimbal. *As a design goal,* the power spectral density of the random torque variation about the mean value of running friction shall be completely enclosed by the PSD curve of Figure 3. The torque tolerances shall be satisfied for LOS velocities of 0.1 to 3.5 deg/sec in cross roll and 0.02 to 0.15 deg/sec in roll.

3.1.1.1.7 Scanner Gimbal Inertia

The cross roll gimbal inertia shall be no less than 0.08 slug foot squared and the roll gimbal inertia no less than 0.36 slug foot squared.

3.1.1.1.8 Scanner Structural Dynamics

The structural dynamics of the scanner assembly, scanner assembly mount, gyro assembly mount and mount location shall be such that the frequency response of each axis of the gyro output signal to motor excitation, normalized to the response at 1 rad/sec and compensated for the motor electrical time constants and the gyro transfer function shall have no amplitude excursions above the profile of Figure 4.

3.1.1.1.9 Scanner Gimbal Position Readout

A. For each scanner axis, an incremental position shall be provided which shall permit, by counting, the measurement of gimbal position. The mean error of these position measurements shall be not more than 10 arc seconds, where the error is defined as the difference between the *encoder output* and the true gimbal position.

Not acceptable

B. The power spectral density of the random components of the position error shall fall within the envelope of Figure 5.

These performance requirements for A and B above shall be met for cross roll gimbal rate of plus or minus 40 deg/sec to plus or minus 0.10 deg/sec, and roll gimbal rate of plus or minus 50 deg/sec to plus or minus 0.02 deg/sec. Ⓐ

3.1.1.1.10 Gimbal Stops

Mechanical stops and energy absorbers shall be provided at the extremes of roll and cross roll gimbal travel to preclude damage to the scanner in the event of a worst case failure which causes a constant 28.0 VDC to be applied to the torque motor terminals. The gimbal stops shall allow for a 1.5 degree travel in excess of the scan field requirements of 3.1.1.1.3 prior to contacting the stop.

3.1.1.1.11 Image Rotation Capability

Image rotation capability shall be provided over a range of plus or minus 50 degrees in response to electrical commands. Electrical indication of rotation shall be provided which shall have an accuracy of 0.5 degrees, 2 sigma. and a resolution of no less than 0.175 degree. Maximum image rotation velocity shall be no less than 60 deg/sec with an acceleration capability of not less than 2 rad/per sec sq.

3.1.1.1.12 Cue Insertion *and Slew Blanking Provisions*

The telescope shall accept an externally-provided cue image into the optical assembly for display through the eyepiece. The design shall provide for routing either the target image from the scanner or the externally-provided cue image to the eyepiece. Switching from one image to the other shall be accomplished in less than 0.4 seconds after the application of power to the drive motor. *The optical assembly shall* *include a shutter which will completely blank the target image from the scanner in less than 0.4 seconds after the application of power to the drive motor. Restoration of the target image to the eyepiece shall be completed in less than 0.4 seconds after application of power to the drive motor. It shall be permissible to satisfy the above requirements with a single mechanism. Provisions shall be made for fail safe in the target blank position.* An electrical indication of the position of the cue device in each position shall be provided.

3.1.1.1.13 Telescope Design Approach

The telescope shall employ a refractive objective lens and shall be corrected over the visible wavelength region according to the spectral response characteristics of the eye as defined in Section 4 of MIL-HDBK-141.

3.1.1.1.14 Window

The optical design shall include a window. This window is in the optical path of the telescope and serves as a boundary between the exterior and interior of the vehicle and through which passes light from the target. The window shall support the pressure differentials present across the lab module structure without degrading optical resolution beyond the limits defined in this specification.

3.1.1.1.15 Aperture

The limiting aperture of the telescope in the high magnification range shall be the objective lens. Its unobscured diameter shall be at least 10 inches. The limiting aperture in the low magnification range shall be compatible with the requirements of 3.1.1.1.1.

3.1.1.1.16 Eye Relief

The eyepiece relief shall be at least 0.40 inch. The eyepiece relief shall not vary by more than 0.060 inches throughout the entire range of magnification specified.

3.1.1.1.17 Reticle

A nonilluminated circular reticle shall be provided as shown in Figure 6.

3.1.1.1.18 Optical Filters

A set of four spectral or neutral density filters shall be provided as part of the optical assembly. Selection and insertion of a filter shall be at the option of crew member.

3.1.1.1.19 Focus

If necessary for focusing of scenes corresponding to nadir distances between 70 & 230nm, a manual focus adjustment shall be provided. The scene shall remain within the focusing accommodation of the eye throughout the tracking scan angles specified in paragraph 3.1.1.1.3 without adjustments.

3.1.1.1.20 Zoom Optics

Zoom operation and the resulting change of magnification shall not degrade on-axis resolution *under conditions "A" through "D" of paragraph 3.1.1.1.2* beyond the limits of an envelope defined as follows: a straight line on log-log paper, between coordinates,

	High Power		Low Power	
Ground Resolution, in feet	*3.3*	*6.6*	13.2	26.4
Magnification	127.0	63.5	31.75	15.88

Radial position displacement during zoom shall not compromise system performance, as defined in the above envelope.

3.1.1.1.21 Zoom and Magnification Change

IS THE [illegible]

The zoom assembly shall be electrically actuated. The full zoom range shall be covered in 1.0 seconds when the maximum position change command is applied. An electrical signal representing zoom-magnification without discontinuity shall be provided with an accuracy of 2.0% of full range. The magnification change assembly shall be electrically actuated. Magnification change shall take place in no more than 1.0 seconds. An electrical

Signal shall be provided to indicate the status of the magnification assembly in either the high or low magnification position.

3.1.1.1.22 Peripheral Display

An illuminated display shall be incorporated in the telescope design. The display shall be designed so that its patterns are visible within the eyepiece field of view and the display shall obscure no more than 5 degrees at the periphery of the apparent field of view. The peripheral display shall consist of 35 illuminated dots having the design characteristics and geometric arrangement requirements described herein. The source light of each dot shall be individually controllable -on-off- from an external source. The light sources shall be designed to permit the ~~luminance~~ of all sources to be continuously controllable via a single control up to TBD foot-candles. Figure 7 illustrates the dot pattern. The lamps of the peripheral display shall be tungsten filaments. The colors of the dot patterns are also shown in Figure 7. Ⓐ

3.1.1.1.23 Solar Blanking

A blanking mechanism shall be provided for solar protection. The mechanism shall consist of a shutter to blank the sun from the eyepiece and a sun sensor to detect the proximity of the solar vector to the LOS. General Electric will provide all associated electronics.

A. The mechanism shall be capable of fully blanking the fov before any portion of the solar disk appears in the fov when the rate of closure between the optical assembly line of sight and the solar vector is equal to or less than 110 degrees/sec. The placement of the blanking stop in the system shall be such as to prevent damage to the astronauts eye or to the optical assembly.

   The reaction time of the electronic circuitry may be neglected by the Subcontractor in meeting the requirements of this paragraph.

B. The mechanism shall not blank the fov when the LOS is more than 15 degrees from the solar vector.

C. The cue insertion mechanism may be used for blanking if feasible in the light of the requirements of this paragraph.

3.1.1.1.24 Environmental Shroud

A protective shroud protecting the scanner, window, and folding mirror shall be provided which shall fit within, and be compatible with the aerodynamic fairing which is required during powered flight and which is jettisoned prior to orbital insertion. *The aerodynamic and heating loads experienced between the times of fairing ejection and orbital insertion are less severe than for normal orbital operations.*

When in the launch or stowed position, the maximum protrusion of the shroud shall not exceed 15.65 inches from the exterior radiator surface of the lab module. The protective shroud shall contain an electrically actuated door which, when closed, shall provide protection for the scanner assembly, window, and folding mirror from exhaust products of the orbital maintenance thrusters and from the *water, which is the* output of the waste management system. The door shall travel from the closed position to the fully open position or from fully open to closed in 25 seconds maximum on receipt of the appropriate signals supplied by others. The door shall be designed to fail safe in the open position. Electrical signals to indicate the fully open or fully closed door position shall be provided. Redundant means to open the door shall be provided.

3.1.1.1.25 Pressure Integrity

The telescope shall be designed such that the space between objective lens and window will be vented *at a controlled rate* to and from the telescope. -()- Flow from telescope to objective lens/window space shall *not exceed 100 cc/day/linear inch of seal for a helium atomosphere at 70°* F when the pressure differential across the objective lens *is* 5 PSIA. The telescope shall be designed for operation in the LM with pressure of 5.0 plus or minus 0.2 PSIA, either 30% helium and 70% oxygen or pure oxygen.

It shall withstand LM depressurization from liftoff pressure of 19.0 PSIA maximum to on-orbit pressurization of 5.0 plus or minus 0.2 PSIA *at a LM pressurization rate not to exceed 0.5 psi/second. The venting shall provide for pressure equalization such that the AO will be operational in no more than 6 hours after launch* ~~depressurization~~. Ⓐ

It shall also withstand two LM depressurization and repressurization events (to orbiting vehicle ambient pressure 10^{-9} Torr) of up to four hours each. *The venting shall provide for pressure equalization such that the AO will be operational in no more than 3 hours after repressurization.*

3.1.1.1.26 Launch Locks

Launch locks shall be provided for any mechanical moving parts if required to sustain the powered flight environments of paragraph 3.1.2.4. Telescope launch locks, if required, shall be designed for manual removal or deactivation. Scanner launch locks, if required, shall have a remote redundant means of removal or deactivaiton.

3.1.1.2 Secondary Performance Characteristics

3.1.1.2.1 Alignment

0.25

References defining the scanner axes to within plus or minus 0.5 arc minute are to be provided on the scanner to permit optical alignment during installation. No on-orbit internal alignment adjustment of the optical assemblies shall be required. The tracking mirror reflecting surface shall be parallel to its cross-roll gimbal axis within plus or minus 0.5 arc minute.

3.1.1.2.2 Target Image

The target image shall be presented through a monocular eyepiece lens assembly.

3.1.1.2.3 Eyepiece Apparent Field of View

The apparent field of view of the eyepiece shall be the same for both magnification ranges and throughout the zoom range.

3.1.1.2.4 Manual Overrides

3.1.1.2.4.1 Cue Insertion and Blanking Mechanism/s

The cue insertion/blanking mechanism/s shall be provided with a manual override which enables a crewmember to manually remove the cue insertion/blanking devices from the optical path between the target scene and eyepiece. This will be an operation in the event of a controle signal or mechanism failures which prohibit display of the target image.

3.1.1.2.4.2 Zoom Mechanism

The zoom mechanism shall be provided with a manual override which enables a crewmember to manually change from low zoom to high zoom or vice versa in the event of control signal or mechanism failure. Manual positioning of the zoom at intermediate powers is desirable, but not mandatory.

3.1.1.2.4.3 Magnification (Power) Change Mechanism

The magnification (power) change mechanism shall be provided with a manual override which enables a crewmember to manually change from low power to high power and vice versa in the event of a control signal or drive motor failure.

3.1.1.2.4.4 Derotation Mechanism

The derotation mechanism shall be provided with a manual override and index which enables a crewmember to manually position the Pechan prism within plus or minus 5 degrees of the neutral or central position in the event of a control signal or drive motor failure.

3.1.1.2.5 Scanner Gimbal Drive

Each gimbal shall be activated by one or two brushless, noncommutated motors. If one torquer is used, two independent stator windings shall be provided for each gimbal, each of which shall be capable of driving its associated gimbal at one-half the acceleration specified in paragraph 3.1.1.1.5 in the event of any failure in the other winding.

3.1.1.2.6 Scanner Gimbal Encoders

Each scanner gimbal shall be provided with an incremental encoder with a resolution of 1 part in 2 to the 20th power for roll and 1 part in 2 to the 18th power for cross roll. The encoders and mounting procedures shall be compatible with the scanner gimbal readout requirements of paragraph 3.1.1.1.9. In addition to the incremental position data, the encoders shall provide two auxiliary signals, one to indicate the CW and CCW limits of gimbal travel and the zero reference position, the second signal to indicate whether the gimbal is CW or CCW from the zero reference position.

3.1.1.2.7 Scanner Gimbal Mounted Gyro Assembly

A gyro assembly, consisting of a rate gyro package, -()- electronic assembly -()- and an interconnecting cable shall be mounted on each gimbal. The gyro assemblies shall be furnished by the Contractor. The Subcontractor shall provide the cabling from the gyro assemblies to the penetration connector,as shown in Figure 10. *Physical & thermal specifications for the gyro assembly are included on the interface control drawing.*

3.1.1.2.8 Instrumentation

Thermal instrumentation, sensors, and associated harnesses shall be provided on the optical assembly as required -()- by the Subcontractor.

3.1.1.2.9 Telemetry Input Signal Requirements

Any signals supplied to the PCM telemetry system shall have the following parameters.

A. Analog Signals
    1. Voltage range - 0.0 to 5.0 VDC
    2. Signal output impedance 10,000 ohms max.
    3. Multiplexer input impedance- 10 megohms min.
B. Discrete event signals and multiple bit binary word signals
    1. Voltage Levels
       Binary one plus 4.5 plus or minus 1.0 VDC
       Binary zero plus 0-.25 plus or minus 0.25 VDC
    2. Signal Source Impedance
       Binary one 10,000 ohms max.
       Binary zero 500 ohms max.
    3. Signal Conditioner Input Impedance
       Binary one 50,000 ohms min.
       Binary zero 3,000 ohms min.

3.1.1.2.10 Optical Transmission Losses

The transmission losses of the optical system as viewed by the crew shall be minimized. Within the scan angles which have no vignetting or obscuration and with uniform scene brightness, the transmissions at the edge of the apparent field of view shall be at least one-half that at the center. At half the distance between the edge and center, the transmissions shall be at least 0.8 of that at the center. The system transmission shall be at least 25%.

3.1.1.2.11 Field Breaks

To facilitate installation, the telescope shall be designed with two field breaks. The first break shall be approximately 27 inches from the window inner surface and the second shall be approximately 29 inches further, measured from the first break.

3.1.2 Operability

3.1.2.1 Reliability

The optical assembly shall have a MTBF of at least 11,600 hrs., exclusive of the rate gyros and peripheral display lamps, where a failure is defined as the inability to perform in accordance with the requirements of this specification. The 35 lamps shall have an MTBF of 46,300 hours. Cyclic operation is as defined in paragraph 3.1.2.3 of this specification.

3.1.2.2 Maintainability

The optical assembly shall be designed for ease of maintainability to minimize equipment down time during prelaunch conditions.

3.1.2.2.1 Maintenance and Repair

During orbital operation there shall be no periodic maintenance. The optical assembly shall be designed to minimize the need for routine maintenance during the entire service of the end item. The design shall not preclude the performance of simple maintenance of the telescope by the astronaut during orbital operation.

3.1.2.2.2 Service and Access

On-orbit crew access shall be considered in the design of focus adjustment and manual override controls. Modular packaging shall be used wherever possible. Ready access to various parts to simplify inspection, servicing, and replacement shall be considered in the design of the optical assembly.

3.1.2.3 Useful Life

The optical assembly shall be capable of operating within a duty cycle of 7% on 93% off in accordance with the requirements of this specification, for a minimum of 7000 hours (490 hrs. on, 6510 hrs. off)during a total useful life of 5 years as required by any combination of the following:

A. Transportation limited to 60 days as defined in DR1100, paragraph 3.1.2.1.
B. Storage per paragraph 3.3.11 of this specification
C. Handling, assembly, and checkout 9 month maximum, as defined in DR 1100, paragraph 3.1.2.3.
D. Prelaunch phase 13 months, as defined in DR 1100, paragraph 3.1.2.4.
E. Launch and ascent 10 minutes, as defined in DR 1100, paragraph 3.1.2.5.
F. Orbital operation a minimum total of 720 hrs., 50 hrs. on, 670 hrs. off with a duty cycle of 1 to 25 minutes on and up to 12 hrs. off.

The optical assembly shall be designed for the following minimum operations during a 30 day on orbit mission

Gimbal slews and tracks	12,000
Magnification (power) changer (in-out)	3,000
Zoom positioning	6,000
Blanking cycles (in-out)	12,000
Prism positionings	12,000
Protective Shroud Door	500

3.1.2.4 Environmental

This component shall be designed to withstand the environmental conditions specified in GE specification No. DR 1100 as defined below. The component shall operate during portions of handling, assembly and checkout, prelaunch, and within the duty cycle of paragraph 3.1.2.3 of this specification when on orbit. The component does not operate during the other mission phases.

The optical assembly shall be designed to operate within an orbit envelope as defined by Figure 11. The specified nominal orbit is 80 nm perigee, 180 nm apogee. Perigee will occur at 55 degrees N. latitude on the sun illiminated side of the earth. The included angle between the earth-sun line and the orbit plane shall vary between plus 60 and minus 60 degree. Thermal doors and sun shields shall be provided as necessary to satisfy the specified optical assembly performance requirements. The optical assembly shall be designed to preclude performance degrading contamination of the optical elements from orbit maintenance nozzle exhaust products and waste management *water* products.

3.1.2.4.1 Scanner, Folding Mirror, & Shroud

The scanner, folding mirror, & shroud shall *be capable of withstanding* the environments listed in DR 1100, Table 111, (environmental criteria for external components) except as follows:

A. *Shock - as per PIR No. 7223-MOL-278.*
B. *Scanner and Fold Mirror - Environmental requirements shall be reduced commensurate with the protection afforded by the shroud and fairing.*
C. *Shroud - Environmental requirements shall be reduced commensurate with the protection afforded by the fairing.*

These components are externally mounted to the vehicle structure as defined onGE Drawing (later), and are located in zone 2 as defined in Figure 1 of DR 1100.

The free molecular heat load experienced by the protective shroud and other extended surfaces will be as shown in Figures 11, 12, 13, and 14.

The temperature of the mounting surface for the GE furnished gyro assemblies shall be maintained within the limits of 0 to 100 degrees F.

3.1.2.4.2 Telescope

The telescope shall be *capable of withstanding* the environments listed in DR 1100, Table 1, (environmental criteria for internal components) *except that shock shall be in accordance with PIR No. 7223-MOL-278.* The telescope is internally mounted in zone 2, as defined in Figure 1 of DR 1100.

Temperature envelope drawing GE 711-00120 defines all of the console surfaces visible to the telescope along with their predicted temperature - time behavior and spectrophotometric properties.

3.1.2.4.3 Optical Window

The optical window shall be *capable of withstanding* the *appropriate* environments listed in Table I of DR 1100 on its internal interface and Table III of DR 1100 on its external interface, *except that shock shall be in accordance with PIR No. 7223-MOL-278.*

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3.1.2.5 Transportability

Procedures and design for transportability shall be in accordance with SSD exhibit 63-3 for highway and rail transportation, and in accordance with MIL-A-8421 for air transportation. Vibration/shock sensors and associated recording devices shall be provided.

The packaging shall be adequate to maintain the specified cleanliness conditions of the component under the shipping environments specified. Containers shall bear precautionary labels or markings that are compatible with the specified cleanliness requirements.

3.1.2.6 Human Engineering Considerations

3.1.2.6.1 Field Flatness

A design goal for the optical assembly is a flat image plane providing maximum resolution with minimal accommodation demands.

3.1.2.6.2 Exit Pupil and Eye Relief

It shall be a design goal that the exit pupil diameter and eye relief shall not result in overly restrictive head and eye positioning which could cause fatigue during prolonged optical assembly operations as described in section 6 of this specification.

The size of the exit pupil and the amount of eye relief should allow full utilization of the total apparent 60 degrees field of view of the optical assembly, including the peripheral displays, with a minimum amount of head movement; vignetting and a loss of imagery resulting from head and eye movement during target search and activity evaluation should be minimized.

3.1.2.6.3 Controls & Displays

Controls required for adjustments or normal operation shall be designed for operator convenience. The telescope mounted manual controls shall be designed for use in ambient light levels as low as 0.1 foot candle. All equipment shall be designed to permit normal control operation while the astronauts are in a space suit with gloved hands. All controls shall also be clearly visible at higher ambient light levels up to 30 foot candles. Paragraphs 3.5.4, 3.6.3, & 5, and 3.8 of MIL-H-27894 shall apply to this design. Technical order WADC-TR52-321 shall govern where applicable. MIL-STD-803 shall also be used as a guide.

3.1.2.7 Safety

The optical assembly shall be designed to conform to the requirements of -()- GE specification No. DR 1100. MIL-S-38130 shall be used as a guide.

3.1.2.7.1 Flight Safety

Parts which may work loose in service shall be safety wired and/or shall have approved locking means applied. Finishes, lubricants, or other materials used in the component shall be carefully selected to avoid adding toxic fumes to a closed, recycling, atmosphere during an operating period of 30 days. Only materials on the approved materials list DR 1115 or otherwise approved by General Electric shall be used.

3.1.2.7.2 Ground safety

All recognized class III and IV hazards, and potential hazards, as defined in MIL-S-38130A shall be reported to the General Electric Company by means of the prescribed hazard report. The optical assembly shall be designed to avoid creating a safety hazard to flight crews inside the vehicle or to the ground crews near the vehicle during ground checkout.

3.1.2.7.3 Personnel Safety

Design of components shall give prime consideration to the minimization of hazard to personnel in using or maintaining the equipment.

3.1.2.7.4 Explosive and/or Ordnance Safety

Emphasis shall be placed on minimization of EMI hazards defined in DP1690 and upon interface specifications on grounding, shielding, and electrical supplies.

3.2 Component Definition

3.2.1 Interface Requirements

3.2.1.1 Schematic Arrangement

The following electrical interfaces shall be provided in accordance with Drawing No. later

3.2.1.1.1 Scanner Electrical Interface

A. A power interface between the acquisition subsystem and the torquers on the scanner gimbals.

B. A power interface between the encoders and other sensors on the scanner and the GE-AVE electrical power and signal distribution subsystem.

C. A signal interface between the encoders on the scanner gimbals and the acquisition subsystem.

D. A power interface between the heater control unit -if required- and the GE-AVE electrical power and signal distribution subsystem.

E. A signal interface between scanner-mounted instrumentation and the GE-AVE command and instrumentation subsystem.

F. A power interface between any pyrotechnic devices -if required- and the GE-AVE.

G. A power and signal interface between the gyro electronics and the acquisition subsystem.

3.2.1.1.2 Telescope Electrical Interface

A. A power interface between the derotation drive motor and the acquisition subsystem.

B. A power interface between the zoom drive motor and the acquisition subsystem.

C. Power interfaces between the zoom and derotation position sensors and the GE-AVE electrical power and signal distribution subsystem.

D. A signal interface between the zoom position sensors and the acquisition subsystem.

E. A signal interface between the derotation position sensor and the acquisition subsystem.

F. A power interface between magnification step drive motor and the acquisition subsystem.

G. A power interface between the blanking mechanism drive and the acquisition subsystem.

H. A signal and power interface between the sun sensor and the acquisition subsystem.

I. A power interface between the peripheral display and the CC & I subsystem.

3.2.1.1.3 Shroud Electrical Interface

A power and signal interface between the shroud door drive motor and the acquisition subsystem.

3.2.1.2 Mechanical Interface Definition

3.2.1.2.1 Scanner Mechanical Interfaces

The scanner shall have the following mechanical interfaces as defined on Drawing -~~later~~-.

A. A harness terminated in two electrical connectors -per MIL-C-26482- to carry the electrical signals and power between the gimbals and the two penetration connectors in the lab module structure.

B. A structural interface between the scanner mounts and the lab module structure.

C. A mechanical interface to provide precise locations for ground alignment.

D. Mechanical interfaces with GE furnished gyro assemblies and associated harnesses.

3.2.1.2.2 Telescope Mechanical Interface

The telescope shall have the following mechanical interfaces as defined in Drawing -later-.

A. Two hard mounted connectors-per MIL-C-26482- within the console to carry electrical signals between the telescope and the acquisition subsystem.

B. A structural interface between the lab module structure and the objective end of telescope barrel.

C. A structural interface between the lab module structure and the elbow section of the telescope barrel.

D. Envelope dimensions and space allocations per GE Drawing No. -later-.

E. A nonstructural interface between the cue projector and its telescope.

3.2.1.2.3 Window Mechanical Interface

The window dimensions, methods of mounting, finishes at mounting points, and load bearing requirements shall be as defined on Drawing No. -later-.

3.2.1.2.4 Shroud Mechanical Interface

The shroud shall have the following mechanical interfaces as defined in Drawing No. -later- .

A. A structural interface with the lab module.

B. An envelope dimension and space allocation within the acrodynamic fairing per GE Drawing No. -later-.

3.2.2 Component Identification

3.2.2.1 Government Furnished Property List - none

3.2.2.2 Contractor Furnished Property List

A. Gyroscopes -1 per gimbal-
B. Gyro Electronics and Interconnecting Cable

3.2.2.3 Special Approval Components

The following components require specification review. Backup analysis sufficient to justify selection of critical performance characteristics shall be provided. Contractor approval is required before procurement.

A. 18 bit incremental shaft encoder
B. 20 bit incremental shaft encoder
C. Roll torque motor
D. Pitch torque motor
E. Derotation-( )-motor
F. Power changer-( )- motor
G. Zoom mechanism -( )-motor
H. Limit switch for gimbals
I. Roll bearings
J. Pitch bearings
K. Shroud drive

3.2.2.4 Logistics Critical Component List -none-

3.3 Design and Construction

3.3.1 General Design Features

Each optical assembly consists of a scanner, folding mirror, and optical window, telescope, and shroud. The two-gimbal scanner is externally mounted to the laboratory module through its tracking pedestal. The folding mirror is separately mounted to the lab module structure. The optical window will be mounted by the lab module contractor into the lab module structure. The internally mounted telescope includes all the optical elements from the objective lens through the monocular eyepiece. The telescope incorporates derotation, magnification step change, and zoom mechanisms. It also includes means for manual focus adjustment and spectral and neutral density filters.

The telescope design makes provision for the insertion of externally provided image cue projection for display through the eyepiece. A device for switching the display from the scanner provided image to the cue projection image is included in the telescope. This device or another will provide for blanking of the target image upon receipt of a command signal. Thermal doors and associated drives, are provided in the shroud assembly.

3.3.1.1 Weight

Each optical assembly shall weigh no more than TBD lbs.

3.3.1.2 Power

The peak power required by each optical assembly shall not exceed TBD watts. -()-

The average power required by each scanner during the tracking mode shall not exceed TBD watts.

3.3.2 Selection of Specifications and Standards

The order of precedence for the selection of specifications and standards shall be in accordance with MIL-STD-143. Only those military doucments listed in ANA bulletin 400 and/or DOD index of specifications and standards shall be interpreted as being group 1 documents as defined in MIL-STD-143. The use of standards and specifications other than those listed or referred to by those listed in Section 2, herein, shall require prior approval of GE. Any MIL-STD-143 group III documents selected for use shall automatically necessitate the preparation of a specification control drawing which shall be so drafted as to establish the specific document being referenced, its date of issue, and control responsibility for its use.

3.3.3 Materials, Parts, and Processes

Microelectronic elements shall be used in electronics circuitry wherever their usage is reasonable for the particular application. In those instances where it can be shown to GE's satisfaction that the use of microelectronic circuits is not feasible, then discrete parts shall be used. These elements and/or parts shall be in accordance with GE specification No. DR 1110, (selected parts list). In the event they do not appear in the listing of DR 1110, data shall be furnished in accordance with requirements of DR 1110 for their subsequent inclusion.

Where discrete parts are used, modular packaging of these parts shall be used wherever possible. The modular packaging techniques to be employed shall be similar to those described in GE specifications S-30000, S-30001, and S-30002.

Other materials, parts, and processes shall be in accordance with GE specification No. DR 1100,-()- DR 1112, DR 1113, and DR 1115. In the event these specifications do not suffice, nonconflicting portions of MIL-E-25366 and MIL-E-5400, may be used, subject to GE's approval.

In the case of the use of equipment built to a design previously accepted by the government, it will not be necessary to change the design to use only parts that are on the MOL selected parts list provided that

A. Evidence of prior acceptance of the equipment is submitted.
B. Prior application-s- included demonstrated capability in equivalent or more severe environments than specified in paragraph 3.1.2.4 herein.
C. The design is approved by General Electric.

3.3.4 Standard and Commercial Parts

For other than electronic or electrical parts maximum use be made of commercially available standard MIL, AN and MS parts. If it becomes necessary to use commercial parts other than those listed as standard, a list shall be submitted to GE identifying each part by name, catalog number, number of parts required, manufacturer's name and equivalent approved government specification -if available- which can be substituted for the commercial part. The reason and substantiation for the use of the commercial or nonstandard item shall also be submitted.

3.3.5 Moisture and Fungus Resistance

This component shall conform to the requirements of MIL-STD-454, requirement 4. Protective coatings will not be acceptable as moisture and fungus preventatives on parts which will lose the coatings during the normal course of manufacture, assembly, and test. Metallic materials shall resist the detrimental effects of moisture, either by nature of the material, or by means of a process or coating similar to those specified in MIL-S-5002. Cadmium plating shall not be used.

3.3.6 Corrosion of Metal Parts

3.3.6.1 Electrolytic Corrosion

Use of dissimilar metals in direct contact with each other shall be avoided as per the requirements of MIL-STD-454, requirement 16 and MS 33586 unless suitably protected by plating, painting or other surface treatment in accordance with the requirements specified in paragraphs 3.2.6.1 and 3.2.6.3 of GE specification No. DR 1100.

3.3.6.2 Stress Corrosion

Metals, techniques, and processes shall be selected and employed with regard to heat treatment procedures, corrosion protection, finish, assembly and installation, so that sustained or residual surface tensile stresses, stress concentrations and the hazards of stress corrosion, cracking and hydrogen embrittlement are minimized.

3.3.6.3 Protective Treatment

Protective treatment shall be accordance with MIL-F-7179- except paragraph 3.1.2, and GE specification No. DR 1100, paragraph 3.2.6.3.

3.3.7 Interchangeability and Replaceability

One optical assembly will be mounted on each side of the lab module. The left and right-hand optical assemblies shall be as near to mirror images of one another as feasible. There shall be a minimum of ocmponents which cannot be used in both installations. Interchangeability of optical assembly components between left and right installations shall be maximized.

Each part, subassembly, or assembly bearing a particular supplier/s part number shall be completely interchangeable with all other parts, subassemblies, or assemblies bearing the same number.

The requirements of MIL-STD-454, requirement 7, shall apply.

3.3.8 Workmanship

This component, including all parts and assemblies, shall be constructed and finished in accordance with MIL-STD-454, requirement 9. Soldering, wiring, impregnation of coils, mating of parts, plating, riveting, machine screw assemblage, welding, brazing, and freedom of burrs shall also comply with MIL-STD-454, GE specifications S-30029, and S-30042 or they shall be in accordance with techniques employed by the supplier, all subject to prior approval by General Electric. Installation of wiring shall be in accordance with specification MIL-W-8160.

3.3.9 Electromagnetic Interference

This optical assembly shall conform to the requirements of paragraph 3.2.11 of GE specification No. DR 1100.

3.3.10 Identification and Marking

Identification and Marking shall be in accordance with MIL-E-5400 paragraph 3.1.1.9, MIL-STD-130, and MIL-STD-195. Selected colors shall be in accordance with FED-STD-595 and MIL-STD-795.

3.3.11 Storage

This optical assembly shall be capable of performance per paragraph 3.1 after two years storage in an environment as defined in paragraph 3.1.2.4.

3.3.12 Cleanliness

This component shall be assembled in a clean area which meets the requirements of FED-STD-209, class 10,000, or shall be capable of being cleaned for use in such an area.

3.3.13 Allowable Acoustic Noise.

The sound pressure level output of the telescope shall be limited to that specified in General Electric specification DR 1100, paragraph 3.2.13. Appropriate noise control measures shall be developed to assure compliance with the requirements of DR 1100 for components whose inherent design is subject to the generation of noise.

4.0 Quality Assurance Provisions

4.1 Engineering Test and Evaluation. This component shall be subjected to such tests as are necessary to provide data, *not obtainable by other testing specified herein,* to verify conformance with the requirements of Section 3.

4.2 Formal Qualification Tests

4.2.1 Analyses Before Testing

These analyses shall include, but not limited to, review of engineering documentation, subcontractor internal documentation, historical and analytical summaries, and stress analyses performed. The following requirements of Section 3 shall be verified by review of analytical data prior to the start of environmental testing:

A. *Maintainability (3.1.2.2)*
B. *Human Factors (3.1.2.6)*
C. *Safety (3.1.2.7)*
D. Interface Requirements (3.2.1)
E. Selection of Specifications and Standards (3.3.2)
F. *Materials, Parts, and Processes (3.3.3)*
G. *Standard and Commercial Parts (3.3.4)*
H. Moisture and Fungus Resistance (3.3.5)
I. Corrosion of Metal Parts (3.3.6)
J. *Interchangeability and Replaceability (3.3.7)*
K. *Workmanship (3.3.8)*
L. *Identification and Marking (3.3.10)*
M. Storage (3.3.11)
N. *Cleanliness (3.3.12)*

4.2.2 Test Conditions and Procedures

Test conditions and procedures shall conform to the requirements of GE specification No. DR 1100, paragraphs 3.3 tests and 4.2 test conditions.

4.2.3 Performance Verification Tests

4.2.3.1 Dielectric Strength and Insulation Resistance Tests

The component shall be tested for dielectric strength and insulation resistance per paragraph 4.3.1.2 of GE specification No. DR 1100. If components employing transistorized circuits are of such a nature that they will not withstand this test, the manufacturer shall perform a test for dielectric strength and insulation resistance using the maximum voltages possible. These tests are subject to the approval of the General Electric Company.

4.2.3.2 Corona and Arcing Test

Corona and Arcing test per paragraph 4.3.1.1 of GE specification No. DR 1100.

4.2.3.4 Scanner Structural Dynamics

The frequency response characteristics of the gyro output signal will be measured in order to insure that the requirements of paragraph 3.1.1.1.8 of this specification are met.

4.2.3.5 Acceptance Test and Operability Demonstration

The component shall be subjected to a complete acceptance test in accordance with Part II of this specification. Successful completion of these tests is a prerequisite for start of the subsequent tests.

4.2.4 Qualification Environmental Test

Qualification environmetal tests shall be performed on two (2) components in accordance with paragraph 4.4 of DR 1100 as noted in this specification.

4.2.4.1 Internal Components

The following qualification test sequence shall be performed on the internal components:

4.2.4.1.1 Acceleration: The component shall be placed in the acceleration apparatus and given an acceleration of 10 g's for 5 minutes along the vehicle x axis and an acceleration of 5 g's for 5 minutes along each of the other two vehicle axes for a total of six directions. The component shall be nonoperating and in a launch condition during this test.

4.2.4.1.2 Performance Test
The following items shall be checked:
A. Optical Magnification and Field of View (3.1.1.1.1)
B. Resolution (3.1.1.1.1.2)
C. Image Rotation Capability (3.1.1.1.1.11)
D. Cue Insertion and Slew Blanking Provision (3.1.1.1.12)
E. Zoom and Magnification Change (3.1.1.1.21)
F. Eye Relief (3.1.1.1.16)
G. Peripheral Display (3.1.1.1.22)
H. Manual Overrides (3.1.1.2.4)

4.2.4.1.3 Vibration per DR 1100 paragraph 4.4.3.5 for pressurized compartment, zone 2, wall-mounted, Figure 10. The component shall be nonoperating during this test, and in a launch condition.

4.2.4.1.4 Performance Test
Same as paragraph 4.2.4.1.2

4.2.4.1.5 Design Shock
The component shall be subjected to tests which simulate the anticipated shock spectra (Figure 2 PIR No. 7223 MOL 278) induced by stage separation or other pyro-technic devices.

4.2.4.1.5.2 Performance Test
Same as paragraph 4.2.4.1.2

4.2.4.1.5.3 Transportation Shock
The packaged component (or an equivalent packaged instrumented dummy) shall be tested for its ability to sustain transportation shocks in accordance with Procedure III of MIL-STD-810 as modified by Table IV in GE specification No. DR 1100.

4.2.4.1.6 Performance Test
Same as paragraph 4.2.4.1.2, if actual component is used in the transportation shock test. (not required otherwise)

4.2.4.1.7 Acoustic noise per DR 1100 paragraph 4.4.3.7.

4.2.4.1.8 Performance Test
Same as paragraph 4.2.4.1.2.

4.2.4.1.9 Temperature cycling per DR 1100 paragraph 4.4.3.1 except that the component shall be nonoperating during this test and performance tests shall not be conducted.

4.2.4.1.10 Performance Test
Same as paragraph 4.2.4.1.2.

4.2.4.1.11 Thermal altitude per DR 1100 paragraph 4.4.3.2 except optical performance shall not be measured.

4.2.4.1.12 Performance Test
Same as paragraph 4.2.4.1.2.

4.2.4.1.13 Oxygen compatibility per DR 1100 paragraph 4.4.3.15.

4.2.4.1.14 Helium compatibility per DR 1100 paragraph 4.4.3.15.

4.2.4.1.15 Performance Test
Same as paragraph 4.2.4.1.2

4.2.4.1.16 Electromagnetic compatibility per DR 1100 paragraph 4.4.3.12.

4.2.4.1.17 Leakage and Pressure Integrity
The component shall be tested to demonstrate the leakage requirement

of paragraph 3.1.1.1.25 and the pressure integrity requirements of paragraphs 3.1.1.1.25 with a safety factor of 1.5.

4.2.4.1.18 Endurance per DR 1100 paragraph 4.4.3.19. The component shall be operated for a period of 980 hours for the total number of cycles stated in paragraph 3.1.2.3F of this specification. This test shall be conducted in the ambient conditions referenced in paragraph 4.2 of DR 1100. During this test, the component shall demonstrate its ability to meet the functional characteristics specified in paragraph 4.2.4.1.2 after every 100 hours of operation,and before and after endurance test.

4.2.4.2 External Components

4.2.4.2.1 Acceleration:

The component shall be placed in the acceleration apparatus and given an acceleration of 10 g's for 5 minutes along the vehicle x axis and an acceleration of 5 g's for 5 minutes along each of the other two vehicle axes for a total of six directions. The component shall be nonoperating during this test and shall be in the launch (stowed) condition.

4.2.4.2.2 Performance Test

The following items shall be checked:

A. Scan Field (3.1.1.1.3)
B. Scanner Orientation 3.1.1.1.4)
C. Scanner Gimbal Acceleration (3.1.1.1.5)
D. Scanner Gimbal Torques (3.1.1.1.6)
E. Scanner Gimbal Position Readout (3.1.1.1.9)
F. Shroud Drive (3.1.1.1.24)
G. Scanner Gimbal Drive (3.1.1.2.5)
H. Scanner Gimbal Encoders (3.1.1.2.6)
I. Sun Sensor (3.1.1.1.23)

4.2.4.2.3 Vibration per DR 1100 paragraph 4.4.3.5 for pressurized compartment, zone 2, wall mounted Figure 10. The component shall be nonoperating during this test, and shall be in the launch (stowed) condition.

4.2.4.2.4 Performance Test
Same as paragraph 4.2.4.2.2.

4.2.4.2.5 Shock Tests
Same as paragraph 4.2.4.1.5.

4.2.4.2.6 Performance Test
Same as paragraph 4.2.4.2.2.

4.2.4.2.7 Acoustic Noise
Per DR 1100 paragraph 4.4.3.7.

4.2.4.2.8 Performance Test
Same as paragraph 4.2.4.2.2.

4.2.4.2.9 Thermal/Vacuum
Per DR 1100 paragraph 4.4.3.3 except optical performance shall not be measured.

4.2.4.2.10 Performance Test
Same as paragraph 4.2.4.2.2.

4.2.4.2.11 Electromagnetic Compatibility per DR 1100 paragraph 4.4.3.12.

4.2.4.2.12 Endurance per DR 1100 paragraph 4.4.3.19. The component shall be operated for a period of 980 hours for the total number of mechanism cycles stated in paragraph 3.1.2.3F of this specification. This test shall be conducted in the ambient conditions referenced in paragraph 4.2 of DR 1100. During the test the component shall demonstrate its ability to meet the functional characteristics, specified in paragraph 4.2.4.2.2 after every 100 hours of operation.

4.3 Reliability Test and Analysis

A reliability mathematical model of the optical assembly will be constructed showing the functional relationship of all parts and assemblies. A listing of all functional parts shall be supplied with a statement of applied operation stress levels for each part (voltage, current, mechanical loads, vibration, temperature, etc.) . For each part application, a failure rate shall be stated. Military Handbook MIL-HDBK-217 for electrical and electronic parts and SP 63-470, Vol. 1 (Farada) for all other parts shall be used as the controlling sources of failure rate data (with the use of appropriate application factors) unless use of other rates is justified by data derived from tests or prior proven experience in equivalent applications. Using the procedure above, the reliability and/or the MTBF for the equipment shall be computed and submitted to General Electric. This analysis, subject to approval by General Electric, will constitute adequate demonstration of the design reliability, provided that the computed reliability and/or the MTBF meets or exceeds the design requirement stated in paragraph 3.1.2.1, and provided that the reliability model and associated reliability computation are updated for every subsequent change in configuration or application.

6.0 Notes

General Optical Assembly Mission Operations

During a payload pass one of the primary tasks of the crew will be to examine a series of targets in the optical assembly to determine the amount of military-relevant activity in the target area. The crewman will perform activity evaluation to provide data for priority determination to assist in the selection of target areas to be photographed by the main optics. Data from the correction of target L.O.S. and rate errors in the optical assembly may be used for computer updating for main optics photography.

In the nominal operation mode, the initial optical assembly pointing commands will be provided by the on-board computer. In addition, the optical assembly system will be capable of operating in a limited search mode during which the crewmen can reposition the optical assembly L.O.S. to evaluate targets of interest in the near vicinity of the pre-programmed target.

The basic events occurring during a target pass are:

- Acquisition scope slew to target
- Observe general weather/cloud cover conditions in target area
- Perform target search, as required
- Identify/validate target
- Correct position and tracking rate error
- Increase magnification, as required
- Perform target activity/weather evaluation
- Perform target priority decision

The amount of time available for performing target pass tasks varies as a function of target density. In high density areas, targets will be available at a maximum rate of one target per four seconds requiring rapid performance of the target detection, acquisition and activity evaluation tasks.

A more detailed description of optical assembly mission tasks can be found in CDRL item #107 entitled, Crew and Time Line Analysis, Volume I -SSH DIN 3849-252-1, dated 15 March 1967-.

The finite resolution requirements for the optical assembly have been derived from the type and characteristics of the activity indicators to be

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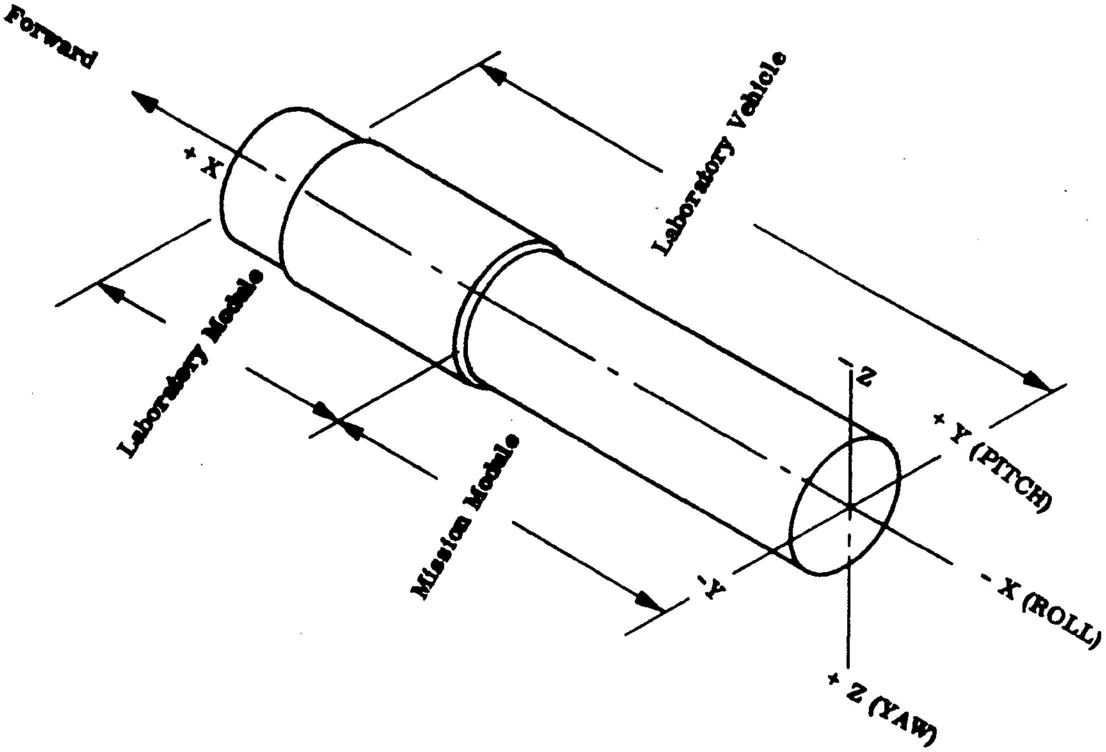
evaluated during mission operations. Several other characteristics of the optical assembly such as image plane characteristics, resolution fall off, and image brightness must receive human engineering evaluation to optimize optical assembly design.

Telescopes typically have different foci at various image axes resulting in curved image planes. In normal telescopes, the central optical axis of the telescope is used for viewing. However, positioning accuracy of the optical assembly results in a distribution of targets of interest across the entire field of view of the telescope, thus, requiring the crew man to scan the entire field of view and to detect targets at different loci in the field of view. A curved image plane or differences in the tangential and saggital foci of the optical assembly image requiring visual system accommodation by the crew man are undesirable since they would result in altered search patterns, crewman fatigue and/or increased time requirements for searching and detecting targets.

During target acquisition operations, the crew member will shift his attention between cue materials, the optical assembly and the main optics. The size of the exit pupil and eye relief of the optical assembly system must be sufficient to insure rapid acquisition of the optical assembly image following changes in head and eye position during shifts between the cue, optical assembly, and main optics displays.

10.0 Appendix



(Use right-hand rule for positive rotations)

Figure 1. Orbiting Vehicle Coordinates

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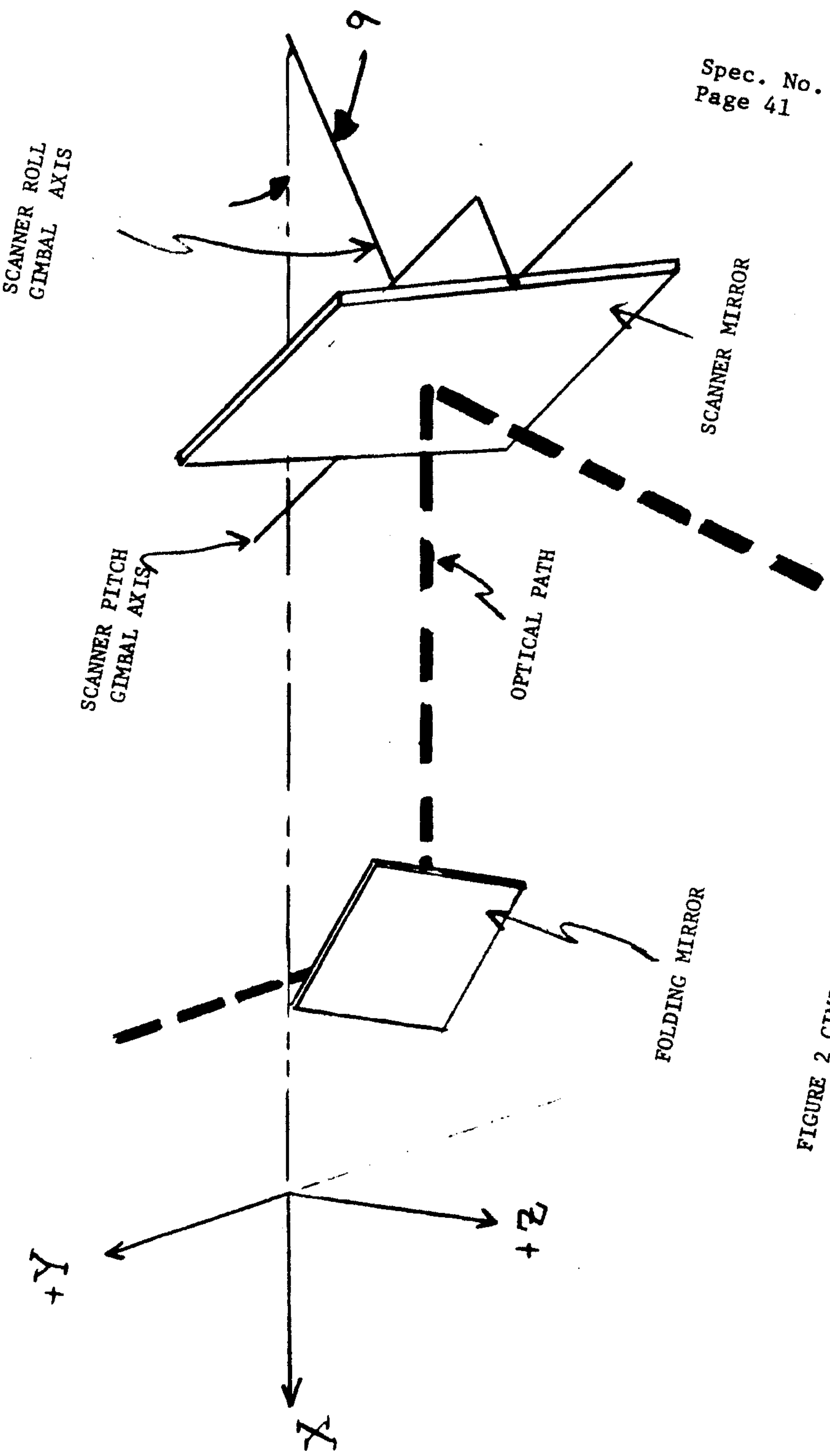

FIGURE 2 GIMBAL CANTED ATS (LEFT SIDE OF VEHICLE)

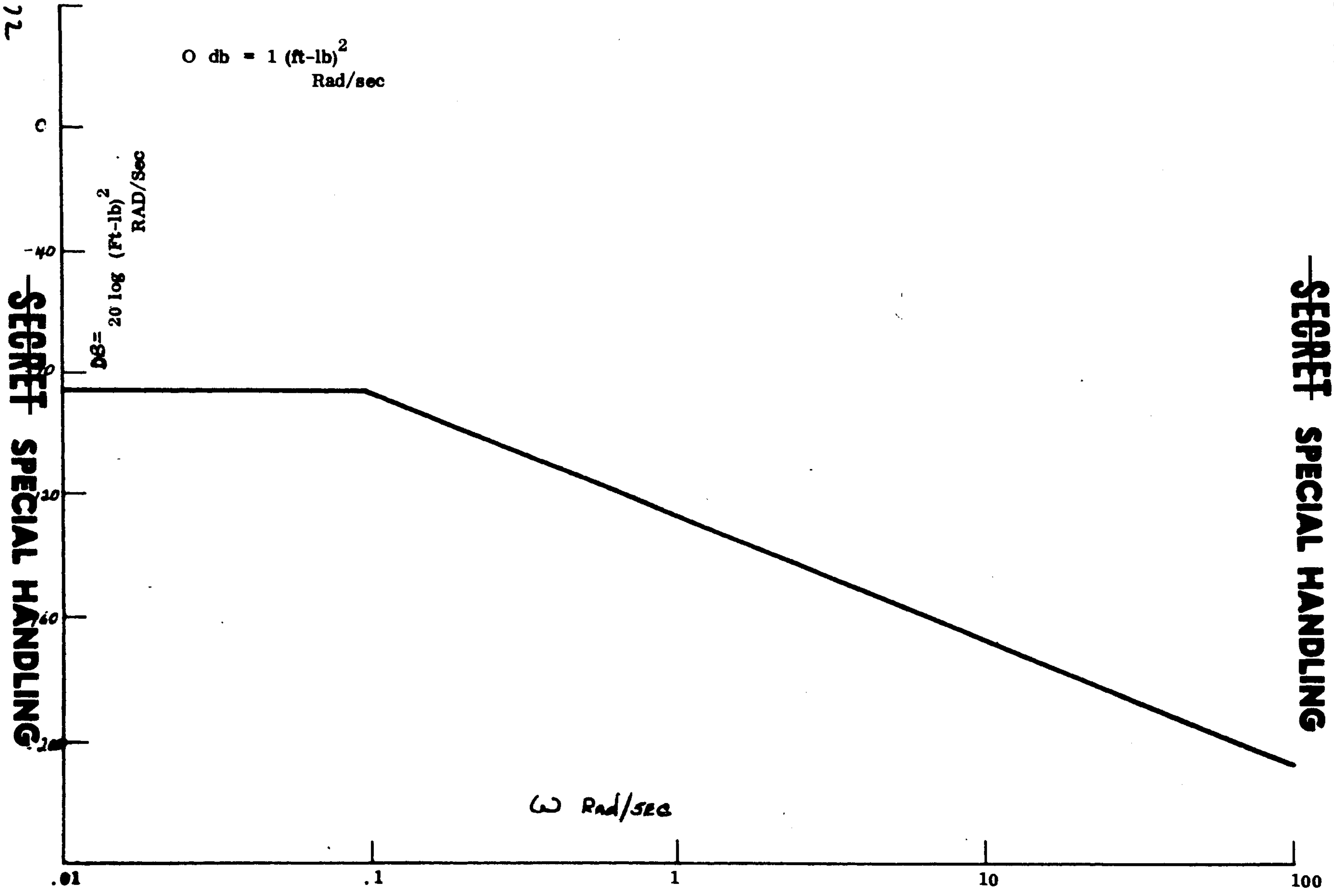

Figure 3. Random Torque Disturb. Power Spectral Density

~~SPECIAL HANDLING/SECRET~~

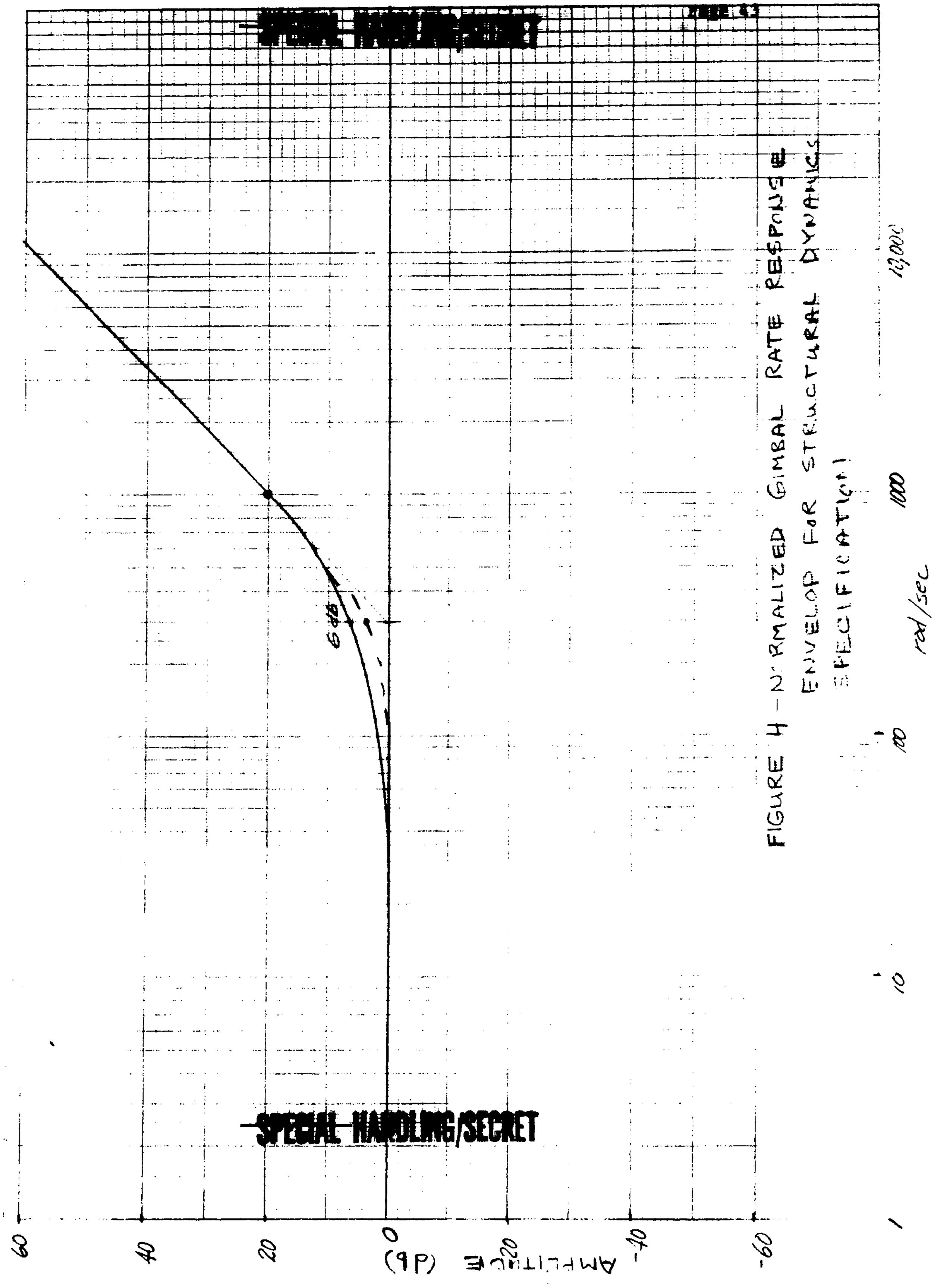

FIGURE H — NORMALIZED GIMBAL RATE RESPONSE ENVELOP FOR STRUCTURAL DYNAMICS SPECIFICATION

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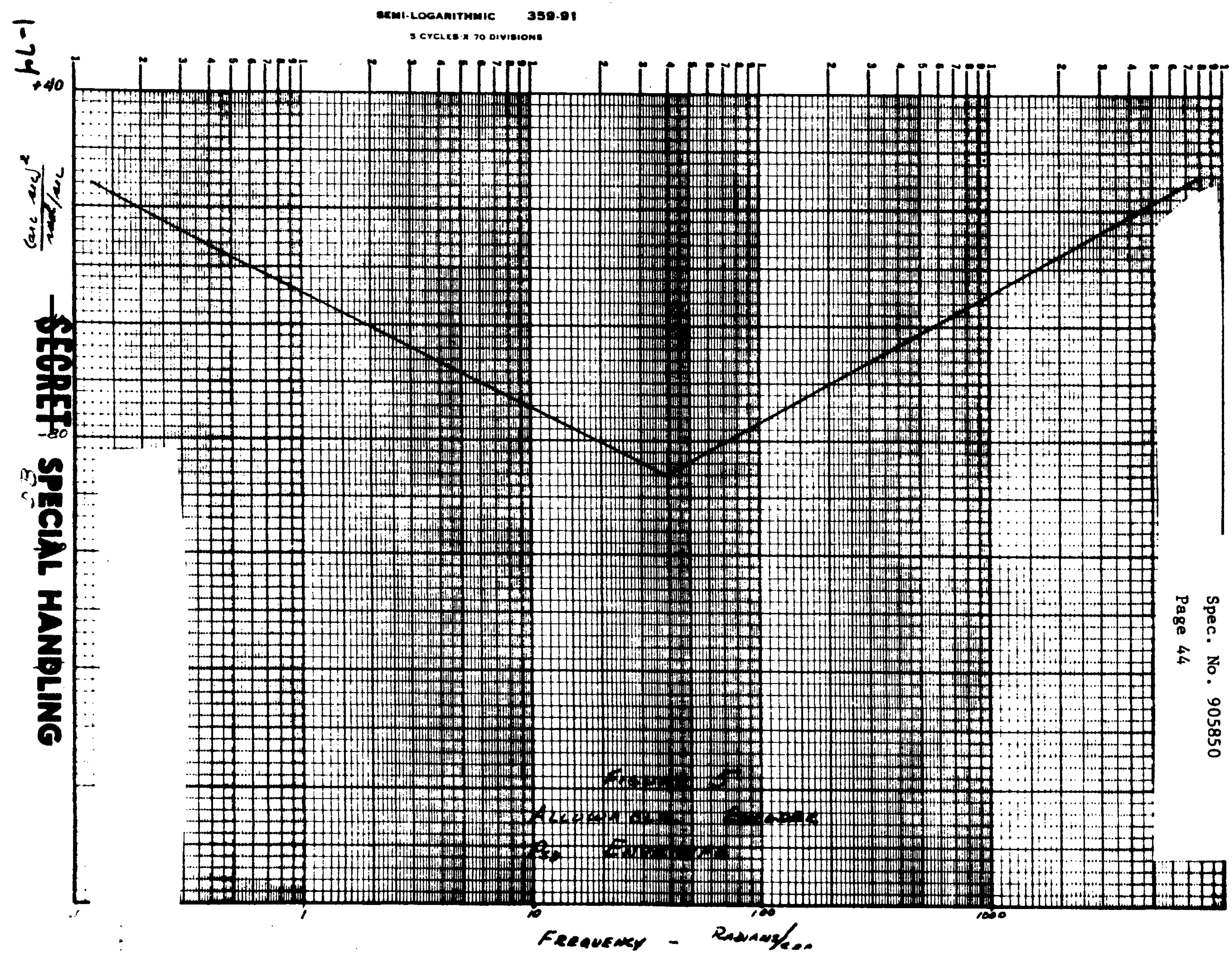

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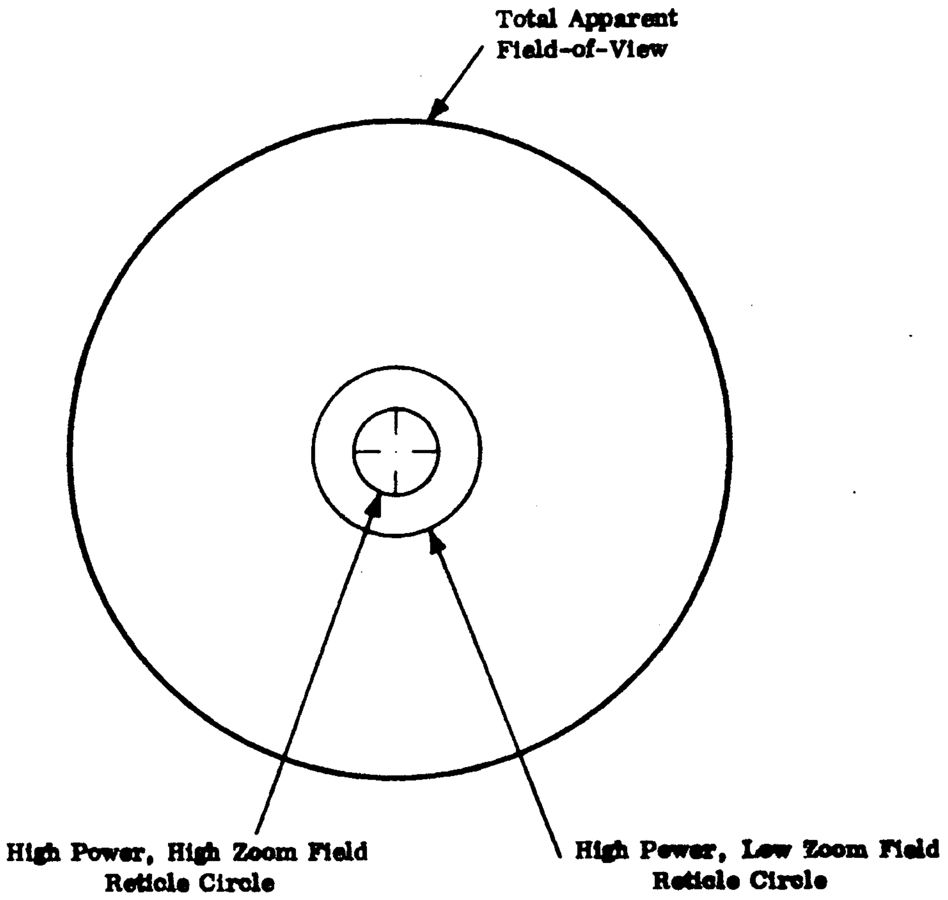
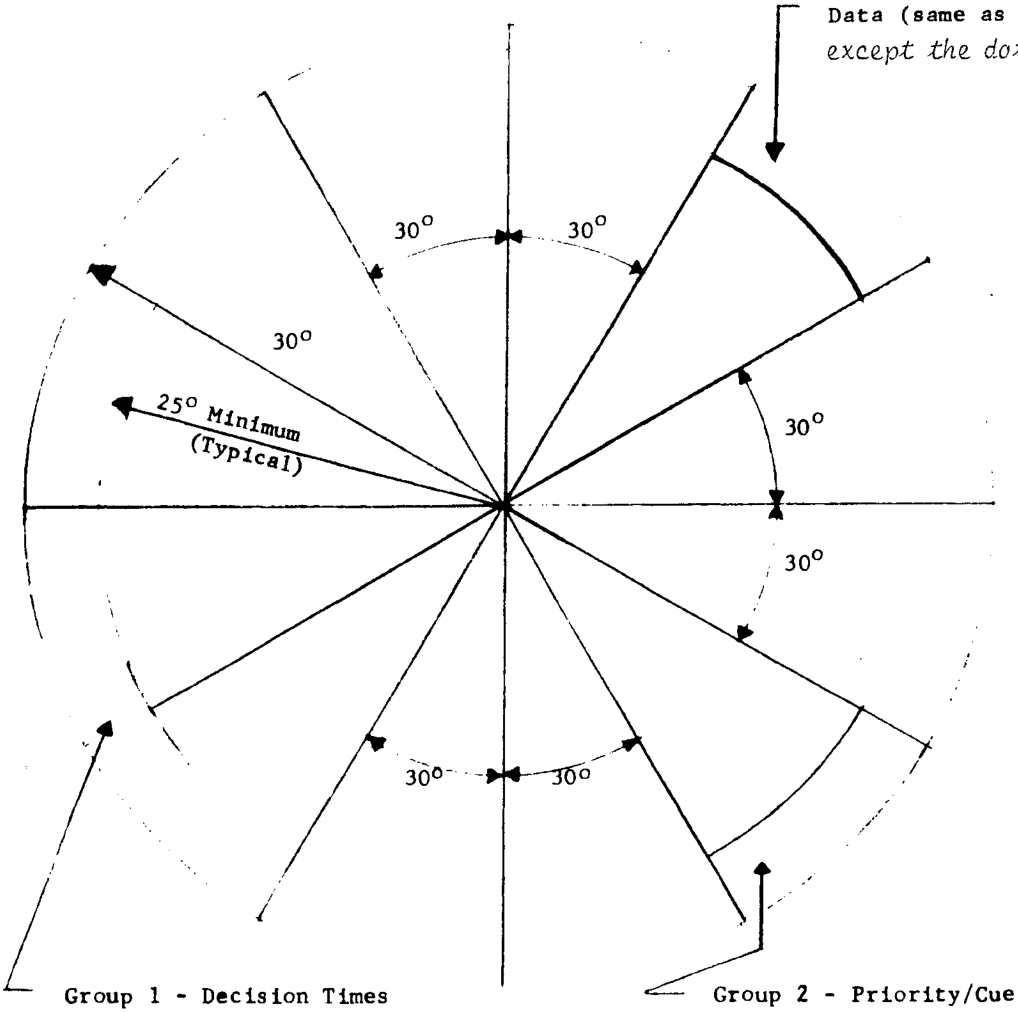


FIGURE 6.

Eyepiece View at Minimum Magnification



Group 3 - Priority/Cue Data (same as group 2 *except the dots are red)* Ⓐ

Group 1 - Decision Times (1 row - 25 equally - spaced dots each row) *Green* Ⓐ

Group 2 - Priority/Cue Data (1 row - 5 equally - spaced dots each row) *Amber* Ⓐ

FIGURE 7 PERIPHERAL DISPLAY PATTERN

FIGURE 8 & 9

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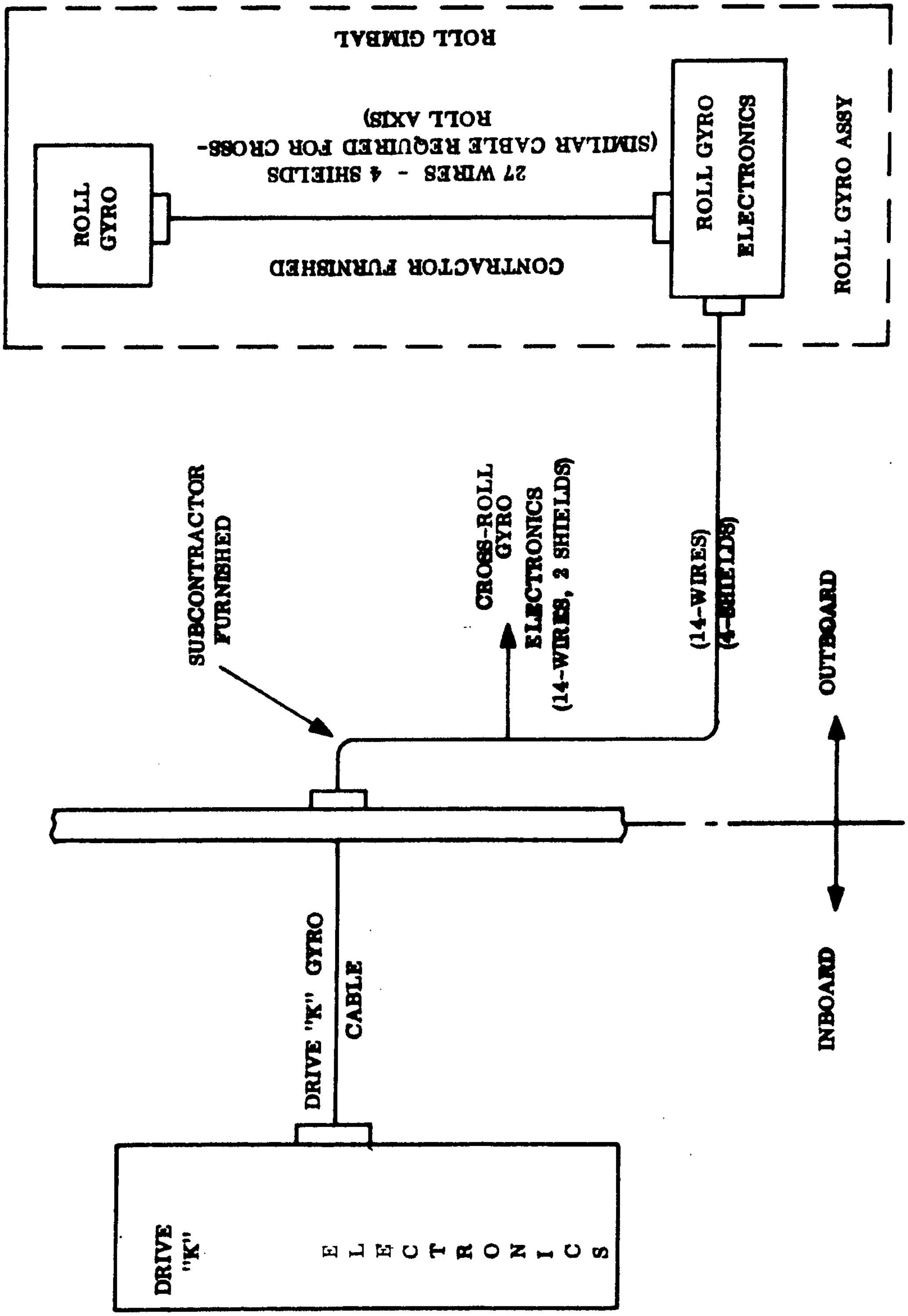

Figure 10. Gyro Interconnection Cabling

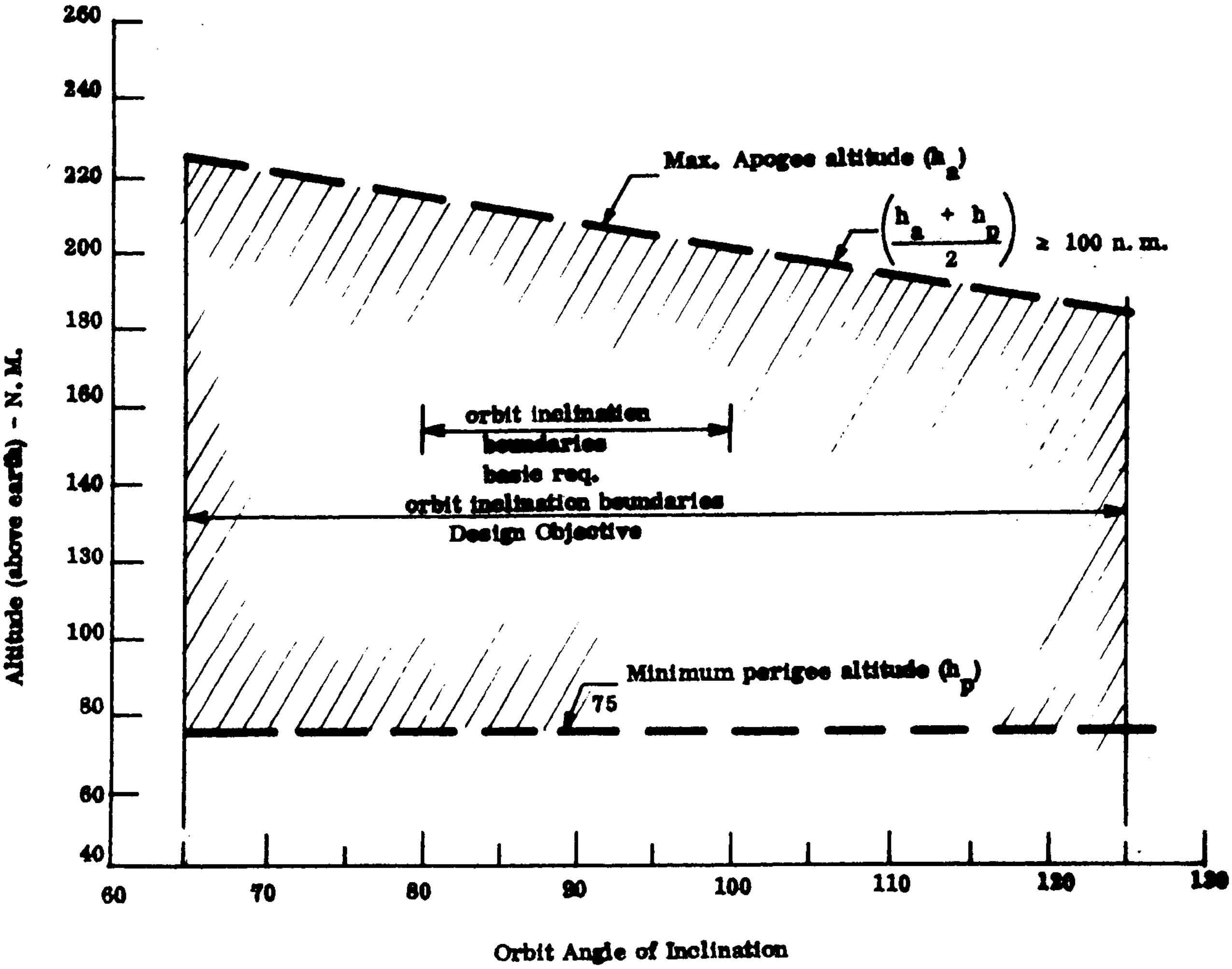

Figure 11. Orbit Parameter Envelope

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FIGURE 12.1 FREE MOLECULAR HEATING CURVES

NOTES: 100 N.M. CIRCULAR ORBIT
TIME=0 OCCURS AT 55°N LATITUDE
ACCOMODATION COEFFICIENT = 0.6

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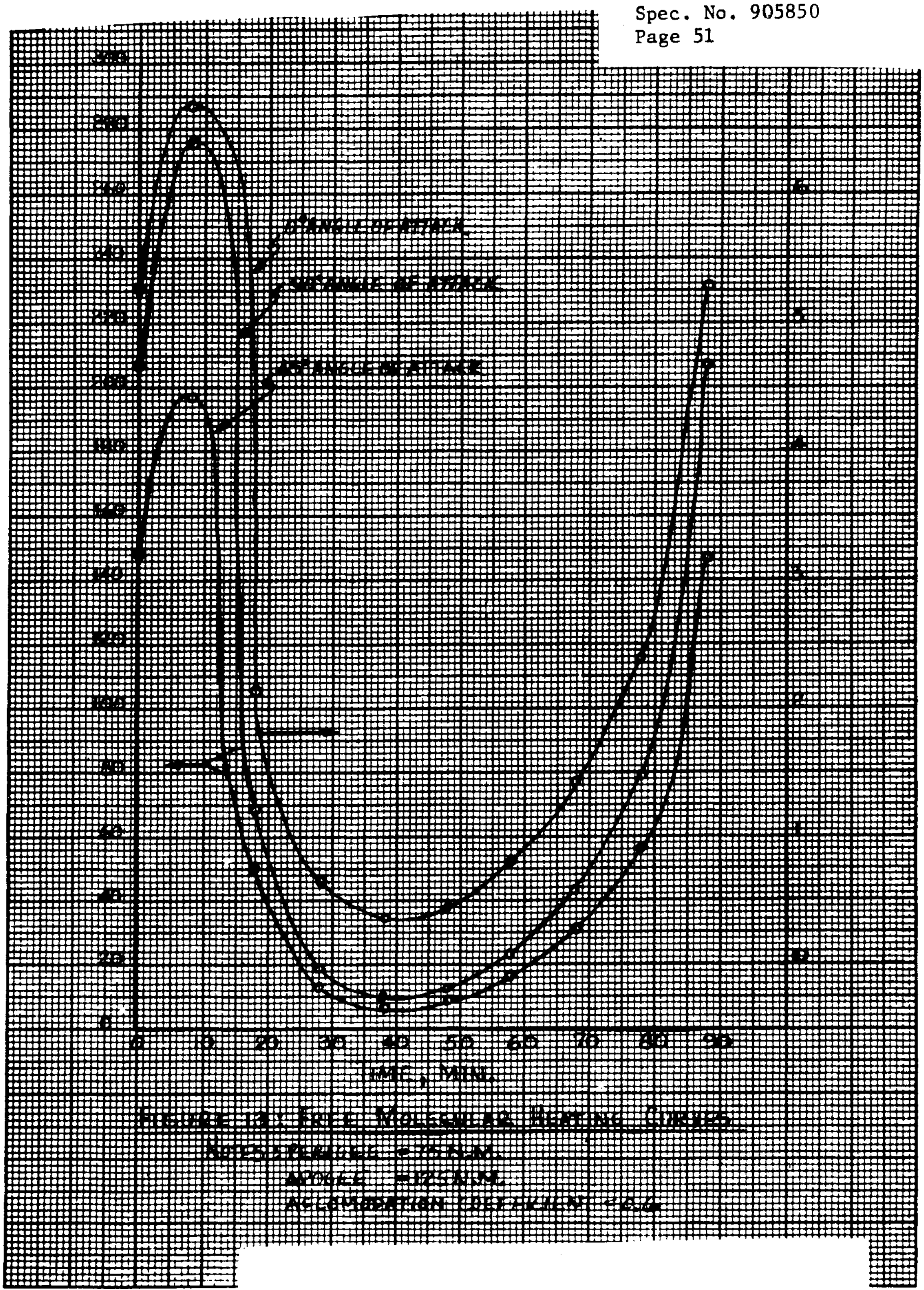

FIGURE 13: FREE MOLECULAR HEATING CURVES

NOTES: PERIGEE = 75 N.M.
APOGEE = 125 N.M.
ACCOMMODATION COEFFICIENT = 0.6

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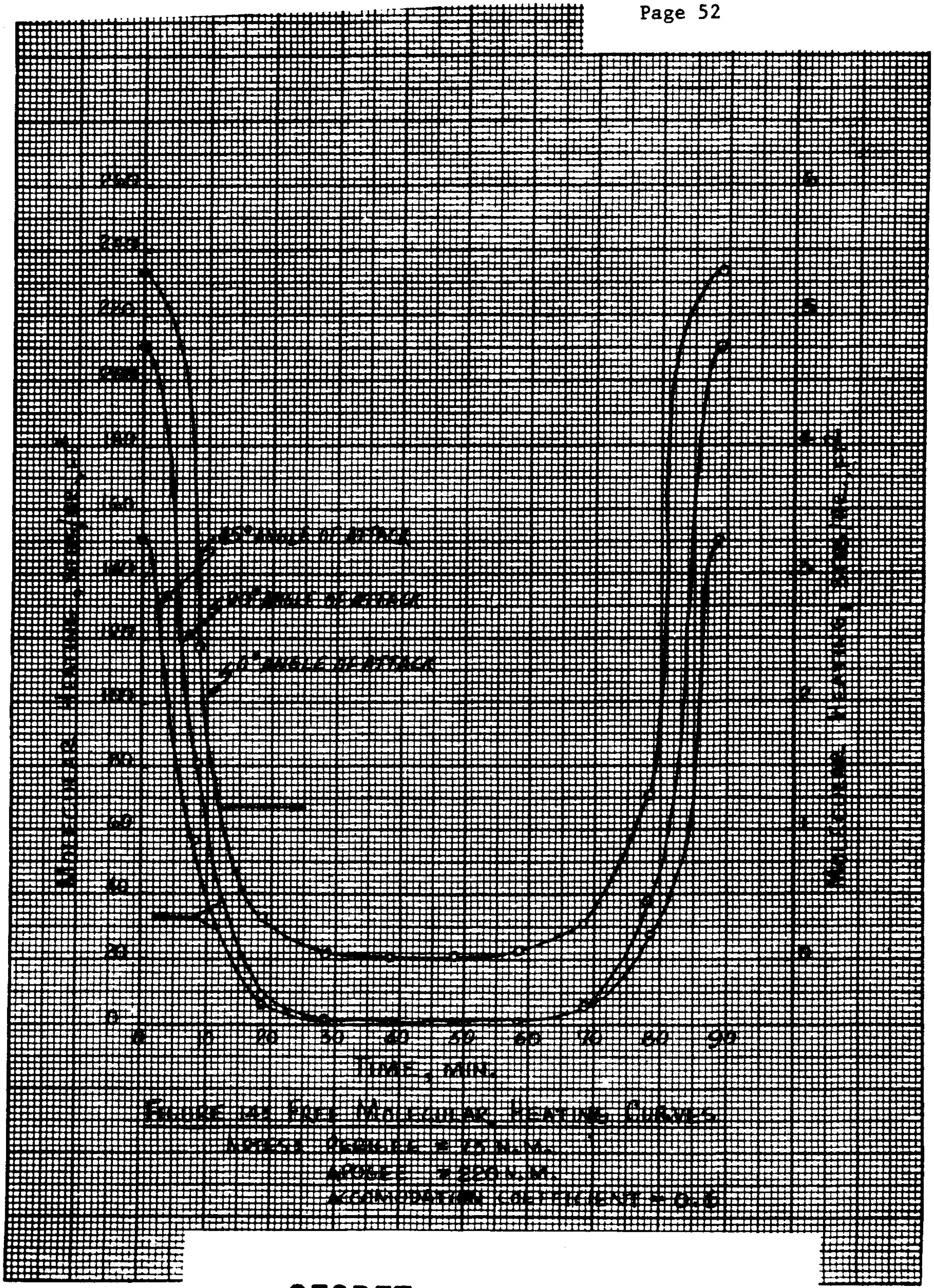

FIGURE 142 FREE MOLECULAR HEATING CURVES
[illegible] PERIGEE = 75 N.M.
APOGEE = 220 N.M.
ACCOMODATION COEFFICIENT = 0.8

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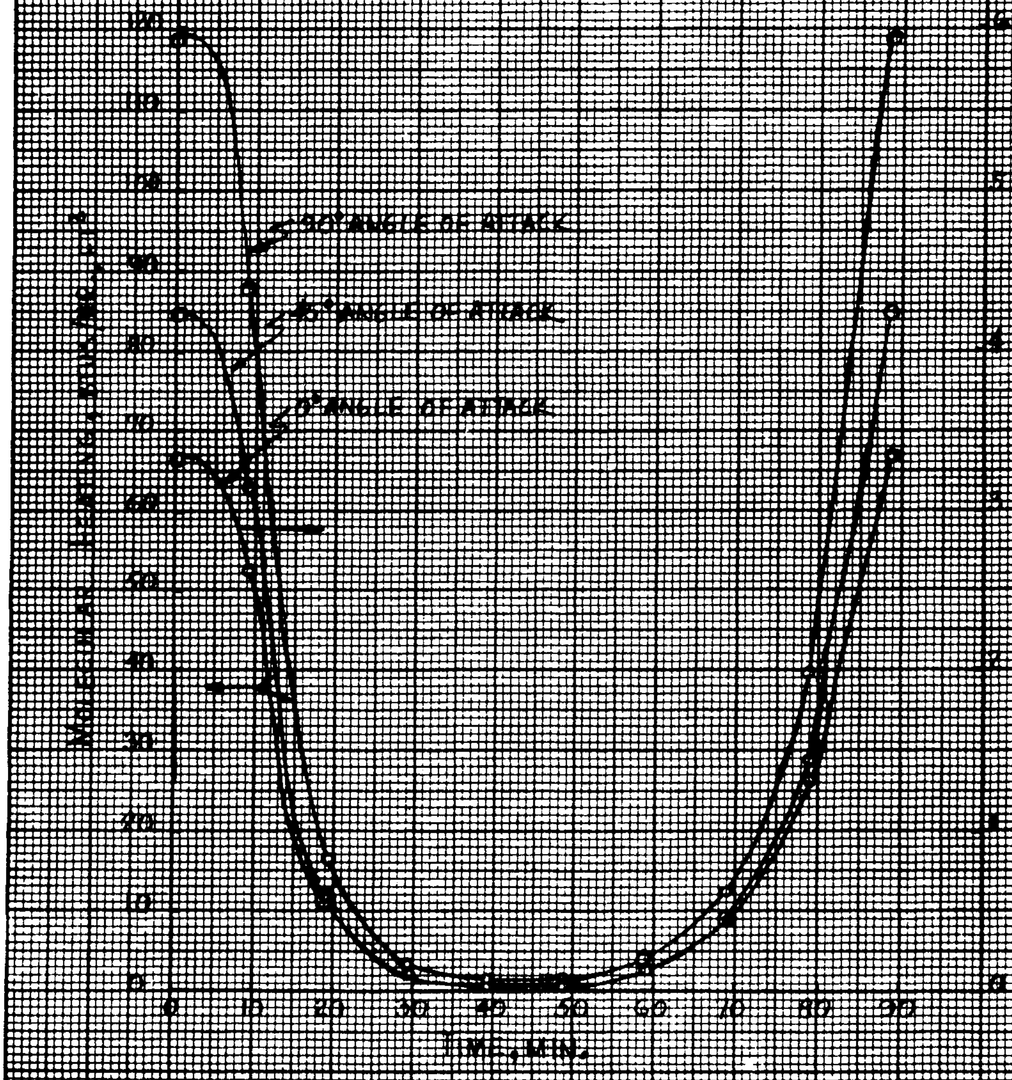

FIGURE 15X FREE MOLECULAR HEATING CURVES

NOTES: 1. PERIGEE = 80 N.M.
APOGEE = 180 N.M.
ACCOMODATION COEFFICIENT = 0.6

Addendum 1.2-B
Human Engineering Specification

1.0 Scope

1.1 This specification establishes the human engineering requirements for the Acquisition Optics (AO) which is a component of the Acquisition and Tracking System (ATS).

2.0 Applicable Documents

2.1 The following documents, of exact issue shown, form a part of this specification to the extent specified herein.

AFSCM 80-3	Handbook of Instructions for Aerospace Personnel Subsystem Design	15 July 1966
MIL-HDBK-141	Optical Design	5 October 1961
EC-331	AO Subsystem Performance/Design and Qualification Requirements	23 December 1966
DIN 3694-200-1 WS 011 B	Acquisition Optics Work Statement	3 January 1967

3.0 Requirements and Applicability

3.1 General

The principles, procedures and criteria of human engineering shall be applied, to the areas specified in 3.1.2, to ensure that adequate consideration is given to the capabilities and limitations of man as a component of the ATS. Within the parameters established by the AO Performance/Design Specification and the AO Work Statement, a human engineering effort will be provided to increase and preserve the effectiveness of the human component during the operation and control of the ATS. The AO design will be adapted to the established capacity and ability of man to produce a more effective system.

3.1.1 Human Engineering Effort

The human engineering effort shall include active participation in the following major interrelated areas of system development.

a. System analysis to identify, define and allocate system operation and control functions

b. Selection, definition, and detail design of equipment associated with the system functions requiring human performance

TITLE
AO HUMAN ENGINEERING SPECIFICATION

Itek ITEK CORPORATION
LEXINGTON, MASSACHUSETTS 02173

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c. Testing and evaluation to verify that the design of the equipment meets human engineering requirements and is compatible with the overall system requirements

d. System reliability evaluation, safety engineering analysis, and design for maintainability.

3.1.2 Areas of Application

The detail design requirements of EC-331 and the imposed location of the eyepiece principally limit the Itek AO human engineering effort to the following:

a. Design of manual backups and controls

b. Human visual interface factors involved in the design of the optical system

c. A limited study to determine human eyeball dynamic resolution for the mission parameters specified in EC-331

d. A sustaining effort to anticipate and identify human engineering problems and advise G.E. accordingly.

3.1.3 Guidance Documents

3.1.3.1 Manual Backups and Controls

The following sections of the indicated documents shall be used as a guide for the design of the manual backups and controls.

a. Section 7 and 10 of MIL-STD-803 A-1

b. Section 7 and 10 of MIL-STD-803 A-3

c. Part B, Chapter 4 of AFSCM 80-3

3.1.3.2 Human Vision

The following sections of the indicated documents shall be used as a guide for optical design and performance evaluation for the AO human visual interface.

a. Part A, Chapter 5 of AFSCM 80-3

b. Section 4 and 15 of MIL-HDBK-141

4.0 Program Implementation Plan

4.1 Manual Backups and Controls

4.1.1 Analysis

Manual backups on AO mechanisms shall be analyzed to ensure efficient, reliable and safe human operation. For each required mechanism, design approaches will be analyzed and compared from a standpoint of: weight, power requirements, reliability, function performance and human engineering considerations. A failure mode analysis of each mechanism will be undertaken as part of this effort. One purpose of this analysis shall be to determine the best trade-off between overall reliability, manual torque requirements, and the selection of where to couple the manual control to the drive train.

4.1.2 Design Criteria

In general, the manual control shall be descriminable both visually and tactually, possess good gripping characteristics, conform to standard of direction movement relationships and be functionally suitable.

4.2 Human Visual Interface

Investigations shall be undertaken to determine human visual interface problems and requirements. These shall be reviewed with G.E. to obtain direction, information and analysis that may be required. Within the parameters established by the system specification, the objective of this effort shall be to provide an optical system consistent with the capabilities and limitations of the user's eye. Performance in excess of that allowed by the AO exit pupil/eyeball combination shall not be required.

4.3 Dynamic Resolution Test

A limited test shall be conducted to determine the affects of image motion and the AO apparent field on the human eye performance for the parameters specified in EC-331. These parameters shall be simulated to a first order level. The results and recommendations from this investigation shall be furnished to G.E. to assist in: defining system performance, establishing image stabilization control requirements, substantiating the need for possible additional tests.

4.4 Organization

4.4.1 Design Implementation

Detail design involving human engineering considerations shall be the responsibility of the project design engineering group and the project optical engineering group.

4.4.2 Systems Engineering

The project systems engineering group participation in the human engineering effort includes the following:

a. Provide requirements and guidance for the design of the manual backups and controls. In this endeavor assistance will be obtained from Itek staff specialists not directly assigned to the project.

b. Maintain liaison with the design engineering group and optical group to ensure inclusion of human engineering criteria in the design process.

c. Advise G.E. on human engineering problems and interfaces for the manual backups and controls. Included in this is the identification of required studies to resolve problems and the estimated effect on the system if the problem is not studied and resolved.

4.4.3 Optical Design

The project optical engineering group participation in the human engineering effort includes the following:

a. Identify problems and establish requirements for the human visual interface.

b. Apprise G.E. of visual interface problems. Included in this is the identification of required studies to resolve problems and the estimated effect on the system if the problem is not studied and resolved.

4.5 Signature Approval of Drawings

Overall layouts, detail design drawings and specifications for the manual controls and the eyepiece design shall be reviewed for human engineering considerations. The signature approval of these documents by design, systems and project management personnel shall verify that the configuration and arrangement of controls and the eyepiece design will satisfy the operator-instrument performance requirements.

4.6 Project Design Reviews

Part of project design reviews conducted by the project management and the staff design review team will include a review of the human engineering requirements of this document and how they are being met.

5.0 Design Verification

5.1 Mock-Ups

The form and external dimensions of all manual controls shall be provided on deliverable mock-ups.

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5.2 Special Deliverable Engineering Pieces

Special engineering pieces of the mechanized components shall possess the required manual controls.

5.3 Qualification Tests

Manual controls will be tested for function as part of the qualification tests for the AO subsystem. Off-axis resolution of the instrument will also be determined as a check on the eyepiece performance in the off-axis region.

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Addendum 1.2-C
Safety Engineering Criteria

1.0 Scope

1.1 This specification establishes the safety engineering requirements for the Acquisition Optics (AO) which is a component of the Acquisition and Tracking System (ATS).

2.0 Applicable Documents

MIL-S-38130A	System Safety Engineering of Systems and Associated Subsystems & Equipment; General Requirements For 6/6/66.
MIL-W-8160D AM1	Wiring, Guided Missile, Installation of, General Specification for 12/24/63.
MIL-E-5400 H	Electronic Equipment, Aircraft, General Specification For 6/1/65.
MIL-STD-195	Marking of Connections for Electronic Assemblies 10/20/55.
MIL-STD-2202C	Test Methods for Electronic and Electrical Component Parts 9/12/65.
EC 331	Performance/Design and Qualification Requirements Optical Assembly 12/29/66.
R1100A	Design, Environmental Criteria and Test Requirements Specification for Components of MDL Mission Payload System Segment - March 1967.
DR 1112	Selected Processes for Use in the Mission Module, General Specification for 4/18/66.
DR 1115	Selected Materials for Use in the Laboratory Module November 1966.

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DP 1690	Specification of EMC Requirements For Equipment and Subsystems MOL 11/11/66.
Doc. No. 114281	AO Human Engineering Specification 6/6/67.
Doc. No. 114218	EMC Design Criteria and Design Requirements 4/12/67

3.0 Requirements and Applicability

3.1 General

The principles, procedures, and criteria of safety engineering shall be applied to the design, development fabrication, test, installation, and checkout of the AO's to eliminate or reduce all equipment operational hazards. The critical nature of the mission requirements imposes a stringent safety requirement to safeguard flight and ground personnel and to avoid the financial impact and program delays resulting from accidents.

Within the parameters established by the AO Performance/Design Specification and the AO Work Statement, a safety engineering program will be undertaken to ensure that:

1. Maximum safety consistent with operational requirements has been designed into the system.
2. Adequate controls over known hazards, inherent to the product, are established to protect personnel, equipment, and property.
3. Minimum risk is involved in the acceptance and use of new materials.
4. Hazards associated with the AO are identified, reported, and eliminated or controlled.
5. The requirements for retrofit actions and the resultant cost to eliminate or control hazards are reduced.

3.2 Gross Hazard Evaluation

The following gross hazard evaluation is based on the requirements of paragraph 3.4 of MIL-S-38130A. Accompanying each hazard is its applicability to the AO design and the means of hazard control or elimination.

3.2.1 Isolation of energy sources. Electrical power requirements are low. Internal voltage requirements do not exceed 33V, external requirements do not exceed 18V. These energy sources will be controlled and isolated by: use of good design practices, use of processes in accordance with DR 1112, use of materials in accordance with DR 1115, installation of wiring in accordance with MIL-W-8160D AM1, workmanship in accordance with MIL-E-5400 paragraph 3.1.1.9 and MIL-STD-195, insulation resistance will be tested per paragraph 4.3.1.2 of DR 1100A.

3.2.2 Fuels and Propellants. Fuel and propellant compatibility is not applicable to the AO since the externally mounted components are shielded by the shroud and fairing.

3.2.3 System Environmental Constraints. The system shall be designed to meet the performance requirements of EC 331 and the environmental requirements of DR 1100A. The ability of the system to meet the environmental requirements, which includes cabin and vehicle compatibility, in a safe manner shall be demonstrated by the environmental tests of DR 1100A.

3.2.4 Explosive devices and their hazard classification. There is a possibility that explosive devices will be used in the external AO assembly. If explosive devices are utilized, they will be analyzed and tested from the following standpoints: (1) Minimum charge to adequately perform function. (2) Reliable means of preventing accidental discharge. (3) Encasement to prevent fragmentation. (4) Ability of support structure and adjacent areas to withstand detonation. (5) The prevention of inadvertent firing of explosive devices is covered by paragraph 3.2.7.

3.2.5 Compatibility of materials. Materials shall be selected for use in accordance with DR 1115 so as to avoid flammable, odor, or toxic hazard.

3.2.6 Human Factors. Manual controls and backups shall be designed and analyzed to meet the requirements of paragraphs 3.1, 3.1.3.1, 4.1.1, and 4.1.2 of Document 114281 to ensure safe reliable human operation. The optical assembly shall include a sun sensor and blanking mechanism to avoid sun viewing. A hazard report shall be submitted to G.E. to cover other possible forms of HI energy radiation that may constitute a safety problem.

3.2.7 Effect of transient current and radio frequency energy. The ability of the system to safely withstand momentary overpotentials shall be demonstrated by meeting the requirements of paragraph 4.3.1.2 of DR 1100A. This paragraph requires the performance of the dielectric strength (Method 301) of MIL-STD-202 as an acceptance test. The proper gas atmosphere for the performance of this test shall be investigated Radio frequency energy shall be controlled and limited by meeting the requirements of DP 1690 and Document 114218. The prevention of inadvertent firing of pyro circuits is covered by paragraph 3.8.5 of Document 114218. The sun sensor shall meet the requirements of paragraph 3.1.1.1.23 of EC 331. The possibility of radio frequency blocking of sun sensor actuation shall be investigated. If required necessary, safeguards to prevent blocking shall be incorporated into the circuit and tested for effectiveness. Electrical components such as motors, switches, relays, etc. used in the equipment shall be hazard free. Particular attention shall be given to eliminating any sources or contributors to flammability.

3.2.8 Pressures seal backup. The pressure integrity of the telescope shall meet the requirements of paragraph 3.1.1.1.19 of EC 331.

3.2.9 Structural Integrity. The structural integrity of the AO shall be demonstrated by meeting the acceptance and qualification tests of DR 1100A.

3.2.10 Documentation and Training. Training programs associated instructional material, and other manuals shall include proper procedural action for safe operating, handling, maintenance, and installation of the AO.

3.3 Safety Procedures and Controls

3.3.1 Controls and checks shall be established so that inherent design safety is not inadvertently degraded by assembly errors, improper test procedures, inadequate maintenance practices, or careless handling during transportation.

3.3.2 Training programs and instructional material will include coverage of proper procedural action for safe operating handling, maintenance, and installation of the AO.

4.0 Program Implementation Plan

4.1 Hazard Reports

Itek shall prepare a hazard report per G.E.-MOL-S-128, for submission to G.E. whenever a hazard is recognized regarding the use or application of the AO. Hazard reports shall describe the hazard, alternative solutions, recommended solution and action planned to eliminate or reduce the hazard. Itek shall submit a report upon identification of each hazard or potential hazard and another report showing final disposition of the problem. The report showing final disposition shall describe action actually taken or problem solution such as safety devices, design improvements, warning devices, and special procedures.

4.2 Safety Engineering Reviews

Project design reviews and TD meetings will include a review of the safety engineering requirements of this document and how they are being met.

4.3 Approximately two weeks prior to PDR a safety engineering conformance review shall be conducted. The purpose of this review shall be to ensure that the requirements of this document are being met.

4.4 Signature Approval of Documents,Layouts, Assembly Drawings, Detail Design Drawings shall be reviewed for safety engineering consideration. The signature approval of these documents by design, systems, and project management personnel shall verify the design meets the requirements of this document.

4.5 Quality Control Responsibility

Part of the project Q.C. function shall be exercise of proper controls so that inherent design safety is not inadvertently degraded by assembly errors, improper test procedures or careless handling.

4.6 Design Responsibility

Detail design involving safety engineering considerations shall be the responsibility of the project design engineering group, the project reliability group, and the project optical engineering group. Prime responsibility for safety eingineering implementation resides with these groups. Safety evaluations are to be incorporated into the detail design process early enough in the design cycle so that possible changes can be accomplished easily and economically. Emphasis is to be placed on preventive design rather than after-the-fact corrective or supportive role. The safety evaluations performed should be systematic in nature, quantitative in character, compatible with other design trade-offs and system evaluation functions.

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4.7 System Engineering Responsibility

The project engineering group participation in the safety engineering effort includes the following:

a) Maintain liaison with the design engineering group and the optical engineering group to ensure inclusion of safety engineering criteria in the design process.

b) Identify and analyze AO hazardous failure modes and possible improper procedural action by operating personnel.

c) Participate in any required trade-off studies where safety requirements are involved.

d) Prepare and submit hazard reports as required by GE-MOL-S-128.

4.8 Nonconforming Parts

When for compelling reasons a nonconforming part is considered for acceptance under established MRB procedures, the part shall be rejected if the nonconformance in any way degrades inherent safety.

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Addendum 1.2-D

Maintainability Program

Requirements

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OUTLINE OF PROPOSED MAINTAINABILITY PROGRAM

Prepared by
J. J. Boh
9-1-67

MIL-STD-470 Requirements	Para. #	Applicability	Implementation
1. Prepare Maintainability Program Plan	5.1	Yes	To be performed using MIL-STD-470 as a guide. The following sections of this tabulation list all of the requirements of MIL-STD-470. Accompanying each requirement is a statement of its applicability and implementation.
2. Perform Maintainability Analysis	5.2	Yes	1. Reliability to determine useful life of components. 2. Components that possess insufficient useful life shall be derated or redesignated. If this is not possible the design will ensure ease of replacement. 3. Identify components that are vulnerable to inadvertent damage. If avoidance of this condition is not possible, ensure that the design allows ease of replacement. 4. Determine that replacement under 2 & 3 is practical from a standpoint of methods, personnel and facility requirements. No operational maintenance shall be required.
3. Prepare Inputs to the Detailed Maintenance Plan	5.3	Yes	Utilize the information obtained under 2 to prepare a written plan stating methods and frequency of required preventative maintainance and methods for corrective maintainance. Information to be also utilized for equipment manuals. System Engineering Responsibility

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OUTLINE ( ) PROPOSED MAINTAINABILITY PROGRAM (cont.)

MIL-STD-4[illegible] Requirements	Para. #	Applicability	Implementation
4. **Establish Maintainability Design Criteria**	5.4	Yes	Establish general requirements for all aspects of the desig by referencing MIL Hdbks and similar guides. Rigid specifi requirements will be established for components possessing insufficient or marginal useful life. •System Engineering Responsibility
5. **Perform Design Trade-Offs**	5.5	Yes	Systems Engineering Participation in Design Reviews and day to day monitoring of design effort.
6. **Predict Maintainability Parameter Values**	5.6	No	Design features requiring corrective action shall be identified under 2, 3, 4, and 5. Effectiveness of the Maintainability will be ensured by simplicity in implementation.
7. Incorporate and Enforce Maintainability Requirements in Subcontractor and Vendor Specifications	5.7	Yes	Procurement Specifications will be reviewed by systems and Reliability Engineering and QA for maintainability consider tions.

OUTLINE OF PROPOSED MAINTAINABILITY (cont.)

MIL-STD-470 Requirements	Para. #	Applicability	Implementation
8. Integrate Other Items	5.8	Yes	This requirement refers to G.F.E., C.F.E., etc. The C.F.E. gyro assembly will be included.
9. Participate in Design Reviews	5.9	Yes	Systems and Reliability Engineering will participate in all design reviews.
10. Establish Data Collection, Analysis, and Corrective Action System	5.10	Limited	Notes and information will be kept in engineering notebooks consistent with good engineering practice.
11. Demonstrate Achievement of Maintainability Requirements	5.11	No	Not a contract requirement. Therefore, no formal demonstration is planned. Requirements in this area can be met by drawing review and inspection of the equipment.
12. Prepare Maintainability Status Report	5.12	No	Maintainability will be kept current with the design and reported on as required at scheduled TD meetings.

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INTEROFFICE MEMORANDUM

Addendum 1.2-E

Date: 18 Sept. 67

Page 1 of 2 Pages

To: J. Boh   Facility: Burl. #11   349-67-492

From: H. Simmons   Facility: Burl. #11

~~Subject~~: TEMPERATURE SENSORS FOR TELEMETRY

In order to provide temperature monitoring of critical AO components, temperature sensors will be required for each telescope. Preliminary locations and quantities are listed below. The locations are subject to change pending further analysis. Also, if heater control units are necessary, additional temperature sensors will be required.

The type of sensor desired is the bonded KP Series resistance thermometer made by RdF Corporation (or equivalent). The carrier material for the sensor grid is mica and the resistance wire is CP platinum. This resistance thermometer has a wide range (-300 to 1000°F), high sensitivity, very good stability, very good repeatability, very good response, and a high signal output. Each sensor requires two lead wires capable of delivering approximately 2 to 10 MV to resistance varying between 50 and 200 ohms.

One major reason for choosing this type of sensor is because they lend themselves to the printed circuit lead cable being considered on the scanner assembly.

TEMPERATURE SENSOR LOCATION	TYPE	QTY.
1. Outside, leading edge of shroud	Bonded Resistance Thermometer	1
2. Inside on skin, leading edge of shroud.	"	1
3. Inside insulation, leading edge of shroud	"	1
4. Inside skin of shroud door	"	1
5. Housing of scanner roll torque motor	"	1
6. Housing of scanner pitch torque motor	"	1
7. Housing of roll axis encoder	"	1
8. Housing of pitch axis encoder	"	1
9. On scan mirror bezel (one near gyro mounting pads)	"	2

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TEMPERATURE SENSOR LOCATION	TYPE	QTY.
10. On rear surface of scan mirror	Bonded Resistance Thermometer	2
11. On exterior fixed fold mirror bezel	"	1
12. On rear surface of fixed fold mirror	"	1
13. Inside housing of shroud door drive motor	"	1
14. On radiator skin in shroud area	"	1
15. Zoom drive motor area	"	1
16. Derotation drive motor area	"	1
17. Inside telescope tube near objective elements	"	1
18. Inner surface of telescope near peripheral display	"	1
19. Inside telescope near Pechan prism	"	1
20. On penetration fitting	"	1
	TOTAL sensors per telescope	22

HS/mmm

Harry Simmons
H. Simmons

c.c.
A. Aube
J. Berenholz
M. Berkowitz
D. Bott
D. Breslow
P. Clifford
R. Heath
G. Lenertz
E. Powers
R. Rosenthal

Dist.
App'd P. Clifford
P. Clifford

2.0 Compatibility of the AO with other equipment.

2.1 Interface Status. The primary method of establishing and controlling interface compatibility is through the generation and subsequent revision of Interface Control Drawings (ICD).

On Sept. 15, 1967 the Itek Project manager notified the GE subcontracts manager that in the absence of acceptable ICD's, the PDR report would be submitted on the basis that our present design is compatible with all interface requirements. Therefore, only a brief summary of interface status is given rather than the usual item by item compatibility determination. (see 9300-67-283)

To improve the generation and formal documentation of interface information Itek has proposed a series of semi-monthly working group meetings. It was further suggested that detailed agenda be prepared for these meetings and that each meeting be confined to one or a small group of subjects in order to maximize the effectiveness of the participants. The meetings should commence immediately. (see 9300-67-272)

2.2 Space Allocation Compatibility

Preliminary ICD 711-03005 was reviewed on Sept. 13th by Itek and GE personnel. At this time Itek reiterated certain required changes. These changes consist principally of: 1) shroud door definition, 2) modifications in the window area, and 3) shear mount definition. Further effort is required to update this drawing to an acceptable level.

2.3 Mechanical ICD

Preliminary ICD 711-03038 was reviewed by Itek and GE personnel on Sept. 13. Further effort is required to update this drawing to an acceptable level.

2.4 CFE ICD

No preliminary ICD has been received.

2.5 Electrical ICD

On September 7, 1967 a preliminary copy of a rough draft of the electrical ICD was reviewed. This document, GE number DIN 50029-80-2, is being revised by G.E. to include:

1) Identification of all required data
2) Use of standard notations and symbols

3) Specification of required data

4) Proper format

No date has been set for completion of this ICD.

2.6 Recommended ICD Items

To fulfill the intent and purpose of the ICD the following items have been suggested to GE for inclusion in ICD's.

MECHANICAL ICD

1.0 MOUNTING INTERFACE

1.1 Scanner Assembly

1.1.1 Vehicle coordinates of three mounting points

1.1.2 Physical description of mating interface surfaces

1.1.3 Tolerances of scanner mount point locations (vehicle coordinates)

1.1.4 Flexibility influence coefficients

1.1.5 Alignment adjustment required

1.1.6 Thermal properties of mounting fittings

1.1.7 Definition of fasteners and responsibility assignment

1.1.8 Electrical bonding requirements

1.1.9 Deflection limits of the three mounting points

1.2 Fold Mirror Assembly

1.2.1 Vehicle coordinates of three mounting points

1.2.2 Physical description of mating interface surfaces

1.2.3 Tolerances of three mount point locations (vehicle coordinates)

1.2.4 Flexibility influence coefficients

1.2.5 Alignment adjustment required

1.2.6 Thermal properties for mounts

1.2.7 Definition of fasteners and responsibility assignment

1.2.8 Electrical bonding requirements

1.2.9 Deflection limits of three mounting points

1.3 Window

1.3.1 Location with respect to telescope objective end mounting interface

1.3.2 Perpendicularity and concentricity with respect to telescope optical axis

1.3.4 Maximum wavefront deformation

2.3.4.1 Unmounted

2.3.4.2 Mounted

1.3.5 Thickness, diameter and material

1.4 Shroud

1.4.1 Physical description of mating interface surfaces

1.4.1.1 Size and shape including flatness

1.4.1.2 Finish

1.4.1.3 Material

1.4.1.4 Thermal properties

1.4.1.5 Deflection envelope with respect to pressure shell

1.4.2 Description of interface fasteners

1.4.2.1 Responsibility

1.4.2.2 Location and tolerance on location

1.4.2.3 Deflection limits with respect to each other

1.4.2.4 Fastener loads

1.4.3 Electrical bonding requirements

1.5 Telescope

1.5.1 Objective End

1.5.1.1 Mounting location, shape, and dimensions

1.5.1.2 Physical description of mating interface surfaces

1.5.1.3 Tolerances on mounting

1.5.1.4 Bolt pattern definition, pattern, size, threads, etc.

1.5.1.5 Flexibility Influence Coefficients

1.5.21 Shear Mount

1.5.2.1 Mounting Pad Location, shape and dimensions

1.5.2.2 Physical description of mating interface surfaces

1.5.2.3 Tolerances on mounting pad

1.5.2.4 Tolerances with respect to objective end mount

1.5.2.5 Mount definition - bolt size, clearance, threads, etc.

1.5.2.6 Flexibility Influence coefficients

1.5.2.7 Alignment provisions

2.0 MASS PROPERTIES

2.1 Scanner Assembly

2.1.1 Weight

2.1.2 C.G.

2.2 Fold Mirror Assembly

2.2.1 Weight

2.2.2 C.G.

2.3 Window Weight

2.4 Shroud

2.4.1 Weight

2.4.2 C.G.

2.5 Gimbal Pitch and roll inertias

- 2.6 Telescope
  - 2.6.1 Weight
  - 2.6.2 C.G.
  - 2.6.3 Moments of inertia
- 3.0 CABLING AND CONNECTORS
  - 3.1 Penetration connectors
    - 3.1.1 Location
    - 3.1.2 Shell Size
    - 3.1.3 Orientation
    - 3.1.4 Mating capability
  - 3.2 External Cable Harness
    - 3.2.1 Routing on radiator
    - 3.2.2 Fasteners to radiator
  - 3.3 Telescope connectors
    - 3.3.1 Type of Connectors
    - 3.3.2 Location of Connectors
    - 3.3.3 Orientation of Connectors
    - 3.3.4 Mating Capability
- 4.0 MANUAL BACKUP DEFINITION
  - 4.1 Changer Mechanism
    - 4.1.1 Configuration
    - 4.1.2 Location
    - 4.1.3 Motion and Forces required

4.2 Blanking Mechanism

- 4.2.1 Configuration
- 4.2.2 Location
- 4.2.3 Motion and Force Required

4.3 Rotation Mechanism

- 4.3.1 Configuration
- 4.3.2 Location
- 4.3.3 Motion and Force Required

4.4 Zoom Mechanism

- 4.4.1 Configuration
- 4.4.2 Location
- 4.4.3 Motion and Force Required

5.0 GIMBAL ALIGNMENT

5.1 Definition of alignment references per paragraph 3.1.1.2.1 of EC331B

5.2 Encoder

6.0 INTERFACE WITH CUE PROJECTOR

6.1 Required opening in elbow structure

6.2 Alignment of cue mirror to cue projector

6.3 Optical parameters of projected image

7.0 THERMAL

7.1 External temperature history of the thermal insulation mounted to the radiator beneath the shroud

7.2 Internal temperature history of the fairing from pre-launch through powered flight

7.3 Penetration Fitting

- 7.3.1 Window Temperature Control Requirements

7.3.2 Fold Mirror Temperatures Control Requirements

7.3.3 Penetration Fitting Heater definition

7.4 Thermal Map of Bays 2 & 8

7.5 Thermal Map of Bays 3 & 7

7.6 Temperature history of penetration fitting around telescope objective end.

8.0 CLEANLINESS AND SEALING REQUIREMENTS

8.1 The fairing shall prevent contamination or degradation of the protective shroud thermal control surfaces.

8.2 All penetrations of the radiator beneath the shroud shall be sealed by the vehicle contractor to prevent contamination of the AO external hardware.

SPACE ALLOCATION ICD

1.0 EXTERNAL SPACE ENVELOPE

- 1.1 Radiator configuration
  - 1.1.1 Bead pattern reference to vehicle coordinates
  - 1.1.2 Bead pattern elimination for scanner clearance
  - 1.1.3 Radiator and Ramp configuration at LM/MM interface
  - 1.1.4 Shroud footprint to define surface blockage
- 1.2 Launch Configuration
  - 1.2.1 Space allocation under aerodynamic fairing including allowances for radiator movements during ascent
  - 1.2.2 Space restrictions due to aerodynamic fairing separation devices
  - 1.2.3 Ascent Venting
- 1.3 Stowed Configuration (On-orbit)
  - 1.3.1 Space allocation including allowances for radiator movements for mission duration.
  - 1.3.2 Restrictions due to proximity of other LM subsystems; e.g., viewport, waste management port, horizon scanner.
- 1.4 Operational configuration (on-orbit)
  - 1.4.1 Space allocation including allowances for radiator movements, door operation and scanner operation for any LOS position.
  - 1.4.2 Restrictions due to proximity of other LM subsystems such as the horizon scanner
  - 1.4.3 Interferences with ATS line of sight
  - 1.4.4 Sun Angle Restrictions

2.0 INTERNAL SPACE ENVELOPE

Referenced to vehicle axes radially and station numbers longitudinally

- 2.1 Normal operational space envelope

2.2 Space Envelope for Manual Backup Operation

2.3 Field Break Definition

2.4 Panel Clearance

[redacted]

C.F.E. ICD

1.0 MECHANICAL

- 1.1 Gyro
  - 1.1.1 Outline drawing including connector location
  - 1.1.2 Weight, C.G. and inertias
  - 1.1.3 Mounting points and tolerances
  - 1.1.4 Physical description of mounting interface
  - 1.1.5 Input axis to output signal transfer function
- 1.2 Gyro Electronics Package
  - 1.2.1 Outline drawing including connector locations
  - 1.2.2 Weight, C.G. and inertias
  - 1.2.3 Mounting points and tolerances
  - 1.2.4 Physical description of mounting interface
  - 1.2.5 Interface connector type and orientation
- 1.3 Interconnecting Cable
  - 1.3.1 3-D shape and size
  - 1.3.2 Weight, C.G. & inertias
  - 1.3.3 Support Requirements

2.0 THERMAL

- 2.1 Gyro
- 2.2 Electronics

3.0 CABLE SPACE ALLOCATIONS

- 3.1 Pitch interconnecting cable
- 3.2 Roll interconnecting cable
- 3.3 Test Cable

3.0 Selected Design Approach/ Integrity

3.1 Error Budgets

3.1.1 Introduction

The performance of the telescope depends upon many factors. In order to control these factors, analysis has shown that the following error budgets are required:

a. Fabrication and alignment error budget: establishes the mechanical, structural and thermal effects on optical element fabrication and alignment which disturb the aberration balance in the optical design of the telescope.

b. Pointing Error Budget: analyzes those factors which will cause the telescope to be aimed inaccurately.

c. Focus Error Budget: analyzes those factors which will cause defocusing of the telescope image.

3.1.2 Error Budget Status

The fabrication and alignment error budget is partially completed. The fabrication and alignment tolerance sensitivities for each optical element are stated in Section 3.6.5 Figures 2, 5 and 6. These sensitivities must now be related to the structural, mechanical, and thermal tolerances which will govern the design, fabrication, installation, and use of the telescope. The completed portion of this analysis has developed the optical sensitivities of the elements related only to the optical design and performance considerations. The remainder of the analysis, yet to be done, will transform optical tolerances to thermal, mechanical, and structural tolerances which are needed for the overall system design of the Acquisition Optics.

The pointing and focus error budgets have not been formally promulgated. However, some of the factors which will be part of these budgets have been investigated such as defocus during zoom and magnification change (Section 3. 6), defocus due to slant range change (Section 3. 5. 4), and alignment techniques for reducing the pointing error (Section 3. 5. 4). The formal issue of these budgets will be forthcoming in the near future.

3.2 Mass Properties

3.2.1 Weight

The weight comparisons shown below and on the following tables are based on data relating to spec. EC 331 in one column and spec. 905850 in the other. The listing under spec. EC 331 is based on the design approach Itek used to establish the original weight budget of 153 lbs. The other column corresponds to calculated and actual data of the most current layouts, details, catalogs, vendor supplied parts and particular selected materials.

WEIGHT SUMMARY

ITEM DESCRIPTION	SPEC. EC 331 WEIGHT LBS.	SPEC. 905850 WEIGHT LBS.
Telescope Assembly	70.75	81.00
Window - Glass only	4.00	4.25
External Fold Mirror Assembly	14.75	15.25
Sun Sensor	.50	1.00
Tracking Pedestal Assembly	61.00	57.00
Shroud Assembly	2.00	23.50
Total for One AO Subsystem	153.00	182.00
	X 2	X 2
Total for Two AO Subsystems	306.00	364.00
Total Weight Budgeted	306.00	Not established

"Note" If gimbal inertias are to be met per specification, additional trim weights totaling 33 lbs., (16.50 lbs. each "AO" Subsystem) are tentatively required. The Spec. 905850 should then be 198.5 X 2 = 397 lbs. total. The graph and tables in section 3.2.2 show pitch and roll gimbal inertias relating to the present design.

3.2.2 Gimbal Inertias

3.2.2.1 Pitch Axis Inertia

The present preliminary design configuration has a pitch axis mass moment of inertia of 0.054 slug-ft^2. The specified requirement for this inertia is 0.08 slug-ft^2 minimum. To meet this specified inertia would require the addition of approximately 2.0 pounds of trim weight.

3.2.2.1 Roll Axis Inertia

The roll axis mass moment of inertia is a function of pitch gimbal angle. The variation of roll inertia with pitch is presented in Figure 3.2.2-1. This figure shows that the present minimum weight design is considerably below the specified minimum inertia and that 16.50 pounds of trim weights would be required to meet this requirement.

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BY ______
CHKD BY ______
REVISED ______

Itek
ITEK CORPORATION
LEXINGTON 73, MASSACHUSETTS

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REPORT NO. ______
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UNIT SERIAL NO. ______

TELESCOPE ASSEMBLY	SPEC EC 331B (153 LBS)		SPEC 905850		REMARKS
	MATL	WGT LBS	MATL	WGT LBS	
OBJECTIVE END					
HOUSING	AL	7.07	AL	8.11	
CELL	AL	1.74	BE	1.01	
ELEMENT #1	GLASS	8.00	GLASS	[illegible]	
ELEMENT #2	GLASS	9.50	GLASS	7.91	
RETAINING RING EL. #1	—	NONE	AL	.11	
RETAINING RING EL #2	BRASS	.33	AL	.20	
SPACER	BRASS	.17	AL	.33	
RETAINING RING - CELL	ST	.45	AL	.19	
RETAINING RING - HOUSING	ST	.83	—	NONE	
TOTAL		24.[illegible]		28.32	
[illegible] POWER GROUP					
HOUSING	AL	4.94	AL	6.80	
TILT SERVO MECH	* ---	6.00	* ---	6.25	
ELEMENT #3	GLASS	.27	GLASS	.43	
ELEMENT #4	GLASS	.19	GLASS	.21	
CELL 1ST L.P.	BE	.27	BE	.15	
RING - SPACER & PIVOT "			AL	.11	
MOUNT CELL	AL	.42	AL	.93	
LENS PIVOT ASSEM	—	NONE	AL	.92	
CELL LOCK DEVICE	* ---	1.00	* ---	.50	
ELEMENT #5	GLASS	.26	GLASS	.41	
ELEMENT #6	GLASS	.90	GLASS	.91	
ELEMENT #7	GLASS	.54	GLASS	.66	
CELL 2ND L.P.	BE	.45	BE	.22	
RING - SPACER & PIVOT " "			AL	.15	
MOUNT CELL	AL	.70	AL	.47	
LENS PIVOT ASSEM	—	NONE	AL	.42	
CELL LOCK DEVICE	* ---	1.00	* ---	.50	
APERATURE STOP - FIXED	AL	.24	AL	.30	
APERATURE STOP - MOVABLE	AL	.17	AL	.12	
STOP PIVOT ASSEM	AL	.24	AL	.47	
SHAFT - LEVER CONNECTING	—	NONE	ST	.34	
DESIGNATOR ASSEM.	*	.50	* ---	.25	
TOTAL		15.12		21.12	

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PROJECT NO.
UNIT SERIAL NO.

TELESCOPE ASSEM. CONT'D.	SPEC EC 331B (152 LBS)		SPEC 105450		
	MAT'L	WGT LBS	MAT'L	WGT LBS	REMARKS
TRANSITION ASSEMB (ELBOW)					
HOUSING	AL	4.97	AL	3.86	
FOLD MIRROR ASSEM.	GL & BE	.51	GL & BE	1.07	
BEARING ASSEM.		NONE	* ---	.84	
CUE MIRROR ASSEM	* ---	2.23	* ---	1.63	
TOTAL		7.71		7.4	
PECHAN ASSEMBLY					
HOUSING	AL	.93	AL	1.92	
MOUNT - BEARING OUTER	AL	.34	AL	.43	
RETAINING RINGS - BRG	AL	.06	AL	[illegible]	
BEARINGS	ST	.54	ST	.97	
RING GEAR	AL	.15	AL	.12	
PRISM - ELEMENT #8	GLASS	1.13	GLASS	1.53	
MOUNT PRISM.	AL	53	AL	.58	
HOLDER PRISM	AL	.15	AL	.21	
MOUNT FIELD EL	—	NONE	AL	1.22	
ELEMENT #7		NONE	GLASS	[illegible]	
DRIVE MECH. ASSEM.	*	.91	* ---	.51	
TOTAL		4.24		6.15	
ZOOM ASSEMBLY					
HOUSING	AL	3.23	AL	2.37	
SHIM	—	NONE	AL	.65	
EL #10 TO #13 - CELL & RINGS	GL & AL	[illegible]	GL & BE	.38	
EL #14 & #15 GROUP 1	GL & AL	.46	GL & BE	.25	
EL #16 & #17 GROUP 2	GL & AL	.31	GL & BE	.25	
EL #18 & #19 - CELL & RINGS	GL & AL	.41	GL & BE	.14	
DRIVE MECH - HOUSING & COVER	* ---	4.22	* ---	1.49	
FILTER ASSEM.	GL & AL	.75	GL & BE	.21	
TOTAL		9.83		5.77	
SHEAR MOUNT					
FITTING	AL	1.54	AL	1.79	

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TELESCOPE ASSEM. CONT'D	SPEC SC 331B (153 LBS)		SPEC [illegible]5850		
	MAT'L	WT LBS	MAT'L	WT LBS	REMARKS
EYE PIECE ASSEMBLY					
HOUSING	AL	.18	AL	.97	
EL #21 - CELL & RING	GLASS	.20	GL & BE	.10	
EL #22 TO #27 - CELL & RING			GL & BE	1.05	
UNIT - FOCUS ADJUST	AL	.09	AL	.18	
FILTER CONTROL MECH.	—	NONE	AL	.08	
PERIPHERAL DISPLAY		NONE	*	.57	
TOTAL		.47		2.97	
ELECTRICAL					
HARNESS & CONN. - DRIVES	ELEC	.75	ELEC	3.75	
HARNESS & CONN. - P. DISPLAY	—	NONE	ELEC	2.00	
TOTAL		.75		5.75	
TOTAL WEIGHT - TELESCOPE		[illegible].74		80.67	MOST WT. INCREASES DUE TO ADDITION OF PERIPHERAL DISPLAY & MANUAL OVERRIDE.
WINDOW					
GLASS ONLY TOTAL	GLASS	3.74	GLASS	4.[illegible]	
EXTERNAL FIXED FOLD MIRROR					
MIRROR	CERVIT	[illegible].83	GLASS	[illegible]	
BEZEL	AL	[illegible]	ST	2.49	
POTTING	SILASTIC	.25	SILASTIC	.80	
FITTING #1	ST	.21	—	.23	
FITTING #2	ST	.21	—	.23	
FITTING #3	ST	.21	—	.23	
TOTAL WEIGHT - EXTERNAL FOLD		14.61		15.10	
SUN SENSOR ASSEMBLY					
SENSORS		.10	ELEC	.10	
LOGIC PKG.		.15	ELEC	.40	
HARNESS & CONNECTORS		.25	ELEC	.50	
TOTAL WEIGHT - SUN SENSOR		.50		1.00	

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TRACKING PEDESTAL ASSEMBLY	SPEC EE 3318 (153 LBS)		SPEC 705850		
	MAT'L	WGT LBS	MAT'L	WGT LBS	REMARKS
PEDESTAL/HOUSING ASSEM.	AL	9.00	AL & BE	5.57	
YOKE	AL	4.61	BE	2.29	
ROLL AXIS SHAFT	AL	.45	BE	.50	
" " BEARINGS FWD.	ST	.50	ST	.52	
" " BEARINGS AFT	ST	.14	ST	.08	
" " LOCK NUTS & RINGS	ST	.87	AL	.48	
" " ENCODER	ST'D	5.75	BE & ELEC	6.00	
" " TORQUE MOTOR	ST'D	10.00	—	9.00	
" " MOUNT GYRO	—	NONE	AL	1.00	
" " ENERGY ABSORBER	—	NONE	—	.25	
" " LAUNCH LOCK	—	NONE	—	.50	
PITCH AXIS HOUSING - MOTOR	—	●	AL	.78	● PART OF YOKE
" " HOUSING - ENCODER	—	●	AL	.64	● PART OF YOKE
" " SHAFT - MOTOR	—	●	AL	.24	● PART OF BEZEL
" " SHAFT - ENCODER	—	●	AL	.20	● PART OF BEZEL
" " BEARINGS - MOTOR	ST	.28	ST	.34	
" " BEARINGS - ENCODER	ST	.14	ST	.30	Added specified
" " LOCK NUT & RINGS	ST	.19	AL	.52	requirements for
" " TORQUE MOTOR	ST'D.	2.00	—	2.00	increased stiffness.
" " ENCODER	ST'D	5.75	BE & ELEC	3.50	& addition of large
" " MOUNT GYRO	—	NONE	AL	1.00	gyros [illegible] such
" " ENERGY ABSORBER	—	NONE	—	.25	from aluminum to
" " LAUNCH/LOCK	—	.75	—	.50	beryllium. [illegible]
BEZEL	AL	5.00	BE	3.15	[illegible]
MIRROR	CERVIT	14.33	CERVIT	11.14	design improvement
POTTING	SILASTIC	.41	SILASTIC	.88	resulted in weight
HARNESS & CONNECTORS	ELEC	3.25	ELEC	5.00	decrease.
TOTAL WEIGHT - PEDESTAL ASSEM.		61.07		56.82	

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SHROUD ASSEMBLY	SPEC EC331B (153 LBS)		SPEC 905 850		REMARKS
	MAT'L	WGT LBS	MAT'L	WGT LBS	
STRUCTURAL FRAME ASSEM	AL	●2.00	AL	7.87	● WAS A COVER OVER TRACKING MIRROR ONLY. CONCEPT CHANGED TO COMPLETE SHROUD WITH DRIVEN DOOR DUE TO DESIGN SPECIFICATION CHANGE.
DOOR ASSEM.			AL	8.92	
DRIVE MECH. (2)			* ---	3.26	
MOVABLE END CLOSURE (2)			AL	.71	
INSULATION - DOOR			NRC	.62	
INSULATION - STRUCTURE			NRC	.42	
EXPLOSIVE DISCONNECT (2)			—	.75	
PAINT			—	1.29	
TOTAL WEIGHT - SHROUD		2.00		23.34	

"NOTE" * --- INDICATES AL AND OTHER MATERIALS

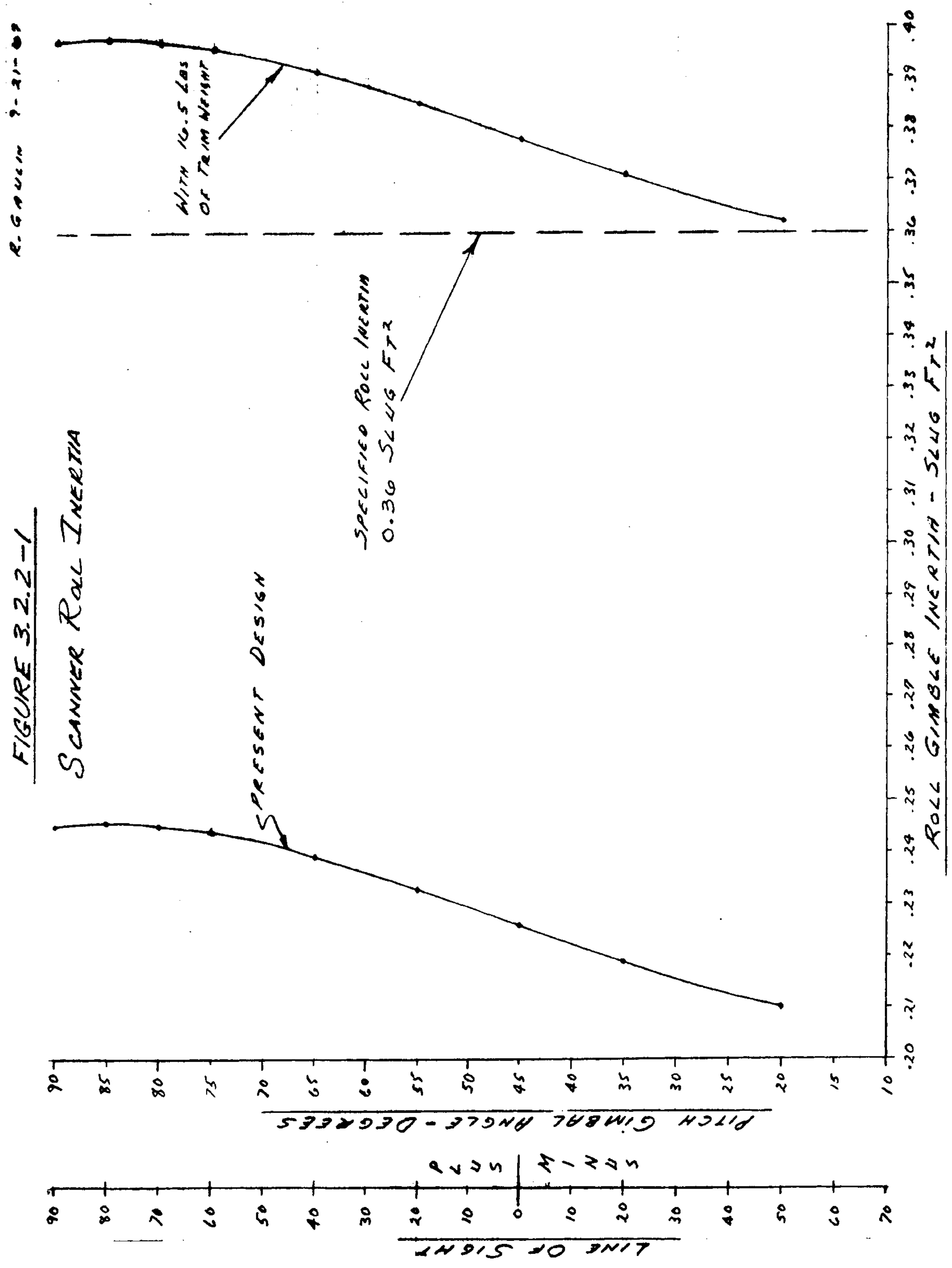

FIGURE 3.2.2-1

SCANNER ROLL INERTIA

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TRACKING MIRROR ASSEMBLY - CURRENT DESIGN - REFER TO SK114403

PITCH AXIS MOMENT OF INERTIA

ITEM	DESCRIPTION	MATERIAL	WEIGHT	K	I_{yo}	$WK^2 + I_{yo}$
	MIRROR (14.31 × 10.88 × 1.0)	CERVIT	11.14	1.00	143.50	154.64
	BEZEL	BE	3.15	.28	55.94	56.19
	POTTING	SILASTIC	.85	.98	4.68	5.50
	SHAFT - MOTOR END	AL	.24	.50	—	.06
	LOCK NUT - BRG.	ST.	.10	.56	—	.03
	LOCK NUT - ROTOR	ST	.11	.31	—	.01
	BEARINGS - MOTOR END	ST	.34	.75	—	.19
	ROTOR - TORQUE MOTOR	ST	.84	.81	—	.55
	SHAFT - ENCODER END	AL	.20	.38	—	.03
	DISC - ENCODER	GLASS	.13	1.69	—	.37
	MOUNT - ENCODER DISC	AL	.25	1.13	—	.32
	CLAMP RING - ENCODER DISC	AL	.03	1.31	—	.05
	BEARINGS - ENCODER END	ST	.30	.63	—	.12
	GASKET - POTTING STOP	RUBBER	.03	.50	—	.01
	GYRO	—	2.89	2.03	5.62	11.91
	ELECTRONIC PKG.	—	2.16	1.78	6.08	12.92
	INTERCONNECTING CABLE (GYRO)	—	.37	3.63	—	4.88
	MOUNT - GYRO	AL	1.00	2.00	2.02	4.00
	~~TRIM WEIGHT~~	~~HEAVY MET~~	~~2.00~~	~~7.88~~	~~.28~~	~~124.47~~
			~~26.13~~			~~370.25~~ 251.78

TOTAL DESIGN WEIGHTS MOVING IN PITCH = 24.13 ~~26.13~~ LBS

TOTAL PITCH MOMENT OF INERTIA OF THIS MASS: 252 ~~376~~ LB IN² = .054 ~~.081~~ SLUG FT²

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TRACKING MIRROR ASSEMBLY - CURRENT DESIGN - REFER TO SK-114403

ROLL AXIS - MOMENT OF INERTIA - 70° SCAN ANGLE

ITEM NO	DESCRIPTION	MATERIAL	WEIGHT	K	I_{xo}	$WK^2 + I_{xo}$
	MIRROR (14.31 x 10.88 x 1.0)	CERVIT	11.14	1.00	224.99	236.13
	BEZEL	BE	3.15	1.00	102.78	105.73
	POTTING / GASKET	SILASTIC	.88	1.00	39.27	40.15
	PITCH AXIS DRIVE ASSEM.	AL / MISC	3.82	8.00	7.24	251.72
	PITCH AXIS ENCODER ASSEM.	AL / MISC	4.90	7.00	9.47	249.57
	PITCH AXIS GYRO	—	2.89	1.12	5.62	7.25
	PITCH AXIS ELEC. PKG - GYRO	—	2.16	1.06	7.06	9.49
	PITCH AXIS CABLE - GYRO	—	.37	3.94	1.52	7.26
	PITCH AXIS GYRO MOUNT	AL	1.00	1.25	2.42	3.98
	~~PITCH AXIS TRIM WEIGHT~~	~~HEAVY MET~~	~~1.00~~ ~~1.00~~	~~8.75~~ ~~6.94~~	~~2.68~~	~~127.40~~
	ROLL AXIS BEARINGS & RETAINERS	ST	1.08	.88	—	.84
	ROLL AXIS SHAFT	BE	.50	.63	—	.20
	ROLL AXIS ENCODER DISC & FLEXURE	GLASS / BE	1.64	2.63	—	11.34
	ROLL AXIS ROTOR (TORQUE MOTOR)	ST	3.50	2.17	—	16.79
	ROLL AXIS GYRO	—	2.89	5.25	5.62	85.28
	ROLL AXIS ELEC. PKG - GYRO	—	2.16	3.75	6.08	36.46
	ROLL AXIS CABLE - GYRO	—	.37	3.38	1.52	5.75
	ROLL AXIS GYRO MOUNT	AL	1.00	3.31	2.42	13.38
	~~ROLL AXIS TRIM WEIGHT~~	~~HEAVY MET~~	~~14.50~~	~~6.00~~	~~50.26~~	~~578.26~~
	ENERGY ABSORBERS	—	.50	1.50	.09	1.22
	YOKE	BE	2.28	.90	25.48	27.33
	LAUNCH LOCK	—	1.00	5.00	.17	25.17
			47.23 ~~63.73~~			~~1842.90~~ 1137.24

TOTAL DESIGN WEIGHTS MOVING IN ROLL : ~~63.73~~ 47.23 LBS

TOTAL ROLL MOMENT OF INERTIA AT 80° : ~~1043~~ 1137 LB IN² = ~~.371~~ .245 SLUG FT²

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TRACKING MIRROR ASSEMBLY - CURRENT DESIGN - REFER TO SK-114403

ROLL AXIS - MOMENT OF INERTIA - 27?° SCAN ANGLE

ITEM NO	DESCRIPTION	MATERIAL	WEIGHT	K	I_{xo}	$WK^2 + I_{xo}$
	MIRROR (14.31 x 10.88 x 1.0)	CERVIT	11.14	.05		99.12
	BEZEL	BE	3.15	[illegible]		46.59
	POTTING / GASKET	SILASTIC	.88	[illegible]		36.82
	PITCH AXIS DRIVE ASSEM.	AL / MISC	3.82	8.00	7.24	251.72
	PITCH AXIS ENCODER ASSEM.	AL / MISC	4.90	7.00	9.47	249.57
	PITCH AXIS GYRO	—	2.89	2.74	5.62	27.32
	PITCH AXIS ELEC. PKG - GYRO	—	2.16	2.52	7.06	20.77
	PITCH AXIS CABLE - GYRO	—	.37	3.50	1.52	6.05
	PITCH AXIS GYRO MOUNT	AL	1.00	2.06	2.42	9.50
	~~PITCH AXIS TRIM WEIGHT~~	~~HEAVY MET~~	~~1.00~~ 1.00	2.75 ~~6.44~~	~~2.68~~	~~129.40~~
	ROLL AXIS BEARINGS & RETAINERS	ST	1.08	.88	—	.84
	ROLL AXIS SHAFT	BE	.50	.63	—	.20
	ROLL AXIS ENCODER DISC & FIXTURE	GLASS / BE	1.64	2.63	—	11.34
	ROLL AXIS ROTOR (TORQUE MOTOR)	ST	3.50	2.19	—	16.79
	ROLL AXIS GYRO	—	2.89	5.25	5.62	85.28
	ROLL AXIS ELEC. PKG - GYRO	—	2.16	3.75	6.08	36.46
	ROLL AXIS CABLE - GYRO	—	.37	3.38	1.52	5.75
	ROLL AXIS GYRO MOUNT	AL	1.00	3.31	2.42	13.38
	~~ROLL AXIS TRIM WEIGHT~~	~~HEAVY MET~~	~~1.60~~	~~6.00~~	~~[illegible]~~	~~[illegible]~~
	ENERGY ABSORBERS	—	.50	2.50	.09	3.22
	YOKE	BE	2.28	.90	25.48	27.33
	LAUNCH LOCK	—	1.00	5.00	.17	25.17
			47.23 ~~59.73~~			~~1678.18~~ 772.[illegible]

TOTAL DESIGN WEIGHTS MOVING IN ROLL = 47.23 ~~59.73~~ LBS

TOTAL ROLL MOMENT OF INERTIA AT 25°. ~~1018~~ LB IN² = ~~.362~~ .210 SLUG FT²

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3.2-11

3.3 Power Budget

The present sub-system power budget is 117 watts peak. Owing to the characteristics of the primary power system, Itek is presently constrained in peak power but not the long term average.

A summary of the Subsystem power consumption by functions is shown in table 3.3-1. These power consuming items are isolated by groups that can occur as simultaneous demands on the vehicle power bus. The non-peak powers are also controlled to minimize short duration spikes, with their attendant poor utilization factors.

The principal power consuming load is the roll gimbal torquer. It is shown in section 3.5.3 that the roll torquer is selected on a peak power basis. The allocation of power to each item, cross checking against the weight budget, and subsequent refinement is a continuous trial and error procedure.

The power consumption calculations for the various activities are presented in the analysis section under the electrical design description of each mechanism.

TABLE 3.3-1

POWER SUMMARY

FUNCTION	SLEW MODE (WATTS)	TRACKING MODE (WATTS)
ROLL TORQUER	36	0.01
ROLL ENCODER	4.72	4.72
PITCH TORQUER	3.9	0.03
PITCH ENCODER	4.72	4.72
SUN SENSOR ELECTRONICS	0.5	
BLANKING		
RELEASE	1.0 } either	
RESET	14.0	
POWER CHANGER	16.0	
ZOOM	4.0	
DEROTATION	10.0	
PERIPHERAL DISPLAY	5.5 to 35.0 depends on illumination level	
THERMAL CONTROL	5.0	
	91.34 to 133.84	9.48

SHROUD DOOR MOTOR: 15 WATTS

3.4 RELIABILITY

3.4.1 Reliability Program Status

The status of the reliability program tasks is presented in terms of the Reliability Program Plan R-107 with schedule revision 26 July 1967. The reliability program activity has been reviewed on three occasions with the contractor reliability representative. The first was a program audit performed during the week of 17 July 1967; the second program review was during the TD Meeting, 17-18 July 1967; the third review was on 7 Sept. 1967. The reliability program effectiveness is also measured against the status of action in response to the audit. A copy of the audit status report dated 13 Sept. 1967 is included.

Part Selection and Application

Schedule - March 1968

Status - Initial stages

Action - 1) Preliminary list given the customer representative for review.

2) Pin lite miniature incandescent lamps.

3) Pyro devices

4) Cabling, flat with Kapton Insulation

5) Encoders

Part Qualification Specs/Requirements

Schedule - Sept. 1967

Status - 90% complete

Action - Contract review to establish the requirements for part qualification.

Burn-in and Screening Specifications

Schedule - Oct. 1967

Status - Recommended method submitted with program plan.

Action - Request contractor guide to burn-in and screening requirements.

Design Standards

Schedule - Jan. 1968

Status - 50% complete

Action - Prepare standard parts, materials, and process list for use by design

<u>Traceability</u> (program requirements procedure)

<u>Schedule</u> - Oct. 1967

<u>Status</u> - 90% complete

<u>Action</u> - 1) Developed procedure for traceability (RE-OP-1)

2) Submitted project policy for implementation of traceability procedure.

<u>FMEA</u> 1st

<u>Schedule</u> - Encoders - 18 Aug. 1967
Brushless Motors- 18 Aug. 1967
Optical Elements- 1 Sept. 1967
Bearings,Gimbal - 1 Sept. 1967
Data Display - 8 Sept. 1967
Scanner Assembly- 22 Sept. 1967
Door Mechanism - 6 Oct. 1967
Window - 15 Sept. 1967

<u>Status</u> - First analysis complete for PDR input (15 Sept. 1967.)

<u>Action</u> - Review and up-date for 2nd. report.

<u>RFMA</u> 1st

<u>Schedule</u> - for PDR Report 15 Sept. 1967

<u>Status</u> - complete

<u>Action</u> - Review and up-date in preparation for 2nd Report.

<u>Vendor Reliability Program Control</u>

<u>Schedule</u> - Program Requirements - Jan. 1968
Audit - Feb. 1968
Liaison - Sept. 1968

<u>Status</u> - Initial stages

<u>Action</u> - 1) Reliability requirements for encoder established.

2) Preliminary survey of encoders vendor's facility performed.

3) Preliminary specifications for brushless torque-motor written (including the reliability requirements.)

<u>Training</u>

<u>Schedule</u> - November 1967

<u>Status</u> - 50% complete

<u>Action</u> - Training has been informal presentation of reliability concepts and program requirements with individual design engineers.

Human Factors Interface (prime responsibility of System Engineering)

Schedule - April 1968

Status - initial stages

Action - The prinicpal inputs will be as a result of performing the other reliability tasks (FMEA). There have been inputs to systems engineering in the areas concerning ease of operation and complexity of operator tasks.

Safety (prime responsibility System Engineering)

Schedule - March 1968(Inputs)

Status - Initial stages

Action - The FMEA tasks has resulted in identifying several possible safety hazards which are transmitted to system engineering for evaluation.

Maintainability (prime responsibility System Engineering)

Schedule - April 1968(Input)

Status - Initial stages

Action - Reviewed program plan and furnishing preliminary inputs resulting from FMEA.

Reporting

Schedule - periodically

Status - up to date

Action - weekly program status reports.

Itek

INTEROFFICE MEMORANDUM

Date: 13 September 1967

Page 1 of 3 Pages

349-67-487

To: J. Boh Facility: Burl. #11

From: E. F. Powers Facility: Burl. #11

Subject: Status of Reliability Action Resulting from Audit

The customer reliability audit has been sub-divided into 31 separate action items. The status of 11 September 1967 is as follows:

A.) 14-have been closed out as completed

B.) 11-are in the final stages of preparation

C.) 1-is in the initial stages of preparation

D.) 5-action has not yet started

Below is a detailed accounting of the categories above:

A. Completed:

1. Reliability included on PDR adgenda
2. In (3) separate areas of the audit restricted activity was noted.
3. TR873-74 is being used as the RFMA procedure.
4. Program examples of the RFMA were reviewed (rough cut of PDR input).
5. Program examples of the FMEA were reviewed (rough cut of PDR input).
6. Project policy for parts and materials control by Reliability.
7. Program example of supplier reliability requirements (encoder).
8. Reviewed schedule for incompatability between supplier reliability requirements and long lead delivery schedule,
9. The encoder SOW requires the supplier to conduct PDR and participate in Itek's CDR & FACI.
10. Traceability procedure is formalized.
11. Safety plan defines reporting of safety incidents (FMEA procedure also includes identifying potential safety problems.)
12. Open failure analysis policy established for the project.

3.4-4

B. Final Stages

1. CDR standard procedure being revised to require reliability participation,
   Responsibility - Central Rel.
   Completion Date: 1 Oct. 67
2. FMEA procedure.
   Responsibility - Project Rel.
   Completion Date: 1 Oct. 67
3. Communication like for problem areas (form in process).
   Responsibility - Project Rel.
   Completion Date: 15 Oct. 67
4. Requirements for a vendor survey procedure was referred to in (2) separate areas. There is now a draft of this procedure.
   Responsibility - Central Rel.
   Completion Date: 15 Oct. 67
5. Traceability program plan,
   Responsibility - Project Rel.
   Completion Date: 15 Oct. 67
6. Calendar life study to be part of the FMEA study (see draft procedure).
   Responsibility - Project Rel.
   Completion Date: 1 Oct. 67
7. Failure reporting and analysis procedure in final draft form.
   Responsibility - Central Rel.
   Completion Date: 15 Oct. 67
8. Reliability role in failure reporting and analysis is defined in procedure.
   Responsibility - Central Rel.
   Completion Date: 15 Oct. 67
9. Reliability position in failure loop (see B7)
   Responsibility - Central Rel.
   Completion Date: 15 Oct. 67
10. Failure reporting and analysis policy during development testing.
   Responsibility - Central Rel.
   Completion Date: 15 Oct. 67

C. Initial Stages

1. The non-standard part program responsibility is being transferred from QA to Reliability. Several books of standards have been prepared for distribution to the design team.
   Responsibility - Cen. Rel./Pro. Rel.
   Completion Date; 1 Nov. 67

3.4-5

D. Action Item Not Yet Started

1. Procedure for submitting failure reports to customer.
   <u>Responsibility</u> - Central Rel.
   <u>Completion Date</u>: 15 Nov. 67
2. Procedure for submitting failure analysis reports to customer.
   <u>Responsibility</u> - Central Rel.
   <u>Completion Date</u>: 15 Nov. 67
3. Procedure for assuring 12 hour notice of failure during qual. test (TWX).
   <u>Responsibility</u> - Central Rel.
   <u>Completion Date</u>: 15 Nov. 67
4. Procedure for reliability data collection and reporting.
   <u>Responsibility</u> - Central Rel.
   <u>Completion Date</u>: 15 Nov. 67
5. Reliability education plan.
   <u>Responsibility</u> - Project Rel.
   <u>Completion Date</u>: 15 Nov. 67

Several of the action items above are to be covered by a single procedure.

In several cases more than one of the above action items will be covered by a single procedure. There are actually (8) procedures involved in closing out the open items above.

E. F. Powers
E.F. Powers
Reliability

DISTRIBUTION
APPROVED: a Van Sickel
A. Van Sickel

EFP/mb
<u>DISTRIBUTION</u>: A. L. Wright
M. Nikonchuk
T. B. Robinson
A. Van Sickel

3.4.2 Reliability Figure of Merit Analysis

3.4.2.1 Abstract

The first RFMA has been performed for the complete system. The source of the design data was preliminary drawings and sketches with estimated stresses. Failure rate data was taken from MIL HDBK 217A and FARADA SP 63-470 Vol. 1. Application (K) factors and prediction methods are in accordance with TR 873-74.

The results of this analysis shows:

99.60% probability of achieving a successful 50 hour mission with all controls operating automatically.

99.81% probability of achieving a successful 50 hour mission with automatic or manual control.

The following system breakdown shows the assemblies which contribute most significantly to the total predicted unreliability with their allocated MTBF's and per cent contribution.

	MTBF	%
Optical Encoders	46,000	10
Solar Blanking Assembly.	27,400	16
Power Changer.	37,200	12
Cue Assembly	36,500	12
Protective Shroud	12,600	35
		85

The Solar Blanking, Power Changer and Cue Assembly have relatively high failure rates principally because of the brush-type fractional horsepower motors planned for use in these assemblies. The Protective Shroud contribution results from the pyro lock devices with no redundant backup and the brush-type drive motors. The MTBF of the Optical Encoders is shown for series configuration (no redundant path). The calculation of system reliability does however reflect the redundant capability.

3.4.2.2 Mathematical Model for Telescope Reliability

There are several states of system performance that can be assessed. Presented here are the two (2) models for a successful (or partially successful) mission considered most meaningful for this equipment.

General Model

$$R = P_A \cdot P_B \cdot P_C \cdot P_D \cdot P_E \cdot P_F \cdot P_G \cdot P_H$$

I. Fully operational with all automatic functioning (redundancy is considered operating except for the encoder).

$$R_I = [\ \{A1A(A1B^2)\}^2 \cdot A3 \cdot A4\ \{A5A(A5B + A5B_1)\}^2] \cdot$$
$$[\ B1 \cdot B2 \cdot B3] \cdot [\ C1 \cdot C2] \cdot [D1 \cdot D2] \cdot [E1 \cdot E2 \cdot [F1 \cdot F2] \cdot$$
$$\cdot\ G \cdot\ (H1)^2 \cdot H2$$

Where the symbols A1A, A1B, A2, etc. are probabilities of success and subscript (1) indicates the probability of (1) failure.

II. Operational by either automatic or manual controls (degraded mode).

$$R_{II} = [\{A1A(2A1B-A1B^2)\}^2 \cdot A3 \cdot A4\ \{A5A(A5B+A5B_1)\}^2]$$
$$[B1(B2+B3-B2 \cdot B3)]\ [C1(C2+C3-C2 \cdot C3)] \cdot [D1(D2+D3-D2 \cdot D3]$$
$$[E2+E3-E2\ E3]\ [F1(F2+F3-F2\ F3]\ [G]\ [(2H1-(H1)^2]H2$$

The success probabilities of the individual terms in the above expression are determined as follows:

$$P_{A1A} = e^{-\lambda(A1A)\ T\ (A1A)} \qquad P_{A5B_1} = 2A5BTe^{-\lambda A5BTA1B}$$

where λ(A1A) = the expected device failure rates (taken from MILHBK217A and FARADA) within the useful life of the item; and T(A1A) = the expected operating time of the item when the telescope mission time (period of use) is 50 hours.

The MTBF of the telescope is determined from the mathematical model expressing reliability (R) as follows:

$$\overline{m} = \int_o^\infty R(t)dT \qquad [1]$$

Condition I

$$R_{(T)} = e^{-v}\cdot(2e^{-w}-e^{-2w})^2(2e^{-x}-e^{-2x})^2(2e^{-y}-e^{-2y}) \qquad [2]$$

where $v = \sum 2T$ for all series elements

$w = \lambda_{A1B}T$
$x = \lambda_{A5B}T$
$y = \lambda_{H_1}T$

Condition II

The form of the expression for $R_{(t)}$ in condition II is the same as above except the manual over-ride cause several terms in V to approach zero. Therefore,

$$R_{(T)}II = \frac{R_{(T)}I}{e^{-v'}} \qquad [3]$$

where v' is the sum of the terms that vanish due to the manual overide.

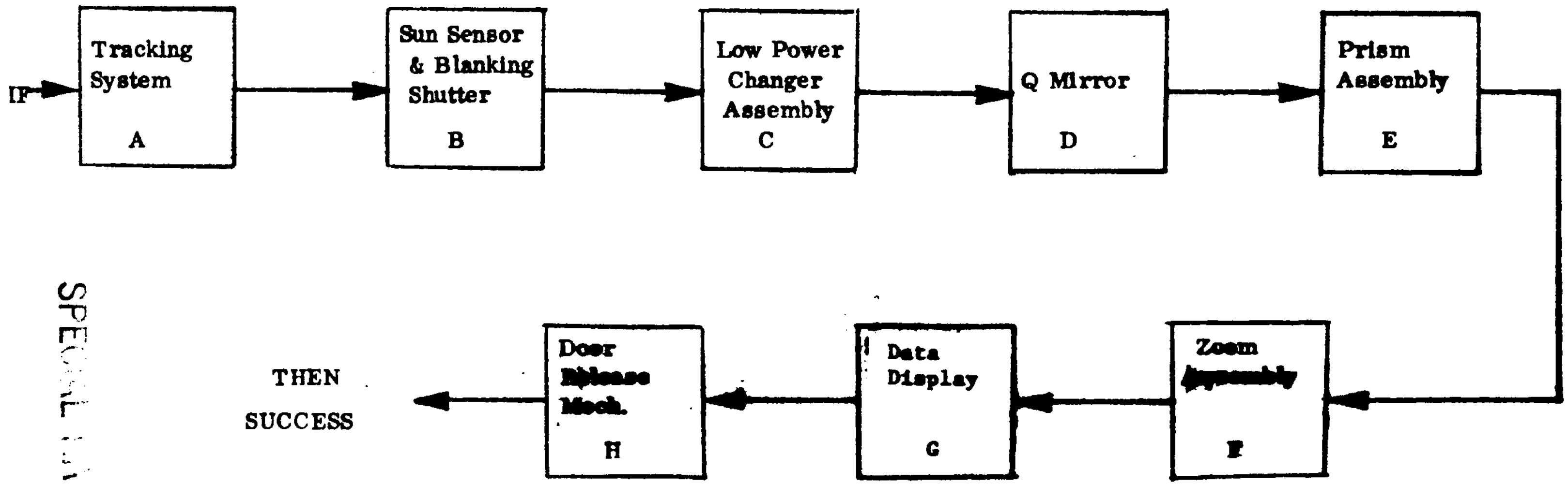
It should be noted that the MTBF in either conditions I or II is not simply the inverse probability operation $\overline{m} = T/-\ln R_{(T)}$ because of the redundant operating modes.

Not all of the functional elements of the telescope are required to operate continuously during the period of use for the telescope. The following duty cycles have therefore been assumed:

Assembly	Duty Cycle	Mission Time
(A) Tracking System	100%	(50 hours)
(B) Sun Sensor and Blanking	20%	(10 hours)
(C) Low Power Changer	25%	(12.5 hours)
(D) Cue Mirror	50%	(25 hours)
(E) Prism	100%	(50 hours)
(F) Zoom	50%	(25 hours)
(G) Data Display Assembly	40%	(20 hours)
(H) Door Release	50%	(25 hours)

34-10

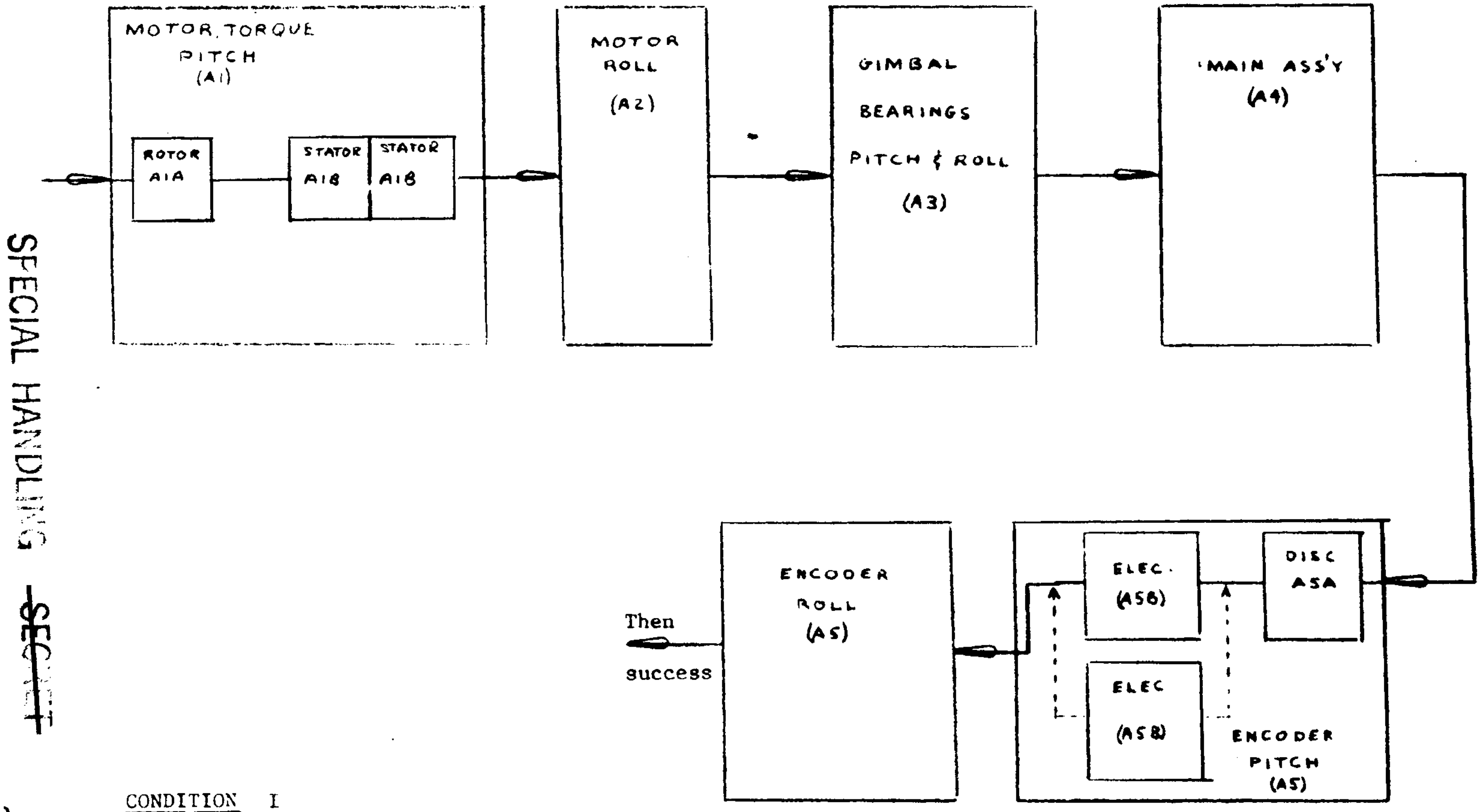
9300 TELESCOPE BASIC RELIABILITY DIAGRAM



If all customer furnished inputs are present and proper; and each of the above assemblies performs its intended function, then mission success is achieved. Several levels of performance are available in this system as described as follows:

1. Fully operational (all motor driven elements and sensing devices operational).
2. Manual operation of adjustments.
3. Sun sensor disabled.

Tracking System (A)

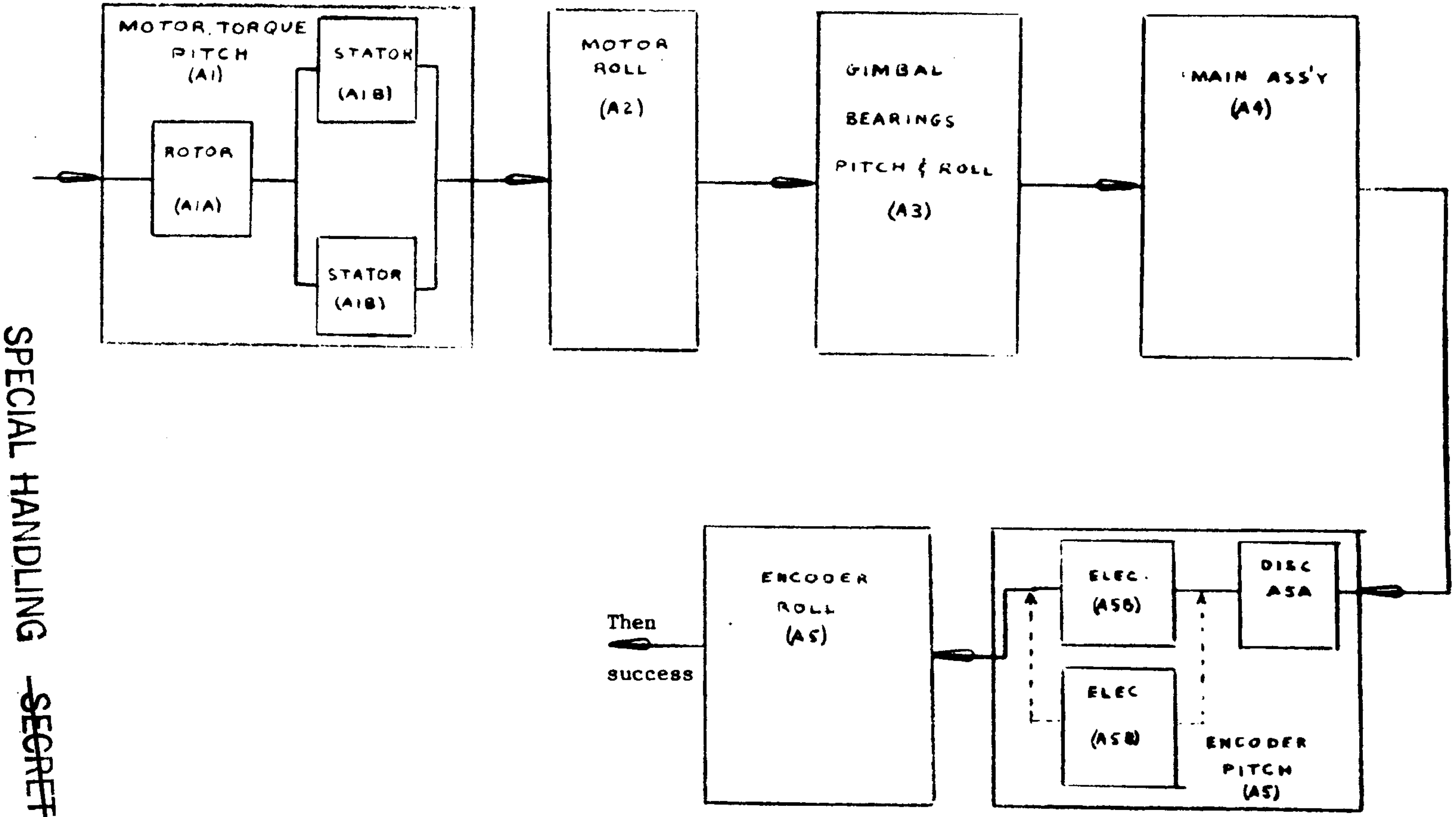


CONDITION I

$$P_A = [A1A \cdot A1B^2]^2 \cdot A3 \cdot A4 \cdot \{A5A(A5B+A5B_1)\}^2$$

3.4-12

Tracking System (A)



Condition II (degraded mode)

$$P_A = [A1A(2A1B-A1B^2)]^2 \cdot A3 \cdot A4 \cdot [A5A(A5B+A5B_1]^2$$

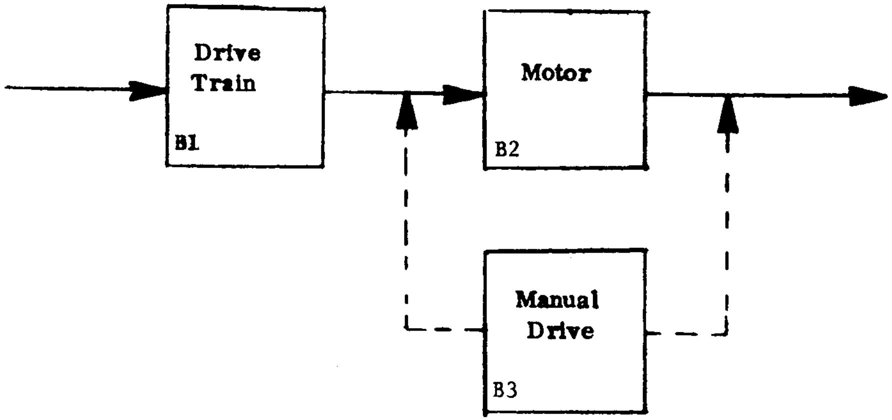
Solar Blanking (B)

Low Power Changer Assembly/, (C)

Cue Mirror Assembly (D)

Prism Assembly/, (E)

Zoom Assembly (F)



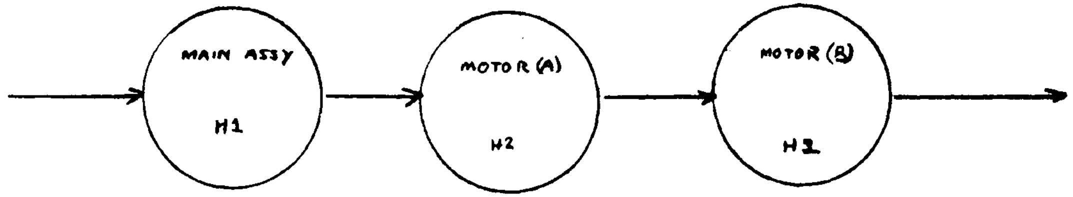
I $\underline{P_B = B1 \cdot B2}$

II $\underline{P_B = B1 \cdot (B2+B3-B2 \cdot B3)}$

NOTE: Same Model for (C), (D), (E) and (F)

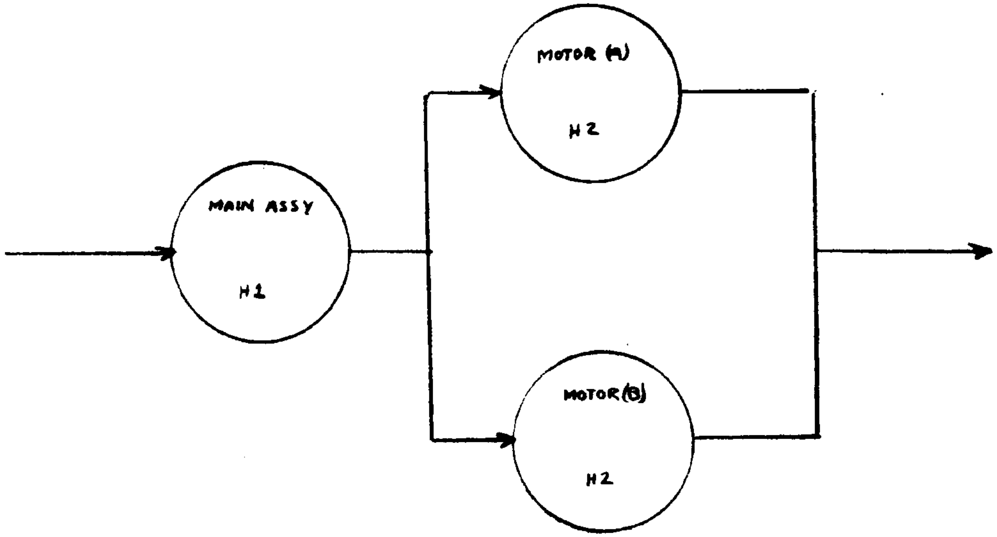
PROTECTIVE SHROUD

Condition I



$PH = H1 \cdot H2 \cdot H2$

Condition II



$PH = H1\ (2H2 - H2^2\ )$

3.4.2.3 Calculation of Telescope Reliability

The calculations below are based upon the support failure rate data attached and the mathematical model.

1.) Scan Assembly (A)

Condition I $P_{A1} = (A1A \cdot A1B^2)^2 = e^{-(2\lambda A1A + 4\lambda A1B)T}$

$A1A = 0; \lambda A1B = \cdot 231; T = 50$ $\boxed{P_{A1} = .999954}$

Condition II

$$P_{A1} = [A1A\ (2 \cdot A1B - A1B^2)]^2$$

$$= e^{-\lambda_{A1A}T}(2e^{-\lambda_{A1B}T} - e^{-2\lambda_{A1B}T})$$

When λT is small

$$e^{-\lambda T} \simeq 1 - \lambda T$$

$$\lambda_{A1A} \simeq 0$$

Therefore, $P_{A1} = 2(1-\lambda_{A1B}T) - (1-\lambda_{A1B}T)^2$

$T = 50$ hours $\lambda_{A1B} = 0.231 \times 10^{-6}$ $\lambda T = 12 \times 10^{-6}$

$1-\lambda T = .999988$ $(1-\lambda T)^2 = .999976$

$P_{A1} = 1.999976 - .999976$ $\boxed{P_{A1} \approx 1.0}$

$P_{A2} = P_{A1}$

A3-Bearings

$P_{A3} = 1-\lambda_{A3}T$ $\lambda_{A3} = 2.184$ $T = 50$

$\lambda T = 109.2$ $\boxed{P_{A3} = .999890}$

A4- Misc

$P_{A4} = 1- \ A4^T$ $\lambda_{A4} = 1.310$ $T = 50$

$\lambda T = 66 \times 10^{-6}$ $\boxed{P_{A4} = .999934}$

A4-Pyro

$P_{A4A} = 2e^{-\ T} - e^{-2\ T}$ $\lambda_{A4A} = 27.30$ $\lambda T = 50$ $\lambda T = 1365$ $2\lambda T = 2730$

$P_{A4A} = 1.997272 - .997274$ $\boxed{P_{A4A} = .999998}$

A5-Encoder

Standby

$$P_{A5} = [A5A\ (A5B + A5B_1)]^2 = \{(1 - \lambda_{A5A}T)\ [1 - \frac{(\lambda_{A5B}T)^2}{2}]\}^2$$

$A5A \approx 1$ (disc) $\quad \lambda_{A5A} \approx 0 \quad \lambda_{A5B} = 21.846 \quad T=50$

$\lambda T = 1092.30 \times 10^{-6} \quad (\lambda T)^2 = 1.192 \times 10^{-6}$

$P_{A5} = (1 - .6 \times 10^{-6})^2 \qquad \boxed{P_{A5} = .999998}$

Operating

$P_{A5} = (2e^{-\lambda_{A5B}T} - e^{-2\lambda_{A5B}T})^2 = 2(1-\lambda T) - (1-\lambda T)^2$

$P_{A5} = (.998908)2 - (.998908)^2$

$P_{A5} = (1.997816 - 997817)^2 \qquad \boxed{P_{A5} = .999998}$

Scanner Ass'y **Condition I**

$P_A = P_{A1}\ P_{A2}\ P_{A3}\ P_{A4}\ P_{A5} \qquad \boxed{P_A = .999774}$

Scanner Ass'y **Condition II**

$P_A = P_{A1} \cdot P_{A2} \cdot P_{A3} \cdot P_{A4} \cdot P_{A5}$

$= (1)\ (1)(.999890)(.999934)(.999998)(.999998)$

$\boxed{P_A = .999820}$

2.) Solar Blanking (B)

Condition I

$P_B = B1 \cdot B2 = e^{-\lambda_B T}$

$\lambda_B = 36.516 \times 10^{-6} \quad T=10$

$P_B = 1-365 \times 10^{-6} \qquad \boxed{P_B = .999635}$

Condition II

$P_B = B1\ (B2 + B3 - B2\ B3)$ but $B3 \approx 1$ and all mechanisms required for automatic are also required for manual.

$P_B = 1 - \lambda_{B1}T \quad \lambda_{B1} = 16.593 \quad T=10$

$P_B = 1-35 \times 10^{-6} \qquad \boxed{P_B = .999834}$

3.) Low Power Changer (C)

Condition I

$P_C = (C1)(C2) = e^{-\lambda_C T}$ $\lambda_C = 26.874$ T=12

$P_C = 1\ 322 \times 10^{-6}$ $\boxed{P_C = .999678}$

Condition II

$P_C = 1-\lambda_{C1}T$ $\lambda_{C1} = 6.952$ T = 12

$= 1-83 \times 10^{-6}$ $\boxed{P_C = .999917}$

4.) Cue Mirror (D)

Condition I

$P_D = D1 \cdot D2 = e^{-\lambda_D T}$ $\lambda_D = 27.370$ T=25

$P_D = 1-\lambda_D T = 1-684 \times 10^{-6}$ $\boxed{P_D = .999316}$

Condition II

$P_D = 1-\lambda_{D1}T$ $\lambda_{D1} = 7.448$ T=25

$P_D = 1-\lambda_{D1}T = 1-186 \times 10^{-6}$ $\boxed{P_D = .999814}$

5.) Prism Assembly (E)

Condition I

$P_E = E1 \cdot E2 = e^{-\lambda_E T}$ $\lambda_E = 5.212$ T=50

$P_E = 1-\lambda T = 1-261 \times 10^{-6}$ $\boxed{P_E\ .999739}$

Condition II

$P_E = 1-\lambda_{E1}T$ $\lambda_{E1} = 4.981$ T=50

$P_E = 1-249 \times 10^{-6}$ $\boxed{P_E = .999751}$

6.) Zoom And Eyepiece Assembly (F)

Condition I

$P_F = F1 \cdot F2 = e^{-\lambda_F T}$ $\lambda_F = 5.403$ T=25

$P_F = 1-\lambda_F T = 1-135 \times 10^{-6}$ $\boxed{P_F = .999865}$

Conditon II

$P_F = 1-\lambda_{F1}T$ $\lambda_{F1} = 5.172$ T=25

$P_F = 1-129 \times 10^{-6}$ $\boxed{P_F = .999871}$

7.) **Data Display (E)**

$P_G = e^{-\lambda_E T}$ $\lambda_G = 23.834$ T=20

$P_G = 1 - 477 \times 10^{-6}$ $\boxed{P_G = .999523}$

8.) **Shroud (H)**

Condition I

$P_H = (H1)^2 \cdot H2 = e^{-(2\lambda H1 + \lambda H2)\ T}$

$\lambda_{H1} = 21.844$ $\lambda_{H2} = 29.996$ T=25

$\lambda\ T = 1842 \times 10^{-6}$

$\boxed{P_H = .998160}$

Condition II

$P_H = \left[(2H1 - (H1)^2)\right]H2 = (2e^{-2\lambda_{H1}T} - e^{-2\lambda_{H1}T})e^{-\lambda_{H2}T}$

$\lambda_{H1}T = 546 \times 10^{-6}$ $\lambda_{H2}T = 750 \times 10^{-6}$

$P_H = (1.998908 - .998909)H2$ $\boxed{P_H = .999241}$

9.) Systems Terms

Condition I

$P_S = \pi P_A \rightarrow P_H$ $P_S = .996349$

Condition II

$P_S = \pi P_A \rightarrow P_H$ $\boxed{P_S = .998426}$

Apportionment of System Reliability

	$\lambda x10^{-6}$	MTBF	%
Pitch and Roll Encoders (for a single non-redundant path)	21.846	21.846	9.64
Scan Motors	.340	——	.15
Solar Blanking Assembly	36.516	27,385	16.12
Power Changer	26.874	37,211	11.86
Cue Mirror Assembly	27.370	36,536	12.08
Prism Assembly	5.212	——	2.30
Zoom & Eyepiece	5.403	——	2.39
Data Display	23.834	41,957	10.52
Protective Shroud	79.136	12,637	34.93
	226.531		100.00

PRELIMINARY RELIABILITY ANALYSIS

ASSEMBLY : SCAN ASSEMBLY (A) λ=52.866

PART DESCRIP	PART NO	EST STRESS	λ_b	K FACTORS	λ_a	QTY	λ_t	REMARKS
(A1A) ROTOR (perm mag)								
(A1B) STATOR		85°C Class A	.340	.679	.340	1	.340	x .679 = .231
(A3) BEARINGS		(1) Pg. 25	.402			8	3.216	x .679 =2.184
(A4)Misc-Main Assy								
Microswt		40°C 1 op/day	.049			4	.196	
(Capac CK05)		40° 30%	0055			2	.011	
" CS13		40° 40%	.023			1	.023	
Resist (Film)		40°C 50%	.170			4	.680	
Conn Miltipon		40°C --	1.020			1	1.020	x .679 =1.310
							1.930	
(A4A) Pyrotechnic Charge		Pg 337 Squibb	20.1			2	40.200	x .679=27.295
(A5) ENCODER		See Seperate Sheet						21.846

(1) FARADA SP63-470 Vol 1 & AD 806546
(2) Mil HDBK2DA
(3) K factor is established as Ke = .756 and Ke = 0.9 therefor K = .679

λ_b = RAW FAILURE RATE λ_a = ADJUSTED FOR K FACTORS λ_t = λ_a × QTY (λ in 10^6 hours)

PRELIMINARY RELIABILITY ANALYSIS

ASSEMBLY : SOLAR BLANKING (B) λ = 36.516

PART DESCRIP	PART NO	EST STRESS	λ_0	K FACTORS	λ_A	QTY	λ_Q	REMARKS
(B1) DRIVE & FILTER								
Spur Gears		Pg. 159	.025			2	.150	
Bearings		Pg. 25	.402			4	1.608	
Resistors		40° 50%	.170			4	.680	
Caps (CK05)		40° 30%	.0055			2	.011	
" (CS13)		40° 40%	.023			1	.023	
Photo diode		Tn =.25	.222			6	1.332	Quantity assumes (6) ea.
Transistors		Tn =.20	.195			24	4.680	Signal processing circuits
Resistors		40° 50%	.0035			84	.294	
Pot		40° 20%	1.300			6	7.800	
Diodes		Tn =.25	.222			12	23.197	
Zener		T_n =.30	.777			6	4.662	
							24.437	x .679 = <u>16.593</u>
(B2) MOTOR		85° Class A	29.340			1	28.340	x .679 = <u>19.923</u>

λ_0 = RAW FAILURE RATE λ_A = ADJUSTED FOR K FACTORS $\lambda_Q = \lambda_A \times$ QTY   (λ in 10^6 hours)

PRELIMINARY RELIABILITY ANALYSIS

ASSEMBLY : LOW POWER CHANGER (C) = 26.874

PART DESCRIP	PART NO	EST STRESS	λ_o	K FACTORS	λ_A	QTY	λ_T	REMARKS
(C1) DRIVE & FILTER								
Clutch-Brake	Autotronics mc-32	Pg. 65	1.660			1	1.660	
Microswt (C)		40°C 1 op/da	.049			•2	.098	
Cap (CK05)		40°C 30%	.0055			2	.011	
Resistor (RN)		40°C 50%	.170			4	.680	
Cap (CS13)		40°C 40%	.023			1	.023	
Speed Reducer	Bomar 185R-20	Pg. 160	2.473			1	2.473	
Cam		Pg. 53	.100			1	.100	
Bearing	NHSFR-188pp	Pg. 25	.402			4	1.602	
Bearing	NHSFR-166pp	Pg. 25	.402			4	1.608	
Differential	Arch Gear B216-200	Pg. 109	1.000			1	1.000	
Gear Mitre		Pg. 159	.120			6	.720	
Spur Gear		Pg. 159	.025			8	.200	
Bellows	Metal Bellows w3-55	Pg. 33	.057			1	.057	
							10.238	x .679 = 6.952
(C2) MOTOR	Globe mm/or ss	85°C Class A	29.340			1	29.340	x .679 = 19.992
(C3) MANUAL			---				---	

λ_o = RAW FAILURE RATE. λ_A = ADJUSTED FOR K FACTORS $\lambda_T = \lambda_A \times$ QTY (λ in 10^6 hours)

3.4-22

PRELIMINARY RELIABILITY ANALYSIS

ASSEMBLY : CUE MIRROR (D) X = 27.370

PART DESCRIP	PART NO	EST STRESS	λ_0	K FACTORS	λ_A	QTY	λ_Q	REMARKS
(D1) DRIVE & FILTER								
Microswt, HW	$1S_x1$	40°C 1 op/da	.049			2	.098	
Resistors, Filter		40°C 50%	.170			4	.680	
Caps (CK05)		40°C 30%	.0055			2	.011	
" (CS13)		40°C 40%	.023			1	.023	
Connector		40°C -	1.020			1	1.020	
Geneva Drive		Pg. 160	2.473			1	2.473	
Ball Bearings		Pg. 25	.402			7	2.814	
Gears		Pg. 156	.630			3	1.890	
Cams		Pg. 53	.100			1	.300	
Brake, Warner	RF80	Pg. 65	1.660			1	1.660	
							10.969	x .679 = 7.448
(D2) MOTOR								
Motor, Brush, Inland	T-0709	85°C Class A	29.340			1	29.340	x .679 = 19.922
(D3) MANUAL							---	

λ_0 = RAW FAILURE RATE. λ_A = ADJUSTED FOR K FACTORS λ_Q = λ_A × QTY (λ in 10^6 hours)

PRELIMINARY RELIABILITY ANALYSIS

ASSEMBLY : PRISM ASSEMBLY (E) X = 5.212

PART DESCRIP	PART NO	EST STRESS	λ_o	K FACTORS	λ_A	QTY	λ_Q	REMARKS
(E1) DRIVE & FILTER								
Servo Pot		40° 20%	1.300			1	1.300	
Caps (CK)		40° 30%	.0055			2	.011	
Resistors (film)		40° 50%	.170			4	.680	
Caps (CS)		40° 40%	.023			1	.023	
Connector		1 mate/500 hrs.	1.020			1	1.020	
Ball Bearings		Pg. 25	.402			6	2.412	
Gears		Pg. 156	.630			3	1.890	
							7.336	x .679 = 4.981
Bellows coupling								
(E2) MOTOR, BRUSHLESS		85° Class A	.340			1	.340	x .679 = .231
(E3) MANUAL							---	

λ_o = RAW FAILURE RATE λ_A = ADJUSTED FOR K FACTORS λ_Q = λ_A × QTY   (λ in 10^6 hours)

PRELIMINARY RELIABILITY ANALYSIS

ASSEMBLY : ZOOM & EYE PIECE (F) X = 5.403

DATA DISPLAY X = 7.483

PART DESCRIP	PART NO	EST STRESS	λ_o	K FACTORS	λ_A	QTY	λ_Q	REMARKS
(F1) DRIVE & FILTER								
Capacitor (.47)		40° 40%	.023			3	.069	
Resistors (film)		40° 50%	.170			4	.680	
Potentionment	6213-Helipot IR	40° 20%	1.360			1	1.300	
Connector		40°C 1 mate/500	1.020			1	1.020	
Ball Bearings	SROSS Barde	Pg. 25	.402			2	.804	
Bearings	SFR655 "	Pg. 25	.402			1	.402	
	SFR16655	Pg. 25	.402			1	.402	
	sfr2-655	Pg. 25	.402			1	.402	
Gears, Sterling	E23-50-P3	Pg. 159	.120			3	1.206	
"	E23-170-P3	Pg. 159	.120			1	.120	
Cam	SK115375	Pg. 53	.100			1	.100	
Ball bushing,	INST 369-55	Pg. 48	.050			6	.300	
Ball Bearing, Filter		Pg. 25	.402			4	.804	
Bushing EP		Pg. 48	.050			1	.050	
Gears, Filter		Pg. 159	.120			2	.240	
							7.611	x .679 = 5.172
(F2) MOTOR, BRUSHLESS	SK114312	85°C Class A	.340			1	.340	x .679 = .231
(F3) MANUAL								
(FG) Data Display								
Lamps			1.000		10		10.000	
Connector		40° mate 500 hrs.	1.020		1		1.020	
							11.020	x .679 = 7.483

λ_o = RAW FAILURE RATE. λ_A = ADJUSTED FOR K FACTORS λ_Q = λ_A × QTY (λ in 10^6 hours)

4-26

PRELIMINARY RELIABILITY ANALYSIS

SPECIAL HANDLING ~~SECRET~~

ASSEMBLY : DOOR ASSEMBLY (H) X = 79.136

PART DESCRIP	PART NO	EST STRESS	λ_o	K FACTORS	λ_A	QTY	λ_Q	REMARKS
DRIVE MECH (H1)								
Motor	Globe [illegible] or ss	85° Class A	29.340			1	29.340	6000 RPM with gear box to 300 RPM
Microswt (type C)	Honeywell	40° 1 op/da	.049			2	.098	Limit & position Ind.
Bearings, Ball	N.H.	Pg. 25	.402			5	2.010	In Drive Links/2ea on Shaft; 3 ea on Links
Gear,	Itek	Pg. 156	.603			1	.603	On Motor Shaft S.S.
" drive	Itek	Pg. 159	.120			1	.120	Sector on Link Alum
							32.171 x .679 = 21.844	
MAIN ASSEMBLY (H2)								
Pyro		Pg. 337 (squibbs)	20.1			2	40.200	Primary Door Release
Bearings	N.H.	Pg. 35	.402			8	3.216	Preloaded pairs for Hinges & Side Plates
Valve		Pg. 395 ( )	.761			1	.761	Pressure Relief
							44.177 x .679 = 29.996.	

λ_o = RAW FAILURE RATE λ_A = ADJUSTED FOR K FACTORS λ_Q = λ_A × QTY (λ in 10^6 hours)

SPECIAL HANDLING ~~SECRET~~

PRELIMINARY RELIABILITY ANALYSIS

ASSEMBLY : ENCODER, OPTICAL (A5B) X = 21.846 x 10-6

PART DESCRIP	PART NO	EST STRESS	λ_0	K FACTORS	λ_A	QTY	λ_ϕ	REMARKS
LAMP ASSEMBLY 1e								
INC. Lamps		---	1.000			3	3.000	Used (2) per enc.
							3.000	x .679 = 2.037
PHOTO READ ASSEMBLY								Use (12) per enc.
Transistor		Th = 20	.195			1	.195	Li, NPN, Lo Pwr.
Resistor (RC07)		40° 50%	.0035			3	.001	
							.206	x .679 = 1.678
PREAMP								Use (4) per enc.
Resistor		40°C 50%	.0035			10	.035	
Cap (CK05)		40° 30%	.0055			1	.006	
1C (FC709)		-- ---	.400			1	.400	
							.441	x .679 = 1.198
SQUARING AMP								Use (2) per enc.
1C 2(709)			.400			16	6.400	
Cap (CK05)		40° 30%	.0055			1	.006	
Resistor (RC07)		40° 50%	.0035			60	.210	
" (RN55)		40° 50%	.170			15	1.020	
							7.636	x .679 = 5.185

λ_0 = RAW FAILURE RATE λ_A: ADJUSTED FOR K FACTORS $\lambda_\phi = \lambda_A \times$ QTY (λ in 10^6 hours)

3.4-28

PRELIMINARY RELIABILITY ANALYSIS

ASSEMBLY: ENCODER, OPTICAL (A5B) - Con't

PART DESCRIP	PART NO	EST STRESS	λ_0	K FACTORS	λ_A	QTY	λ_Q	REMARKS
RFI FILTER								Use (3) per enc.
Choke, RF		75° Class A	.200			1	.200	
Resistor		40° 50%	.0035			1	.004	
Cap, mica		40° 10%	.0003			1	.000	
" CS13		40° 40%	.023			1	.023	
							.227	x .679 = .462
GVDC SUPPLY								Use (1) per enc.
Zener		Tn.30	.770			1	.770	
Resistor		40° 50%	.0035			1	.007	
							.774	x .679 = .526
TOTALIZING COUNTER								Use 1 per enc.
1C			.400			19	7.600	
							7.100	x .679 = 5.160

1X 45B = 21.846

λ_0 = RAW FAILURE RATE λ_A = ADJUSTED FOR K FACTORS λ_Q = λ_A × QTY   (λ in 10^6 hours)

PRELIMINARY RELIABILITY ANALYSIS

ASSEMBLY : ENCODER, OPTICAL (A5B) - Con't

PART DESCRIP	PART NO	EST STRESS	λ_o	K FACTORS	λ_A	QTY	λ_ϕ	REMARKS
LOGIC AMP								Use (2) per enc.
1C (fus)			.400			8	3.200	
							3.200	x .679 = 2.173
AUX OUTPUT ASSEMBLY								Use (2) per enc.
1C (946)			.400			4	1.600	
							1.600	x .679 = 1.086
DIRECTION SENSING								Use (2) per enc.
Resistor		40° 50%	.0035			4	.014	
Caps (CK05)		40° 30%	.0055			4	.022	
1C			.400			2	.800	
Diode, si.		Tn = .25	.222			4	.888	Small signal si.
							1.724	x .679 = 2.341

λ_o = RAW FAILURE RATE λ_A = ADJUSTED FOR K FACTORS λ_ϕ = $\lambda_A \times$ QTY (λ in 10^6 hours)

3.4.3 Failure Mode and Effects Analysis

3.4.3.1 Introduction

Three submissions of FMEA reports are planned for this contract. Contained herein is the first report which is deliverable for PDR. This analysis is based upon preliminary design information since detailed drawings and specifications are not yet available. Subsequent analysis will be referenced directly to the applicable drawings and specifications using the family tree, system block diagram and reliability block diagrams as guides to organization. The FMEA report is concentrated in the area of critical functions and long lead items. An analysis was performed to determine critical functions, then each such function was analyzed.

The detailed report was summarized into areas representing potentially critical and major problem areas, potential safety hazards, a preliminary list of life limited devices and possible added compensations for potentially critical or major problem areas. The detailed analysis report is augmented with narrative and block diagrams where necessary for ease of understanding.

Reference document no.61SD52 was used as a guide in the performance of this analysis. A draft procedure for FMEA is complete which assigns responsibility as it relates Itek operations and includes consideration of life limited devices and safety hazards but in other respects is in accordance with 61SD52.

The following criteria was used to categorize assumed failure mode and effects:

Safety and/or Hazard Modes - in accordance with MIL S 38130.

Failure Class - the determination of the failure impact is based upon the proper operation of the optical instrument as a tool for obtaining useful visual data.

3.4.3.2 Potential Critical Problems

Scan	Without this function, the system is completely inoperative. This is a complex function having a significant probability of occuring.
Window	This forms part of the vehicle pressure integrity. A back-up is provided in the event of excessive leakage but because of crew safety, this assembly is considered critical. (The telescope main barrel and objective lens assembly are the back-up.)
Optical Path	Any disturbance or condition which causes the optical parameter (i.e., distortion, resolution, focus, etc) to be severely degraded will result in mission abort (for the telescope). The probability of this occuring in not great, but the impact would be critical.
Door	A mal-function of the protective shroud which prevents its opening (or restricts) results in an aborted mission. The complexity of the mechanism with pyros and drive trains results in a significant probability of this occurance.
Solar Blanking	If the response time of this mechanism is slow (or inoperative) serious injury to the operator may occur. Although the mechanism is simple and has a low probability of occuring,since failure would directly affect the safety of the operator, it is considered a critical item.
Cue Mirror	If the switch contacts are welded, it will cause the Geneva pin to hit a mechanical stop with each index. If the impact is strong enough, the pin eventually could bend or break, disabling the Cue Mirror from any control, even manual.

Potential Critical Problems (cont.)

Window Assembly — The window seal is considered of major importance even though there is a back-up first element seal, since complete mission abort may be required in the event of failure. This seal is the responsibility of the vehicle contractor.

3.4.3.3 Potential Major Problems

Door Assembly

1. If one motor fails, the door cannot maintain a strong seal when closed. Thus, contaminants may enter which may degrade the optical elements.

2. If Pyro release does not work, and one motor fails, it could interfere with performance.

3. If motor and its pyro both fail, the door could be jammed in any position. If not open wide enough to allow scanner to work, it would be a Critical failure. However, two unique failures are necessary before this condition could occur .

4. If motor A failed and pyro B were activated, the door drive would be completely inoperative and the scanner could not work. If the door were opened wide enough for the scanner to operate, the impact of the failure would not be as great, but the door could not be closed and the scanner would not be protected from unfriendly environment. If pyro A were then activated, the door would fail safe - open, however, the scanner would still not be fully protected.

Lo Power Changer

1. If a bearing should freeze so that the manual control were ineffective, and it froze in a mid-position it would cause excessive distortion.

Brushless Motor Torque (2 winding type used in Pitch and Roll drives)

1. Open winding. The second winding provides enough torque to meet the spec. but the resultant slower response is a degradation in performance.
2. Partial or complete short. Same as above.
3. Both windings fail. The possibility of two failures occuring puts this in the major problem area.

Gimbal Bearing (either pitch or roll)

1. If the bearing has high friction, is sticky, jumps, or brinells the performance will be degraded.

Scanner Launch Locks & Pyros

1. Both redundant pyros do not fire.

Sun Sensor

1. Both redundant sensors open.
2. " " " shorted.
3. One sensor shorted.

3.4.3.4 Compensations for Potential Problem Areas

Cue Mirrors

1. Two switches in series redundancy
2. Drive Geneva slower to lessen pin impact, in case of welded switch contacts, so pin won't bend.
3. Drive mirror via slip-clutch, while manual control connects to mirror (Push-to-operate knob).

Window

(If window and first element seals both leak excessively)

1. Pressure sensor between the window and element to indicate loss of pressure.

Door Assembly

1. Redundant pyros in each motor linkage
2. Redundant mechanical drives
3. Redundant switch
4. Operator control of motor power and direction.

Brush Type Motor

1. Redundant brush leads.
2. High enough armature resistance or other current limiting component.
3. Wound - field motor in place of PM type.
4. Threshold sensor (current)
5. On - off switch
6. Circuit - breaker

Blanking

1. Redundant springs, either of which is able to close the shutter fast enough.

2. Have the redundant sun-sensors isolated from each other, so that if one is shorted, it does not affect the success of the other.

3. Have one of the four filters dense enough so that the operator can safely use the manual control to open the shutter, (or white cardboard etc).

Specify a sequence of operation before using the telescope in order to prevent inadvertent exposure to sun (e.g. insert dense sun filter before use or have image projected onto a screen behind eye piece before viewing).

3.4.3.5 Life Limited Devices

A preliminary list of items that could be life-limited

1. Lamps
2. Brushes
3. Epoxy
4. Lubricants
5. Adhesives
6. Switches
7. Paint
8. Insulation

Definition of Life-Limited:

1. Shelf life less than five years.
2. Age life less than one year.
3. Operational life of less than 500 hours.

3.4.3.6 Possible Safety Hazards

Window

If both the window and first element seals leak excessively, the rate of pressure loss may exceed safe conditions.

Blanking Shutter

The criticality of this device has been covered elsewhere. However, there should be an operator safety procedure when using the manual control to open the shutter.

PREP. BY E. F. Powers
DATE 9-8-67

FAILURE MODE & EFFECTS ANALYSIS

PROJECT NO. 9300
TASK OPTICAL SYSTEM

ASSY	FUNCTION	FAILURE MODE	CAUSES	PROVISIONS	EFFECT	PROB.	SAFETY
Scanner	Track & Scan	Inoperative	Motor, Encoder, Bearings, Lock pyro, Shroud	Redundant Enc, Motor windings	A	C	IV
Dero Prism	Image Orient	Automatic Control inop.	Motor, bearings	Manual	C	C	I
Eye piece	Fine Focus	Seize	Corrosion	None	A	Nil	I
Window	Seal, Filter, Optics	Leaks excessively	Dynamic loads	Back-up seal	B	C	II
Mag. Changer	Hi/Lo Power	Inop. (in or out)	Motor, Bearings, Clutch	Manual	C	C	I
Optical Elements	Optics	Aberration	Dynamic loads (mis alignment)	None	A	C	IV
Blanking	Solar Blanking	Inoperative	Spring, Sensing	Redundant	A	C	III
Data Display	Mission Data	Bulb Inoperative	Hot Spot	Sensing. None	C	C	I
Cue Mirror	Mission Data	Inop. (out)	Motor, Bearings, Geneva drive.	Manual	C	C	I
Shroud	Protection	Inop (mid range)	Motor, Bearing	Redundant Drive	B	C	II

NOTE: This tabulation is intended to show the major functional assemblies and the possible failure mode. The detailed analysis for each assembly is included elsewhere in this report.

Prep. by: I Spiegel

Approv. by:

Date 9-13-67

Itek

SPECIAL HANDLING ~~SECRET~~

FAILURE MODE & EFFECTS ANALYSIS

Project No. 9300

Task Descrip. OPTICS

ITEM IDENTIFICATION	DESCRIPTION MANUFACTURE & NO. MIL-SPEC	ASSUMED FAILURE MODES	POSSIBLE CAUSE	SYMPTOM & CONSEQUENCE	COMPENSATION & RESULTS	POSSIBLE ADDITIONAL COMPENSATION	EFFECT ON ASSEMBLY	EFFECT ON SYSTEM	FAILURE CLASS	PROB. OF OCCURRENCE	SAFETY AND/OR HAZARDS MODES	LIFE LIMITED DIVICES
Fixed Optical Elements		Breaks to the extent that it is no longer a useful element.	Shock. Thermal. Mounting. Acoustical Noise.	Target is out of focus.	None	None	Loss of Integrity	Loss of Usefulness	A	C	I	
		Hairline Crack	"	Distortion	None	None	Loss of Integrity	Usefulness of telescope Seriously impaired	A	C	I	
		Degradation of coating	Handling. Environ. Age.	Parts of target less distinct than others	None	None	Loss of light. Transmission	Hardship on operator to perform task.	B	C	I	
Moveable Optical Elements	Zoom Assembly	Decentration of optics	Shock Vibration. Travel. Rotation of optics.	Resolution is lower.	None	None	Light rays not optimized.	Operator Hardship	B	C	I	
		Frozen in one pos	Bearing Broken wire	Cannot vary the magnification	Manual Override	None	Automatic Control Inoperative	Performance is limited	B	C	I	
	Lo-Power Changer Ass'y	Frozen in one pos.	Bearings Broken wire	Cannot Drive to other pos.	Manual Override	None	Automatic Control Inoperative	Hi Magnification available only.	B	C	I	
	Prism	Spacing Change	Shock Vibration	Distorted image	None	None	Light rays not optimized.	Limited Performance. Operator Hardship. Time-to-perform is out of spec.	B	C	I	

Legend If an optical element in the Lo Power Changer breaks or cracks, we can move it out of the optical path and use the telescope in the hi-magnification mode. In the case of the Zoom moveable elements and the rotating prism, they cannot be moved out of the way of the optical path.

A loss of optical clarity (distortion), will work a hardship on the operator and in some cases, he may exceed the time allowed to perform the operation.

SPECIAL HANDLING ~~SECRET~~

RF'10/34

MDF-667

Prep. by: I. Spiegel
Approv. by:
Date 9-7-67

Itek

SPECIAL HANDLING ~~SECRET~~

FAILURE MODE & EFFECTS ANALYSIS

Project No. 1300
Task Descrip. WINDOW ASSEMBLY

ITEM IDENTIFICATION	DESCRIPTION MANUFACTURE & NO. MIL-SPEC	ASSUMED FAILURE MODES	POSSIBLE CAUSE	SYMPTOM & CONSEQUENCE	COMPENSATION & RESULTS	POSSIBLE ADDITIONAL COMPENSATION	EFFECT ON ASSEMBLY	EFFECT ON SYSTEM	FAILURE CLASS	PROB. OF OCCURRENCE	SAFETY AND/ OF HAZARDS MODES	LIFE LIMITED DIVICES
Window Ass'y		Crack or excessive seal-leakage.	Envir.	Drop in pressure of chamber between window & 1st elemen Pressure equalizing vent comes into play & gas escapes to environment but at slow desig rate.	st element ote: If this springs a leak he gas willescape o the environment uickly, rather han being programmed y the capillary ent tube, since t is downstream rom this tube. See Below		None	Loss of pressure normal (system eing vehicl	B	C	I	No (epoxy used to mount may have shel life and/ or age life).
		Leak at Window seal & 1st element seal	"	(Increased flow rate or pressure drop in vehicle) No noticeable effect on optics.	None	Include pressure sensor between 1st element & window to indiaate when window leak occurs.		Drop in vehicle press. Mission Abort.	A	C	IV	

Legend

SPECIAL HANDLING ~~SECRET~~

FMEA Index

Detailed FMEA's for individual subassemblies are presented in the following sections:

Tracking Assy	3.7.7.1
Fix Fold Mirror & Mount	3.8.6
Protective Shroud	3.9.7.1
Telescope Assy	3.10.2.7.1
Pechan, Blanking & Cue	3.10.3.7
Zoom Assy	3.10.4.7

3.5 STUDIES

3.5.1 Protection Shroud

This section presents the development of the current baseline for the protective shroud.

3.5.1.1 Original Baseline

The design concept baseline for protection of the AO external hardware from the degrading effects of exhaust impingement was given in Technical Proposal 3010-66-052, 28 November 1966, and Addendum 3010-66-073, 22 December 1966. Figure 3-21 of the proposal is reproduced in Figure 3.5.1-1 for reference.

This configuration calls for the on-orbit ejection of a portion of the aerodynamic fairing with the remaining portions providing partial sun shielding and exhaust product baffling. The bonnet contained a spring loaded door which acted as a sun shield when open and provided a labyrinth or "soft" seal when closed. As stated in paragraph 4.0 of the referenced proposal addendum, this approach was considered adequate at that time.

3.5.1.2 Shroud Configuration Development

While the original baseline concept was considered adequate, there was considerable concern, both at G.E. and Itek, that the contamination problem might be worse than anticipated. During the first 10 to 12 weeks of the program (Jan. - March 1967) repeated attempts were made by Itek and GE to obtain definitive exhaust products data (see 3.5.3.5). As a result of this concern and lack of data, a development cycle was initiated at the April TD meeting. (Refer to table 3.5.1-1 for descriptions of the configurations discussed below.)

Configurations A through G were presented at the April TD meeting. Since only configuration D provided positive sealing, Itek was directed to proceed with that approach.

At the May TD meeting, configuration E_1 was presented. Direction was received to initiate a detailed shroud study. (See Addendum 3.5.1-A)

At the 12 May meeting, configurations F_1 through H were presented. Itek was directed to proceed with configuration H which had minimum impact on the position of the AO window proposed by DACo.

At the 18 May meeting, configurations J through L were presented. Since configuration L afforded the minimum violations of the design requirements, Itek was directed to proceed with this.

At the 25 May meeting with GE, AF and Aerospace, configuration M and N were presented. Since configuration N met all requirements except the horizon scanner interference, for which a system solution appeared possible, Itek received direction to use this as the new baseline.

3.5.1.3 Current Baseline

The current shroud baseline concept is shown on drawing 114400 and is discussed in detail in section 3.9.

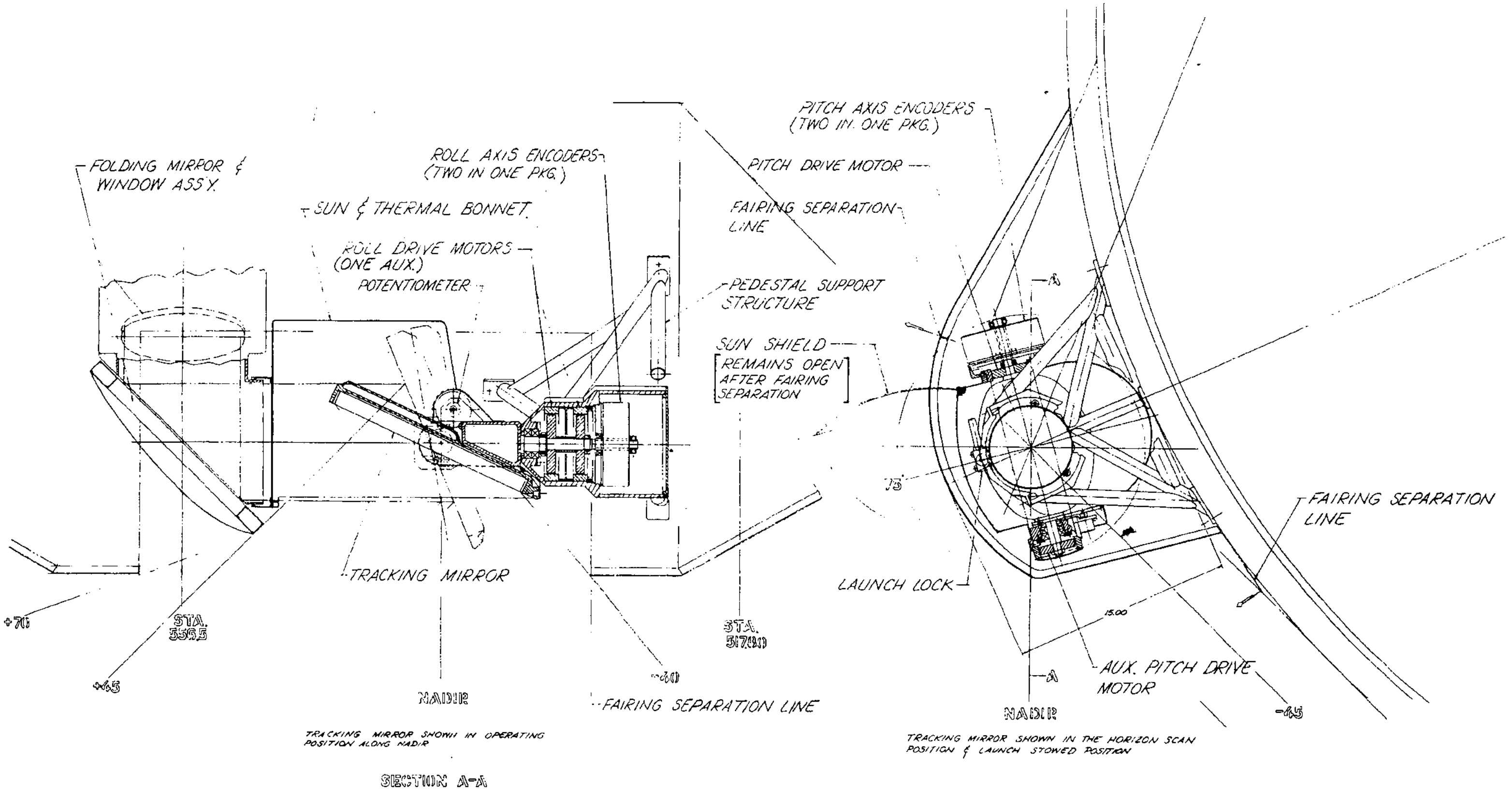
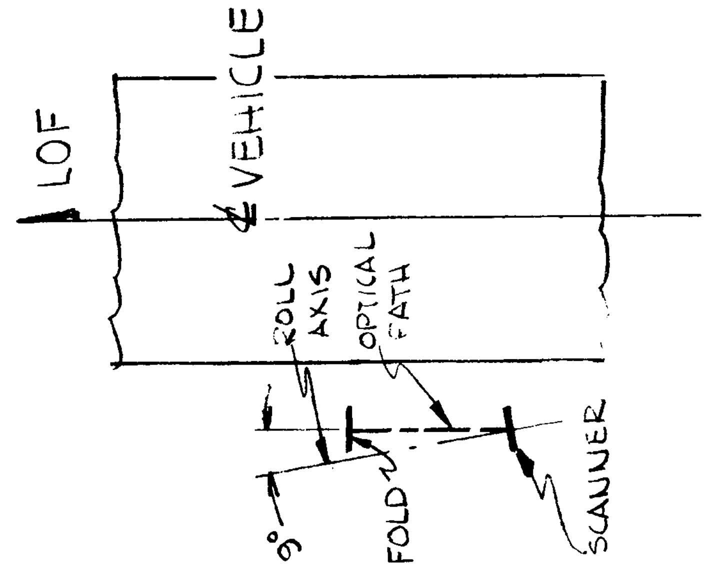


Fig. 3.5.1-1 — Tracking pedestal assembly (8-inch aperture)

BY: C. SURETTE	TITLE:	PAGE OF
DATE: 24 MAY 67		MODEL:
DWG:	Figure 3.5.1-2	CHKD BY:
LOADS:		DATE:

CONFIGURATION "N"

9° GIMBAL CANT OUTBOARD



CONFIGURATION "M"

9° TOTAL CANT INBOARD

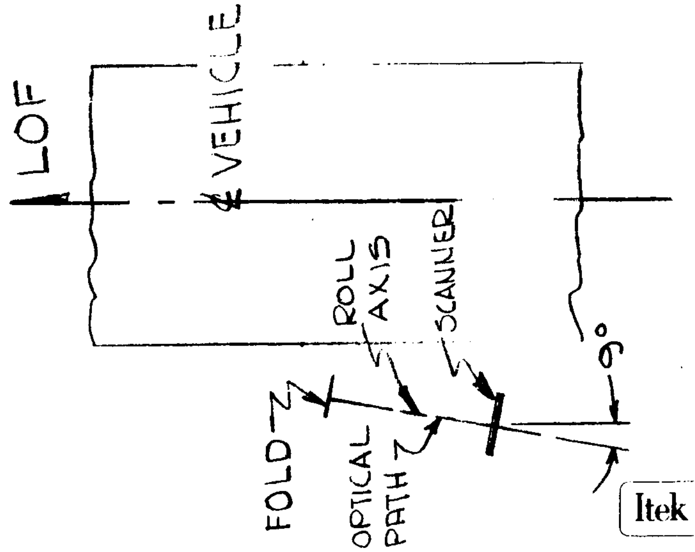


Table 3.5.1 - 1

SHROUD STUDY SUMMARY

Configuration	Drawing	Date Presented to GE	Cant Angle	Cant Type *	Seal Type	Shroud Description	Closure Description	Sun Shield Description	Minimum Sun Angle
Original Baseline	Fig. 3-21 of proposal 3010-66-052, Also see 3010-67-072. para. 4.2	28 Nov.1966	0^o	-	Labyrinth	Rotating (roll) enclosure "Mailbox"	Spring loaded door roll actuated	Door	8^o
A	114257	6 Apr. 1967	5^o	gimbal outboard	Labyrinth	Rotating (roll) enclosure "Mailbox"	Spring loaded door Roll actuated	Door	8^o
B	114253	6 Apr. 1967	5^o	gimbal outboard	Labyrinth	Concentric Half Cylinders	Rotating (roll) half cylinder	Spring loaded flap	8^o
C	114255	6 Apr. 1967	5^o	gimbal outboard	Labyrinth	Fixed baffles plus curtain	Motor actuated curtains	Spring loaded flap	8^o
D	114258	6 Apr. 1967	5^o	gimbal outboard	Positive	Fixed housing	Motor actuated double door	Door	8^o
E_o	114256	6 Apr. 1967	5^o	total outboard	Labryinth	Rotating (roll) enclosure "Mailbox"	Spring loaded door Roll actuated	Door	8^o
F_o	114252	6 Apr. 1967	5^o	total outboard	Labryinth	Concentric Half Cylinders	Rotating (roll) half cylinder	Spring loaded flap	8^o
G_o	114254	6 Apr. 1967	5^o	total outboard	Labyrinth	Fixed baffles plus curtain	Motor actuated curtain	Spring loaded flap	8^o

* See Figure 3.5.1-2

[redacted]

Table 3. 5. 1-1, Continued

Configuration	Drawing	Date Presented to GE	Cant Angle	Cant Type *	Seal Type	Shroud Description	Closure Description	Sun Shield Description	Minimum Sun Angle
E_1	114275 114276(Scanner) 114272 (Structure)	4 May 1967	9°	total outboard	Positive	Fixed housing	Motor actuated double door	Door	8°
F_{1A} F_{2A} F_{3A}	905803 905816 905813	12 May 1967	9°	total inboard	Positive	Fixed housing	Motor actuated double door	Door	8°
G_{1B} G_{2B} G_{3B}	905807 905814 905815	12 May 1967	9°	gimbal outboard	Positive	Fixed housing	Motor actuated double door	Door	8°
H	905805	12 May 1967	9°	total outboard	Positive	Fixed housing	Motor actuated double door	Door	8°
J	905820	18 May 1967	8°	total outboard	Positive	Fixed housing	Motor actuated single door	Door	8°
K_{1A} K_{2A}	905819 905817	18 May 1967	8°	total outboard	Positive	Fixed housing	Motor actuated single door	Door	8°
L	905818	18 May 1967	8°	total inboard	Positive	Fixed housing	Motor actuated single door	Door	8°
M	905824	25 May 1967	9°	total inboard	Positive	Fixed housing	Motor actuated single door	Door	0°

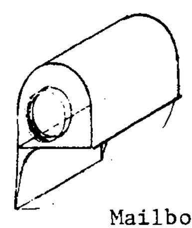
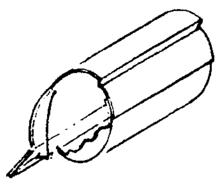
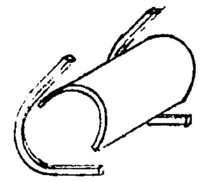
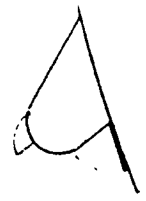
Table 3.5.1 1, Continued

Configuration	Drawing	Date Presented to GE	Cant Angle	Cant Type *	Seal Type	Shroud Description	Closure Description	Sun Shield Description	Minimum Sun Angle
N	305825	25 May 1967	9°	gimbal outboard	Positive	Fixed housing	Motor actuated single door	Door	0°
Current Baseline	114400	With PDR report	9°	gimbal outboard	Positive	Fixed housing	Motor actuated single door	Door	0°

[redacted]

Table 3.5.1-2

(Presented at the April T D Meeting)

Parameter	Configuration A		Configuration B		Configuration C		Configuration D	
	Deployed	Stowed	Deployed	Stowed	Deployed	Stowed	Deployed	Stowed
ENVELOPE (sq.ft.)								
Max. Protrusion	29.88	18.00	26.75	18.00	26.00	18.25	30.62	18.00
Frontal Area	5.17	4.23	6.06	5.50	5.89	5.07	5.27	3.84
Surface Area	29.1		31.05		32.0		32.0	
WEIGHT (lbs.)	13.50		16.25		24.0		19.00	
ELEC. POWER (watts)	12*		12*		12*		25**	
COMPLEXITY	50		80		100		20	
RELIABILITY DEGRAD.	60		90		100		15	
RADIATOR AREA (sq.ft.)								
Blocked	3.6		3.6		3.6		10.6	
Shielded	3.2		4.3		5.7		0	
	 Mailbox		 Rotating Can		 Curtain		 Inner Fairing	

* Additional peak operational power required to meet maximum slew acceleration of EC-331

** Power requirement to stow (not at peak power phase of flight)

TABLE 3.5.1-3

(Presented at the May 24th Meeting)

SHROUD PARAMETERS

	"M" INLINE	"N" OUT OF LINE
Max. Protrusion		
Deployed	25.00 in.	24.88 in.
Stowed	15.65 in.	15.65 in.
Frontal Area		
Deployed	3.9 sq. ft.	3.6 sq.ft.
Stowed	2.1 sq. ft.	1.8 sq. ft.
Radiator Blockage	6.4 sq. ft.	4.5 sq. ft.
Surface Area	18 sq. ft.	18 sq. ft.
Weight	10 lbs.	10 lbs.

9300-67-X130
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2 PAGES

Attachment 3.5.1-A

5 May 1967

To: A. L. Wright, Manager, Project 9300

From: J. E. Brogan, Subcontract Project Manager

Subject: Investigation of External Interface Problems

1. Background

The current design of the externally-mounted acquisition optics presents the following interface problems:

- interference of the shroud with the viewport and molecular sieve.
- excessive radiator coverage and blockage.
- optical interference with the horizon scanner field-of-view.
- excessive protrusion from surface of Lab Module.

Itek is directed to perform investigations aimed at the minimization of the above problems.

2. Investigation Design Goals

The design goals for the external installations are as follows:

a. Maximum Protrusion

The maximum protrusion of the stowed system shall not exceed 15.65 in. from the radiator surface. The following constraints, in descending order of acceptance, are delineated:

- The radiator can be "cut-away" in the area of mechanical interference with the scanner.
- Vignetting in obliquity from 35° to 45° is permissible on the vehicle side only.
- The forward scan field can be reduced from +70° to +50°.
- The aft scan field can be reduced from -40° to -35°.

b. Viewport and Molecular Sieve Interference

The shroud shall not interfere with the viewport and the molecular sieve outlet.

c. Radiator Coverage and Blockage

The surface area of the radiator which is covered and blocked by fixed and movable parts of the shroud shall be minimized - at the expense of shroud design complexity as necessary.

d. Horizon Scanner Field-of-View

The shroud, in either the stowed or deployed position, shall not violate the horizon scanner field-of-view plus 1 inch.

This study shall result in layouts and performance data of sufficient detail to permit reliable system decision making.

The gimbal configuration remains at 9° total cant; i.e. the optical axis between the folding and tracking mirrors is oriented at 9° with respect to the roll axis of the OV. The roll gimbal axis is also oriented at 9° to the OV roll axis.

3. Study with 9° Gimbal Cant

When the above study is completed, similar results shall be provided for a design based on 9° gimbal cant.

4. The study shall be based on the following schedule:

12 May 1967	First cut; trades identified
19 May 1967	Itek Recommendation/s
25 May 1967	GE/AF/AS/Itek/DAC. meeting at Radnor (tentative date)

J. E. Brogan
Subcontract Project Manager
General Electric Company

3.5.2 Cant Angle

3.5.2.1 Description

Cant angle is incorporated into the AO system to increase the minimum roll tracking rate. By canting the tracker roll axis relative to the vehicle roll axis, the increase in minimum roll rate is achieved by a cross roll component of the vehicle forward velocity vector.

The cant angle effects can be realized by either an inboard or outboard cant. The inboard cant, however, necessitates a tracking pedestal support of approximately twice the length of the outboard cant.

Cant angle may be incorporated in two ways:

a. Total Cant - when the tracker roll axis is coincident with the optical axis (between the tracker and fold mirror) and not parallel to the vehicle roll axis.

b. Gimbal cant - When the tracker roll axis is not coincident with the optical axis (betewen the tracker and fold mirror) or parallel to the vehicle roll axis. For this cant scheme the optical axis between tracker and fold is parallel to the vehicle roll axis.

3.5.2.2 Design Considerations

Cant angle impact on shroud design was primarily aggrevating the maximum protrusion criteria as the inboard total cant moved the tracker roll housing outboard and the outboard total cant moved the folding mirror bezel outboard Inboard gimbal cant had the distinct disadvantage of severely cutting into the radiator. Outboard gimbal cant was most advantageous because:

1) No radiator interference

2) between pitch angles of +40° and +10° more than 35° roll towards the vehicle was realizable without vignetting.

3) Gimbal pitch and roll total angular excursions increased from 55° in pitch to 58°, and 90° in roll to 103°. This angular excursion obviously meant restudying pitch and roll torquer selections.

4) Mirror size was not a significant factor in cant method (inboard, outboard, total or gimbal) because when the tracker mirror would increase the fold would decrease a similar amount and vice versa.

3.5.2.3 Conceptual Layouts

Cant angle concepts and layouts are listed in Section 3.5.1 Drawing SK 905842 indicates gimbal angles required to cover the target area with a 9° gimbal cant.

3.5.2.4 Further Analysis

Final vignetting and obscuration studies are still necessary.

3.5.3 Engineering Trade-off Studies

The Work Statement, WS011 (3010-67-090), requires that certain engineering trade-off studies be performed. A verbatim statement of these requirements is as follows:

"The Subcontractor shall perform trade-off studies to support the Acquisition Optics (AO) design. These studies shall culminate in reports which shall be prepared and submitted in accordance with DRL GE-MOL-S-115. Specific studies to be performed shall include, but not be limited to, a weight trade-off which shall consider the following:

(a) Minimum weight of the fairing/scanner combination
(b) Minimum added launch vehicle propellant weight to overcome the fairing drag during ascent.
(c) Minimum added orbital vehicle weight for orbit adjust propellant to overcome the effects of the scanner drag both in the stowed and operating position.

Related areas to be considered in preparing this trade-off study shall include:

(a) Means of reducing the scanner envelope with minimum compromise to the optical, mechanical and thermal aspects of the design.
(b) Means of protecting the optical surfaces and other operating components from the degrading effects of exhaust impingement emanating from the attitude control and orbit-adjust thrustors, and from the effects of meteoroid erosion.
(c) Trade-off of torquer size and weight versus peak power requirements.

The result of this trade-off study shall be a report which describes in detail the various trade-off factors and arrives at a scanner design approach which is optimum from the point of view of over-all system weight compatible with the other aspects of the design (e.g., optical, mechanical, electrical, and thermal."

3.5.3.1 Minimum Weight of Fairing/Scanner Combination

To attain a minimum fairing/scanner weight the volume to encompass the external AO components must be minimized. Of the two major components on the exterior of the vehicle (fixed fold and scanner) only the scanner position could be changed significantly. Volume to be enclosed by the fairing is controlled dimensionally by:

1. Length of optical path from the centerline of the fixed fold to the face of scan mirror,

2. The protrusion of the equipment radially from the vehicle wall and,

3. The circumferential dimension required by the AO components

To obtain a minimum distance from fixed fold to scanner, the system was designed to maintain the no vignetting, no obscuration in pitch (+10° to +40°) requirement and maintain the scanner pitch axis as close to the front face of the scan mirror as weight and balance would allow.

It was readily shown in concept drawings of the "Protective Shroud Study" (section 3.5.1) that the maximum radial protrusion from the vehicle is dictated by the fixed fold bezel. The position of the fixed fold mirror however, is determined by the scan mirror line of sight requirements in roll. In the stow position the scan mirror offers little protrusion.

The circumferential dimension is determined by the scanner pedestal mount spread at the vehicle wall, the mirror minor diameter, and the requirement of protection to be afforded the penetration fitting.

The evolution and trade off of the above to attain minimum envelope without compromise of the design requirements and to incorporate mirror protection are discussed in sections 3.5.1 and 3.5.2.

3.5.3.2 Launch vehicle propellant minimization study deleted per letter of 20 April 1967 from R.G. Emerson to D. Jones (DIN 50099-164-2)

3.5.3.3 Orbital adjust propellant minimization study deleted per letter 20 April 1967 from R. G. Emerson to D. Jones (DIN 50099-164-2)

3.5.3.4 Scanner Envelop optimization study

This topic is related to section 3.5.3.1 and is discussed in its references.

3.5.3.5 Exhaust Impingement Study

In order to insure that the impingement of exhaust products for the translation thrustors will not be allowed to degrade the performance of the AO, a three-fold effort was conducted.

First, an intensive search was made of open literature on contamination of optical surfaces in a space environment. The major sources were the Gemini Mid program Conference report (NASA SP-121) and the Attitude Control Rocket Exhaust Plume Experiment Final Report (AFRPL-TR-67-3) supplied by GE. This data was inconclusive. The interpretation of flight data is somewhat contradictory and the extrapolation from idealized test conditions questionable. Combustion product data was received from G. E. at the 2 February 1967 TEM; however, further specific data has been unavailable from AF/Aerospace sources.

Secondly, at the request of G. E., Itek has proposed a cooperative effort to support the forthcoming Air Force test program. The initial proposal is shown in Addendum 3.5.3.5-A. It is anticipated that further requests for participation will be made shortly by G. E.

The third aspect of this effort is reflected in the shroud design concept baseline described in Section 3.9. Due to the lack of firm definition of the exhaust hazard and as a result of the study detailed in Section 3.5.1, Itek proposed the current "positive seal" approach. At a meeting on 25 May 1967 and as a result of AF/Aerospace direction, G. E. directed Itek to implement the configuration shown on drawing SK905825 (Configuration N). This resulted in the design concept being changed from the lightweight labrynth sealed shroud to a shroud completely enclosing the external components. This required an operational door which is tightly closed during translation thrustor operation.

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To: Distribution

Date: 4 April 1967

From: R. R. Heath

Page 1 of 2 Pages

Subject: Recommendations for Exhaust Impingement Experiment

ADDENDUM 3.5.3.5-A

Scope

This memo presents preliminary recommendations for Itek participation in an experiment to be conducted by Air Force/DACo to investigate the effects of translation engine exhaust on vehicle external material and devices. Since the experiment is not as yet well defined, the recommendations presented are quite general. All Itek participation will be through General Electric.

Approaches

There are two general approaches which could be taken. The first and most desirable, from a strictly program viewpoint, is to include a scaled model of the external AO hardware to be located appropriately in the exhaust path. The second approach is to fabricate a sample block containing optical and finish samples in several configurations such that fundamental information could be obtained. It is strongly recommended that both approaches be implemented since this would yield maximum benefit to the program and the state of the art in general. Details of each approach follow.

Scale Model

The model, constructed to the scale of the experiment (probably 1:4), should include the two mirrors (fixed), a window, some supporting structure, the fairing or shield and thermal control finishes. In addition, it may be necessary to include temperature control to maintain the surfaces at the expected temperatures. Some study is necessary to determine how such things as opening size and location in the exhaust stream should be scaled since this may be a function of the pressure and mean free path in the test chamber.

Sample Block

The sample block should be designed to allow the sample to be mounted in three locations: 1) perpendicular to the exhaust stream, 2) parallel to the exhaust stream, and 3) inside a baffled enclosure. Each sample location would contain the following items:

1. Aluminum surface mirror with no overcoat

2. Aluminum surface mirror with silicon-monoxide overcoat

3. Optical glass blank (probably BK-7)

4. Thermal finishes

These samples would be on the order of one inch in diameter. Consideration must be given to the shape of the blank since this will effect the exhaust flow in its vicinity.

Handling Considerations

The samples would be prepared at Itek and initial optical and thermal measurements made. They would then be enclosed in a suitable bag and/or container purged with dry nitrogen. All subsequent handling should be done under strictly controlled conditions.

After the test, the chamber should be purged with dry nitrogen and the samples repackaged in their container which will again be purged with dry nitrogen. The samples should be returned in this condition to Itek for final measurements.

RRHeath

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pm

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3.5.3.6. POWER CONSUMPTION VS. WEIGHT OF SCANNER

BRUSHLESS DC TORQUE MOTORS

This data is presented in satisfaction of section 1.1.1. (item C) of statement of work WS011, dated 3 January 1967.

A situation exists where a DC torque motor is used in an equipment in which weight, power, and energy must all be minimized. An important design consideration is optimum sizing of the motor with respect to weight, power, and energy budgets. It is shown that if the weight and energy budgets are not considered simultaneously, the overall design may stray from optimum.

In the following descussions, it is assumed that there is a choice from among several motors that can satisfy the torque-speed requirements of a load. It is first assumed that the load torque can be developed independently of the available peak power; the peak power restriction is then added.

The rationale behind the weight and energy budgets is assumed to be for purposes of minimizing total system weight of motor plus energizer. Accordingly, the most realistic criterion for sizing a torque motor under such conditions is to select a motor such that the total weight of motor plus energy source is a minimum. The key electrical consideration is total energy, not power.

We will define the optimum design as the one which minimizes total system weight. After solving for the optimum motor weight we will than introduce the constraint on peak power and show that this limitation causes a shift from the minimum weight design.

The volt-ampere load the torquer presents to the power supply is computed as follows:

$$V = I R + K_B \omega \qquad (1)$$

$$I = T / K_T \qquad (2)$$

$$P = V I = I \ (I R + K_B \omega)$$

$$= I^2 \ R + K_B \ I \omega$$

$$= \underbrace{I^2 \ R}_{\text{armature loss}} + \underbrace{\frac{K_B \omega \ T}{K_T}}_{\text{mechanical work done on load}} \quad \text{watts} \qquad (3A)$$

Where:

V = terminal voltage, volts
I = current, amperes
K_B = back voltage constant, volts/rad/sec
R = armature resistance, OHMS
K_T = torque constant, ft-lb/amp
T = load torque, ft.-lbs
ω = load speed, rad/sec
P = power in watts drawn from energy source

The ratio K_B/K_T may be shown to have the value 746/550 equal to 1.36, which represents a conversion factor from English mechanical units of power (Ft-lb/sec) to watts.

Using this constant, and substituting I from equation (2), equation (3A) may be expressed in alternate form:

$$P = \left(\frac{T}{K_T} \right)^2 R + 1.36 \ T\omega \qquad (3B)$$

The second term in equation (3B) represents the mechanical power transferred to the load by electromagnetic induction. This term may be minimized by keeping both T and ω small. This implies low torque and low speed. These parameters are functions of the mechanical design and the equipment operation profile. Torque has components due to friction and acceleration. The friction component will be minimized by using very high quality bearings. Acceleration and speed are contractor imposed requirements over which Itek has no control.

It should be pointed out that in this application the torquers will be operated at very low speeds so that the I^2R loss term (due to contractor imposed acceleration torque) far exceeds the mechanical load power term. Since the second term is negligible compared with the first, we will concentrate our efforts on minimizing the loss term.

The loss term represents heating due to resistance of the copper windings. It is possible to minimize such losses by using an oversize motor with smaller R. The question now arises: Will the extra weight of the oversize motor be offset by a greater reduction in the energizing system's weight? Note again that the discussion that follows is concerned only with minimizing the I^2R term in either of equations (3). We seek to minimize the weight induced by the loss term by an optimum trade-off of motor weight and energizing system weight.

Referring to (3B), the loss term is shown to be related to the torque T, the torque constant K_T, and armature resistance R.

A good design would be to choose a motor with large K_T and small R, at the same time keeping T to a minimum.

Although the torque loading is not a motor design parameter as such, it is quite apparent that any steps taken to minimize T will be well rewarded since the power loss is proportional to T^2. We might briefly consider how operating time t_O, and power loss zre related.

A frequent problem is choosing a torque or speed profile required to move a member some angle θ_o in time t_o. Notice that peak power is related to torque $(T)^2$. It is observed that one should keep the peak torque substantially constant to maximize its second integral, which is position, and to avoid excessively high peak powers associated with tapered or contoured torque profiles, which contribute negligible integrated position. Accordingly, the profile selected will be one that provides constant rates of acceleration and deceleration. Such a profile is illustrated in Figure 1:

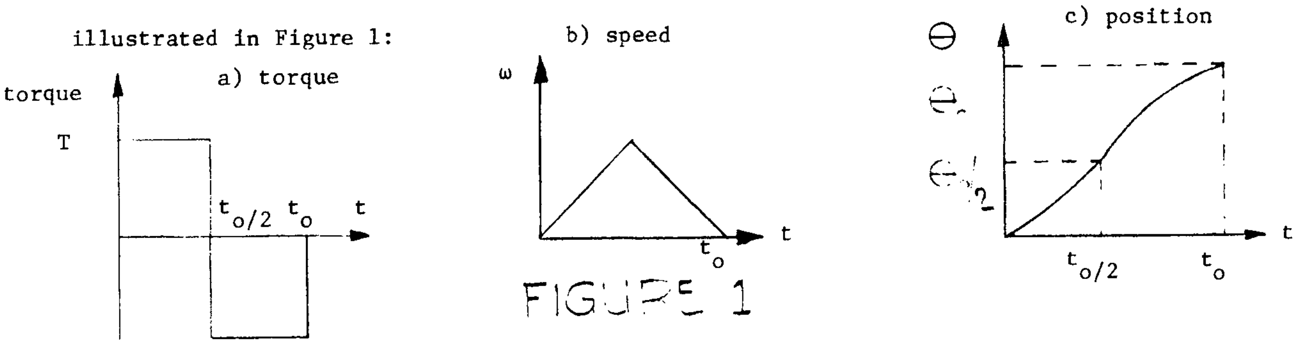


FIGURE 1

Using the well-known formula of mechanics, $\theta = 1/2\, \alpha\, t^2$, we have:

$$\frac{\theta}{2} = \frac{1}{2}\, \alpha \left[\frac{t_o}{2}\right]^2 , \quad \alpha = \frac{4\, \theta_o}{t_o^2} \tag{4}$$

Since $T = T\alpha$, we have:

$$T = \frac{4J\theta_o}{t_o^2} \tag{5}$$

Substituting (5) into (3 B), we have:

$$P = \left(\frac{T}{KT}\right)^2 R + 1.36\ TW$$

$$= \left[\frac{4J\theta_o}{t_o^2\ KT}\right]^2 R + 1.36\ TW$$

$$= \frac{(4J\theta_o)^2}{t_o^4\ K_T^2}\ R^2 + 1.36\ TW \tag{6}$$

Power is therefore related to $(1/t_o)^4$. The fourth power behavior of power vs. t_o calls for obvious use of t_o as long as is possible. The penalty of high accelerations is immediately made obvious.

We now examine the factors R and K_T, those motor parameters which we seek to optimize.

The torque in a brushless torque motor is given by the equation:

$$T = B\,IlnrK_1 \qquad (7)$$

Where:

B = field strength, Gauss

I = Armature current, amperes

l = length of conductor (in field B), meters

n = Number of stator turns

r = radius of armature, meters

K_1 = Geometrical form factor and proportionality constant

Equation (7) places in evidence the conflicting factors that must be compromised in order to secure an acceptable design for a given application.

A high field strength B is very desirable. This will be achieved by using a premium grade magnetic material. In order to achieve high torque sensitivity K_T (torque/ampere) it is desirable that l, n, and r all be large. Large r and l implies a thick motor with large radius, but this means a high weight. Large n and l implies a long winding length, and hence large ohmic resistance R. Making available more winding area (l and r) will permit use of a larger wire size, with attendant lower resistance, at the expense of more weight. K_1 accounts for such non-linearities as leakage flux and air gaps. In general, large dimensions will tend to increase K_1, again at the expense of weight.

It is thusly apparent that a design of torque motor with arbitrarily high torque/current and with arbitrairly low power loss for a fixed weight (itself arbirtarily low) is impossible.

Having examined the factors which effect power consumption, we now consider the weight - power trade-off. We seek to minimize total system weight of motor plus energizer subject to a maximum power constraint.

The total system weight is given by the following equation:

$$\underset{\text{total}}{\underset{\uparrow}{W_t}} = \underset{\text{motor}}{\underset{\uparrow}{W_m}} + \underset{\text{energizer}}{\underset{\uparrow}{W_e}} \qquad (8)$$

The term W_e may be estimated as follows:

$P(W_m)$ = motor input power as a function of weight that is required to develop load torque

$\frac{P(W_m)\ (\text{Hours})}{\eta}$ = watt-hours delivered from energizer through control amplifier of efficiency η

$$W_e = \frac{P(W_m)\ (\text{Hours})F}{\eta \qquad K_2} = \text{energizer weight in pounds} \qquad (9)$$

Where:

F = gimbal factor which is a measure of torque sensitivity decrease at wide angles.

Hours = total operating time in hours

K_2 = energizer factor, Watt hours per pound (Typically 80 watt hours/lb for a silver-zinc battery and 1000 watt-hours/lb of fuel for a $H_2 - 0_2$ fuel cell)

Equations (8) and (9) are combined to obtain:

$$W_t = W_m + \frac{P(W_m)\ (\text{Hours})F}{\eta \qquad K_2} \qquad (10)$$

If $P(W_m)$ was known in closed mathematical form, we could evaluate the following derivative to obtain the most favorable operating point:

$$\frac{d\,W_t}{d\,W_m} = 1 + \frac{(d\,P(W_m)/dW_m)\ (\text{Hours})\ F}{\eta \qquad K_2} \quad ; \quad \frac{d\,W_t}{d\,W_m} = 0 \text{ for an extremum.} \qquad (11)$$

Previous discussion has pointed out that there are strong geometrical relationships between power and weight at a given torque level amoung output torque and motor geometry. Accordingly, a closed relationship $P(W_m)$ does not seem unreasonable.

The following manufacturer's data was used to emperically derive a relationship between $P(W_m)$ and W_m:

AEROFLEX BRUSHLESS TORQUERS

Model	Weight (pounds)	Peak Torque	Power at Peak Torque	Power at 40 oz.-in	Diameter Thickness ratio
TQ 34 W	1.0	40 oz. -in.	20 watts	20 watts	3.38/.73 (4.5/1)
TQ 52 W	5.0	220 oz. - in.	80	2.6	5.1/1.5 (3.4/1)
TQ 82 W	11.3	480 oz. -in.	90	.62	8.19/1.40 (5.2/11)

INLAND BRUSH TYPE MOTORS

Model	Weight	Peak Torque	Power at Peak Torque	Power at 1 ft.-lb.	Diameter Thickness ratio
T 3203	1.13	1.0 ft. -lb.	100 watts	110 watts	3.24/1.09 (3/1)
T 4036	3.0	1.8 ft. -lb.	91	28	3.9/1.25 (3.1/1)
T 5135	8.5	4.0 ft -lb.	119	7.4	5.1/1.5 (3.4/1)
T 7202	11.5	11.0 ft -lb.	375	3.1	7.2/1.6 (4.4/1)

Note that all of the above motors are of "pancake" construction, with approximately the same diameter thickness ratio.

Plotting the Aeroflex and Inland data on log-log paper (Figure 2) shows that the following function is a reasonable description of the relationship between weight and power:

$$P = \frac{P_o}{W^a} \qquad (12)$$

where a ranges from about 1.3 to 1.7. A value of 1.5 is a reasonable slope for fitting the plotted data. Accordingly, we have

$$\text{Aeroflex } P\ (W_m) = \frac{20}{W^{1.5}} \text{ watts} \qquad (13A)$$

$$\text{Inland } P(W_m) = \frac{133}{W^{1.5}} \qquad (13B)$$

The validity of equation (12) was confirmed in discussions with Aeroflex.

Equations (13 A) + (13 B) relate the motor power required to develop 40 in.-oz. in the Aeroflex line and 1.0 ft.-lb. in the Inland Line as a function of motor frame size or weight. The selected motors of each vendor all have comparable thickness to diameter ratios: i.e., they are the same approximate form factor.

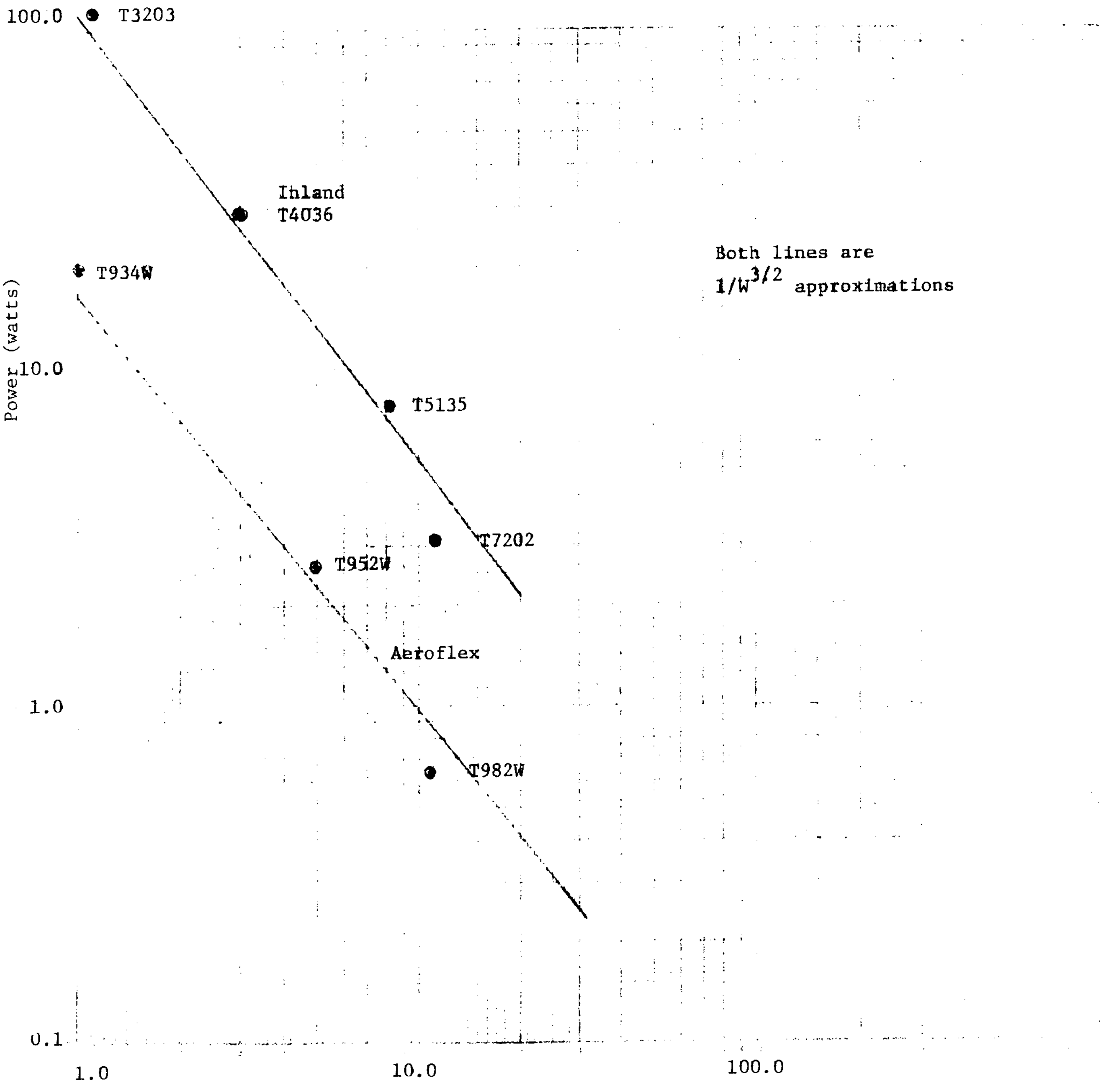
In summary, use of equation(11) with a P (W_m) of equation (12) permits sizing of torquers so that the total weight of motor and energy source can be minimized. The constants 20 and 133 will change as $(T/40)^2$, depending on the motor, where T is the new load torque.

The Globe line of small DC brush torque motors was also examined for behavior as to watts vs. frame size at fixed torque. The power losses tended to remain fixed as the frame size went up, thus indicating that the increased copper, and hence reduced copper losses, were offset by higher brush friction, windage, and other losses.

A previous report (document BOS-COR-9300-67-080 dated 16 March, 1967) estimated that a 9.4 hour total operating time was realistic. Let us examine the weight-power trade-off on this basis. The latest value of roll torque is 104 oz.-in./winding (total of 208 oz.-in.) and 13 oz.-in. per winding (26 oz.-in. total) on the pitch axis. The gimbal factors of 1.1 for pitch and 1.4 for roll of the referenced memo are assumed to apply.

FIGURE 2

Graphical Determination of Power vs.
Weight Law for Two Types of DC Torquers



The total weight of each axis 's motor is computed from equation (10) repeated below:

$$W_t = W_m + \frac{P(W_m)\ (\text{Hours})\ (F)}{K_2} \qquad (10)$$

Each winding of one half the rated torque is assumed to act independently; the power and weight value/axis is double that of a single winding. This last equation (10) may be rewritten as:

$$W_t = 2W_m + \frac{P_0\ K_3\ 2}{W_m} \qquad (14)$$

where:

$$K_3 = \frac{(\text{Hours})\ (F)}{\eta\ \ K_2}$$

F pitch = 1.1; F roll = 1.4 η = 0.8 (estimated)

K_2 , the incremental fuel energy constant in watt hours/lb. is estimated as 1 Kw-hr./lb for the oxygen-hydrogen fuel cell. Using this data, we have:

$$K_3 \text{ pitch} = \frac{(1.1)\ \ (9.4)}{(.8)\ \ (10^3)} = 1.29 \times 10^{-2}$$

$$K_3 \text{ roll} = \frac{(1.4)\ \ (9.4)}{(.8)\ \ (10^3)} = 1.64 \times 10^{-2}$$

The Aeroflex motor constants P_0 are computed as:

$$P\ (W_m\ ) = \frac{P_0}{W_m{}^{1.5}}$$

Using a 5 lb. TQ-52 at 104 oz.-in., the power is computed as 80 $(104/220)^2$ or 18 watts. Accordingly,

$$18 = \frac{P_0}{5^{1.5}}\ , \qquad P_0 = (18)\ (\ 5)^{2/3} = 200 \qquad (15A)$$

Using a 1.0 lb. TQ-34 at 13 oz.-in, the power is computed as $(13/40)^2$ (20) or 2.2 watts.

$$2.2 = \frac{P_0}{1^{3/2}}\ , \quad P_0 = 2.2 \qquad (15B)$$

The general form of (14) may be differentiated with respect to W_m ; this yields:

$$\frac{dW_t}{dwn} = 2 + 2\ P_0\ K_3\ \ (3/2)\ Wm^{-5/2} \qquad (16)$$

Setting the derivative equal to zero to find the extremum, we have:

$$W_m = \left[3/2\ \ P_0\ \ K_3 \right]^{2/5} \qquad (17)$$

Using previously computed values of P_0 and K_3 of the roll and pitch axes, we have:

$$W_m \text{ Pitch} = [(1.5)\ (1.64)\ 10^{-2}\ (2)\ 10^{2}]^{2/5}$$

$$= [4.9]^{2/5} = 1.87 \text{ lbs.}$$

$$W_m \text{ pitch} = [(1.5)\ (1.29)\ 10^{-2}\ (2.2)]^{2/5}$$

$$= [4.3 \times 10^{-2}]^{2/5} = 0.27 \text{ lbs.}$$

The total system weights then become:

$$W_t = 2W_m + \frac{2P_o\ K_3}{W_m^{\ 3/2}} \qquad (14)$$

For Pitch

$$W_t = (2)\ (0.27) + \frac{(2)\ (1.29)\ 10^{-2}}{(0.27)^{3/2}}$$

$$= (0.54) + .41 = .95 \text{ lbs.}$$

For Roll

$$W_t = (2)\ (1.87) + \frac{(2)\ (200)\ (1.64)\ 10^{-2}}{(1.87)^{3/2}}$$

$$= 3.74 + 2.56 = 6.30 \text{ lbs.}$$

We now consider the peak powers that would be drawn:

$$P = \frac{2P_o}{W^{3/2}}$$

For Pitch

$$P \max = \frac{(2.2)\ (2)}{(.27)^{3/2}} = 31.5 \text{ watts}$$

For Roll

$$P\ max = \frac{(2)\ (200)}{(1.87)^{3/2}} = 155 \text{ watts}$$

These values are clearly above the subsystem power budget of 105 watts. Since no energy storage is available, the motor weights must be increased above the optium to restrict power. Just how to do this is a matter of engineering judgement. Consideration of other sub system power consuming elements dictate that about 40 watts of power be allocated for roll and about 4 watts be allocated for pitch. This decision makes use of motors near Aeroflex catalogue sizes, namely a double model TQ-34 for pitch and a single, somewhat reduced model TQ82W for roll.

Using these motors, we have:

$$P\ pitch = \frac{2\ P_o}{W^{3/2}} = \frac{(2)\ (2.2)}{(1.0)^{3/2}} = 4.4 \text{ watts}$$

$$P\ roll = \frac{(2)\ (200)}{(5)^{3/2}} = 36 \text{ watts}$$

The total system weights become:

For Pitch:

$$W_t = 2W_m + \frac{2\ P_o\ K_3}{W_m^{3/2}}$$

$$= (2)\ (1) + \frac{(2)\ (2.2)\ (1.29)\ (10^{-2})}{1^{3/2}}$$

$$2 + .06 = 2.06 \text{ lbs.}$$

For Roll:

$$W_t = 2\ W_m + 2\ \frac{P_6\ K_3}{W_m^{3/2}}$$

$$= (2)\ (5) + \frac{(2)\ (1.64)\ (200)\ 10^{-2}}{5^{3/2}}$$

$$= 10 + 0.59 = 10.59 \text{ lbs.}$$

The analysis may be summarized as follows:

OPTIMUM DESIGN

(Minimum system weight of motors plus energizer - no peak power restriction)

	Motor Weight	Fuel Weight	Total Weight	Peak Power
Pitch Axis	0.54	0.41	0.95	31.5
Roll Axis	3.74	2.56	6.30	155.0
	4.28	2.97	7.25	186.5

CONSTRAINED DESIGN

(Subsystem power limited to approximately 40.4 watts for roll and pitch actuations)

	Motor Weight	Fuel Weight	Total Weight	Peak Power
Pitch Axis	2.0	0.06	2.06	4.4
Roll Axis	10.0	0.59	10.59	36.0
	12.0	0.65	12.65	40.4

The effect of the peak power limitation is to increase the weight of the sub-systems motors from the minimum of 4.28 lbs to 12.0 lbs. At the same time, the fuel load (elsewhere in the system) drops from 2.97 lbs. to 0.65 lbs. The net system effect is a motor weight increase of 7.72 lbs., which is partially offset by a fuel savings of 2.32 lbs. The net system weight penalty caused by the peak power restriction is 5.40 lbs. (7.72-2.32).

We conclude as follows:

Although fuel weight is not an Itek responsibility, it is shown that minimum system weight (which is assumed to be a mutual objective) can only be realized when the gimbal motors are considered together with their energy source. Since the peak powers associated with the minimum weight design are prohibitive, the subsystem motor selection must be shifted away from the optimum point. There are no clear cut design procedures for locating the best constrained optimum. Engineering judgement, rather than mathematical formulation, must be used to allocate weight and power of individual mechanisms so as to stay within allowable subsystem budgets.

Having determined that a total of 40 watts power can be allocated for slewing the gimbals, the design study results can be used to some extent to guide the motor design for minimum weight. To this end, Itek is specifying motor with premium magnetic components (high B), and investigating optimum motor geometries to obtain maximum torque with minimum weight and power consumption. These investigations will proceed until further returns are no longer obtained.

3.5.4 Miscellaneous Analysis

This section contains several supporting analytical studies of general nature. They are principally products of the System Engineering effort.

3.5.4.1 Line-of-Sight and Gimbal Angles

3.5.4.1.1 Scope

This memo supercedes the two referenced memos which may be discarded since the appropriate information has been repeated here for completeness.

Presented herein are derivations for line-of-sight (LOS) and gimbal angles for orthogonal pitch and roll axes with a cant rotation about the third orthogonal axis (vehicle z-axis). Results of computer solutions to these expressions are given for several angular positions and worst case conditions.

3.5.4.1.2 Derivation of LOS Angles

The line of sight with respect to vehicle reference is formed by taking the unit line of sight vector and applying the pitch, roll and cant rotations. Thus:

$$\hat{L}_v = \hat{L}\, R_{p\ell}\, R_{r\ell}\, R_c$$

where: $\hat{L} = \begin{bmatrix} 0 & 0 & 1 \end{bmatrix}$

$$R_{p\ell} = \begin{bmatrix} \text{Cos } p\ell & 0 & -\text{Sin } p\ell \\ 0 & 1 & 0 \\ \text{Sin } p\ell & 0 & \text{Cos } p\ell \end{bmatrix} \quad ; \; p\ell = \text{LOS pitch angle}$$

$$R_{r\ell} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \mathrm{Cos}\ r\ell & \mathrm{Sin}\ r\ell \\ 0 & -\mathrm{Sin}\ r\ell & \mathrm{Cos}\ r\ell \end{bmatrix} \quad ;\ r\ell = \text{LOS roll angle}$$

$$R_c = \begin{bmatrix} \mathrm{Cos}\ c & \mathrm{Sin}\ c & 0 \\ -\mathrm{Sin}\ c & \mathrm{Cos}\ c & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad ;\ c = \text{gimbal cant angle}$$

This gives:

$$\hat{L}_v = \begin{bmatrix} \mathrm{Sin}\ p\ell\ \mathrm{Cos}\ c + \mathrm{Cos}\ p\ell\ \mathrm{Sin}\ r\ell\ \mathrm{Sin}\ c \\ \mathrm{Sin}\ p\ell\ \mathrm{Sin}\ c - \mathrm{Cos}\ p\ell\ \mathrm{Sin}\ r\ell\ \mathrm{Cos}\ c \\ \mathrm{Cos}\ p\ell\ \mathrm{Cos}\ r\ell \end{bmatrix} = \begin{bmatrix} L_x \\ L_y \\ L_z \end{bmatrix} \qquad (1)$$

Now define the two pointing angles with respect to vehicle coordinates as:

α = roll angle measured in y-z plane.

β = pitch angle measured in x-z plane.

Then:

$$\mathrm{Tan}\ \alpha = \frac{-L_y}{L_z} \quad ; \qquad \mathrm{Tan}\ \beta = \frac{L_x}{L_z}$$

Now, solving for LOS angles:

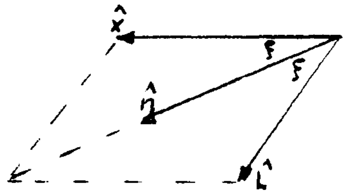
$$\mathrm{Tan}\ r\ell = \mathrm{Tan}\ \beta\ \mathrm{Sin}\ c + \mathrm{Tan}\ \alpha\ \mathrm{Cos}\ c \qquad (2)$$

$$\mathrm{Tan}\ p\ell = \frac{\mathrm{Tan}\ \beta\ \mathrm{Cos}\ r\ell - \mathrm{Sin}\ r\ell\ \mathrm{Sin}\ c}{\mathrm{Cos}\ c} = \frac{-\mathrm{Tan}\ \alpha\ \mathrm{Cos}\ r\ell + \mathrm{Sin}\ r\ell\ \mathrm{Cos}\ c}{\mathrm{Sin}\ c} \qquad (3)$$

3.5.4.1.3 Derivation of Gimbal Angles

Since the optical path between the moving and fixed mirrors is always parallel to the vehicle x-axis and the line-of-sight from the moving mirror is known from the derivation above, the normal to the moving mirror can now be found.

$$\hat{n} = \frac{\hat{L}_v + \hat{X}}{\left|\hat{L}_v + \hat{X}\right|} = \begin{bmatrix} n_x \\ n_y \\ n_z \end{bmatrix} \tag{4}$$



Now, referring to Figure 1 and doing a bit of trigonometry the gimbal angles are:

$$\text{Tan rg} = (n_y \sec c + (n_x - n_y \tan c) \sin c) / n_z \tag{5}$$

$$\text{Tan pg} = (n_x - n_y \tan c) \cos c \cos rg / n_z \tag{6}$$

It is possible to arrive at a more fundamental form of equations (5) and (6) by use of equations (1) and (4). However, there is little computational difference, so equations 2, 3, 5, and 6 were used in computer program PLUM to calculate the LOS and gimbal angles. A copy of PLUM is attached for those interested.

3.5.4.1.4 Results

The results of this study are given on individual data sheets attached. Each sheet gives either the LOS or gimbal angles for a given cant angle. The top chart shows the extreme or worst case angles along with the corresponding LOS angles with respect to vehicle axes. This gives the pitch and roll ranges required to cover the entire +70° to -40° in pitch and ±45° in roll. The lower chart shows the angles corresponding to various points of interest within the total range. For example, no vignetting is allowed between +10° and +40° in pitch. Data for any other angles is available on request.

```
                                31/32/3300 FORTRAN (2.1)/MSOS   03/30/67
      PROGRAM PLUM
C
C                PLOT      NO    ANGLES
C          K   NEW  SAME  PLOT  LOS  GIM
C          1               X          X
C          2               X     X
C          3    X                     X
C          4    X                X
C          5        X                 X
C          6        X            X
C
      KPL=49
C
      RPD=0.0174532925
      DPR=1.0/RPD
C
  100 READ(60,1001) AMIN,AINC,AMAX,BMIN,BINC,BMAX,CD,K
      GO TO(101,102,101,102,101,102) K
  101 WRITE(61,1003) CD
      GO TO 103
  102 WRITE(61,1004) CD
  103 IF(AMIN.EQ.200.0) 800,104
  104 GO TO(110,110,105,105,110) K
  105 CONTINUE
      IF(AXISXY(KPL,10,11,10.0/26.0,10.0,11.0,0.0,-1.0,0.0,0.0,10.0/26.0
     $,2)) 106,900
  106 CONTINUE
      CALL PLOTXY(0.1,-0.9,0,0)
      CALL PLOTID(0)
  110 CR=CD*RPD
      SINC=SIN(CR)
      COSC=COS(CR)
      IMIN=AMIN
      IINC=AINC
      IMAX=AMAX-AMIN+1.0
      DO 300 I=1,IMAX,IINC
         AD=I+IMIN-1
         AR=AD*RPD
         TANA=TANF(AR)
         JMIN=BMIN
         JINC=BINC
         JMAX=BMAX-BMIN+1.0
         DO 280 J=1,JMAX,JINC
            BD=J+JMIN-1
            BR=BD*RPD
            TANB=TANF(BR)
              RR=ATANF(TANA*COSC+TANB*SINC)
              PR=ATANF((TANB*COS(RR)-SINC*SIN(RR))/COSC)
              GO TO(120,122,120,122,120,122) K
  120         SINP=SIN(PR)
              COSP=COS(PR)
              SINR=SIN(RR)
              COSR=COS(RR)
              ENX=SINP*COSC+COSP*SINR*SINC+1.0
```

```
                      ENY=-SINP*SINC+COSP*SINR*COSC
                      ENZ=COSP*COSR
                      QEN=SQRT(ENX*ENX+ENY*ENY+ENZ*ENZ)
                      ENXN=ENX/QEN
                      ENYN=ENY/QEN
                      ENZN=ENZ/QEN
                      FACT=ENXN-ENYN*SINC/COSC
                      RR=ATANF((ENYN/COSC+FACT*SINC)/ENZN)
                      COSR=COS(RR)
                      PR=ATANF((FACT*COSC*COSR)/ENZN)
         122          RD=RR*DPR
                      PD=PR*DPR
                      WRITE(61,1002) CD,AD,BD,RD,PD
                      GO TO(280,280,130) K
         130        X=(RD+50.0)/12.0
                    Y=(PD+50.0)/13.0
                    CALL PLOTXY(X,Y,0,11)
         280        CONTINUE
         300     CONTINUE
             GO TO 100
         800 CONTINUE
             GO TO(900,900,850) K
         850 CALL AXISXY(0,0,0,0.0,0.0,0.0,0.0,0.0,0.0,0.0)
         900 RETURN
       C
        1001 FORMAT(7F10.0,I2)
        1002 FORMAT(5X,5F10.2)
        1003 FORMAT(1H1,3HGIM,5X,3HCD=,F4.1,46X,1HI)
        1004 FORMAT(1H1,3HLOS,5X,3HCD=,F4.1,46X,1HI)
       C
             END
               3200 FORTRAN DIAGNOSTIC RESULTS - FOR    PLUM


NO ERRORS
LOAD,56
RUN
```

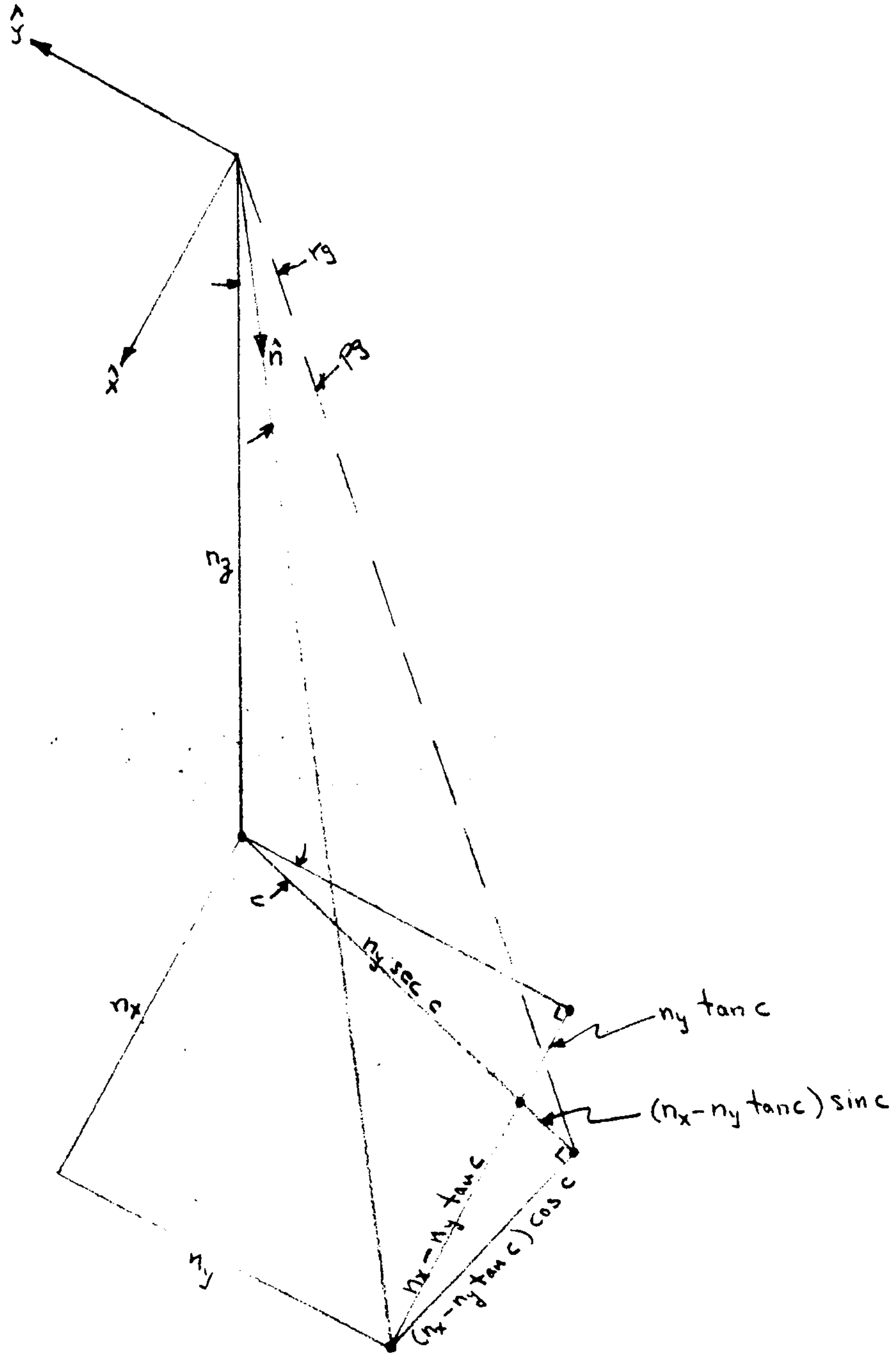

ŷ
x̂
n̂
rg
pg
n_z
c
$n_y \sec c$
n_x
$n_y \tan c$
$(n_x - n_y \tan c) \sin c$
n_y
$n_x - n_y \tan c$
$(n_x - n_y \tan c) \cos c$

Figure 1

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LOS Angles for 0° Cant

Geometry I

Extreme Angles		Corresponding LOS Angles (with respect to vehicle axes)	
Roll	**Pitch**	**Roll**	**Pitch**
-45.00		-45	any
	-40.00	0	-40
	+70.00	0	+70
+45.00		+45	any

PITCH

(LOS angles with respect to vehicle axes)

+70	+62.76 +45.00	+70.00 ±0	+62.76 -45.00
+40	+30.68 +45.00	+40.00 ±0	+30.68 -45.00
+10	+7.11 +45.00	+10.00 ±0	+7.11 -45.00
0	± 0 +45.00	± 0 ±0	± 0 -45.00
-40	-30.68 +45.00	-40.00 ±0	-30.68 -45.00
	+45	0	-45

ROLL

(LOS angles with respect to vehicle axes)

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LOS Angles for +5 ° Cant

Geometry I

Extreme Angles		Corresponding LOS Angles (with respect to vehicle axes)	
Roll	Pitch	Roll	Pitch
-46.92		-45	-40
	-40.26	+10	-40
	+70.08	-15	+70
+51.02		+45	+70

PITCH (LOS angles with respect to vehicle axes)

+70	+59.04 +51.02	+69.41 +13.47	+66.06 -37.12
+40	+27.09 +46.92	+39.82 +4.18	+34.15 -42.71
+10	+3.56 +45.33	+9.96 +0.88	+10.63 -44.45
0	-3.53 +44.89	± 0 ± 0	+3.53 -44.89
-40	-34.15 +42.71	-39.82 -4.18	-27.09 -46.92
	+45	0	-45

ROLL (LOS angles with respect to vehicle axes)

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LOS Angles for +6° Cant

Geometry I

Extreme Angles		Corresponding LOS Angles (with respect to vehicle axes)	
Roll	Pitch	Roll	Pitch
-47.26		-45	-40
	-40.37	+12	-40
	+70.11	-18	+70
+52.04		+45	+70

PITCH
(LOS angles with respect to vehicle axes)

+70	+58.26 +52.04	+69.15 +16.02	+66.65 -35.27
+40	+26.35 +47.26	+39.74 +5.01	+34.82 -42.20
+10	+2.85 +45.37	+9.94 +1.06	+11.33 -44.31
0	-4.24 +44.84	± 0 ± 0	+4.24 -44.84
-40	-34.82 +42.20	-39.74 -5.01	-26.35 -47.26
	+45	0	-45

ROLL
(LOS angles with respect to vehicle axes)

LOS Angles for +7 ° Cant

Geometry I

Extreme Angles		Corresponding LOS Angles (with respect to vehicle axes)	
Roll	Pitch	Roll	Pitch
-47.59		-45	-40
	-40.51	+14	-40
	+70.16	-21	+70
+53.01		+45	+70

PITCH
(LOS angles with respect to vehicle axes)

+70	+57.46 +53.01	+68.86 +18.51	+67.21 -33.33
+40	+25.62 +47.59	+39.64 +5.84	+35.49 -41.68
+10	+2.14 +45.40	+9.92 +1.23	+12.02 -44.16
0	-4.94 +44.79	± 0 ± 0	+4.94 -44.79
-40	-35.49 +41.68	-39.64 -5.84	-25.62 -47.59
	+45	0	-45

ROLL
(LOS angles with respect to vehicle axes)

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LOS Angles for +8 ° Cant

Geometry I

Extreme Angles		Corresponding LOS Angles (with respect to vehicle axes)	
Roll	**Pitch**	**Roll**	**Pitch**
-47.91		-45	-40
	-40.66	+16	-40
	+70.20	-24	+70
+53.93		+45	+70

PITCH

(LOS angles with respect to vehicle axes)

+70	+56.66 +53.93	+68.52 +20.93	+67.75 -31.30
+40	+24.88 +47.91	+39.53 +6.66	+36.15 -41.14
+10	+1.42 +45.42	+9.90 +1.41	+12.72 -44.00
0	-5.65 +44.72	± 0 ± 0	+5.65 [illegible]4.72
-40	-36.15 +41.14	-39.53 -6.66	-24.88 -47.91
	+45	0	-45

ROLL (LOS angles with respect to vehicle axes)

3.5-44

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LOS Angles for +9 ° Cant

Geometry I

Extreme Angles		Corresponding LOS Angles (with respect to vehicle axes)	
Roll	**Pitch**	**Roll**	**Pitch**
-48.21		-45	-40
	-40.83	+18	-40
	+70.26	-26	+70
+54.80		+45	+70

PITCH (LOS angles with respect to vehicle axes)

+70	+55.85 +54.80	+68.14 +23.26	+68.25 -29.16
+40	+24.13 +48.21	+39.41 +7.48	+36.81 -40.58
+10	+0.71 +45.43	+9.88 +1.58	+13.41 -43.83
0	-6.35 +44.65	± 0 ± 0	+6.35 -44.65
-40	-36.81 +40.58	-39.41 -7.48	-24.13 -48.21
	+45	0	-45

ROLL (LOS angles with respect to vehi-cle axes)

3.5-45

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LOS Angles for +10° Cant

Geometry I

Extreme Angles		Corresponding LOS Angles (with respect to vehicle axes)	
Roll	Pitch	Roll	Pitch
-48.51		-45	-40
	-41.03	+20	-40
	+70.32	-29	+70
+55.63		+45	+70

PITCH (LOS angles with respect to vehicle axes)

+70	+55.03 +55.63	+67.73 +25.51	+68.72 -26.92
+40	+23.39 +48.51	+39.27 +8.29	+37.45 -40.00
+10	+0.00 +45.44	+9.85 +1.75	+14.10 -43.66
0	-7.05 +44.56	± 0 ± 0	+7.05 -44.56
-40	-37.45 +40.00	-39.27 -8.29	-23.39 -48.51
	+45	0	-45

ROLL (LOS angles with respect to vehicle axes)

3,5-46

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Gimbal Angles for 0° Cant

Geometry I

Extreme Angles		Corresponding LOS Angles (with respect to vehicle axes)	
Roll	Pitch	Roll	Pitch
-45.00		-45	any
	+25.00	0	-40
	+80.00	0	+70
+45.00		+45	any

PITCH

(LOS angles with respect to vehicle axes)

+70	+76.38 +45.00	+80.00 ±0	+76.38 -45.00
+40	+60.34 +45.00	+65.00 ±0	+60.34 -45.00
+10	+48.55 +45.00	+50.00 ±0	+48.55 -45.00
0	+45.00 +45.00	+45.00 ±0	+45.00 -45.00
-40	+29.66 +45.00	+25.00 ±0	+29.66 -45.00
	+45	0	-45

ROLL
(LOS angles
with
respect
to vehi-
cle axes)

3.5-41

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Gimbal Angles for +5 ° Cant

Geometry I

Extreme Angles		Corresponding LOS Angles (with respect to vehicle axes)	
Roll	Pitch	Roll	Pitch
-42.80		-45	-40
	+24.07	+19	-40
	+80.12	-29	+70
+56.40		+45	+70

PITCH (LOS angles with respect to vehicle axes)

+70	+72.49 +56.40	+78.83 +26.30	+79.33 -25.99
+40	+56.63 +50.49	+64.54 +10.59	+63.66 -37.95
+10	+44.90 +48.64	+49.74 +5.93	+51.95 -40.58
0	+41.36 +48.23	+44.78 +4.98	+48.42 -41.12
-40	+26.07 +46.84	+24.90 +2.33	+33.13 -42.80
	+45	0	-45

ROLL (LOS angles with respect to vehicle axes)

3.5-48

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Gimbal Angles for +6° Cant

Geometry I

Extreme Angles		Corresponding LOS Angles (with respect to vehicle axes)	
Roll	**Pitch**	**Roll**	**Pitch**
-42.31		-45	-40
	+23.68	+22	-40
	+80.17	-34	+70
+58.07		+45	+70

PITCH **(LOS angles with respect to vehicle axes)**	**+70**	+71.65 +58.07	+78.35 +30.66	+79.73 -21.02
	+40	+55.86 +51.43	+64.34 +12.63	+64.26 -36.31
	+10	+44.15 +49.28	+49.63 +7.10	+52.60 -39.59
	0	+40.61 +48.80	+44.69 +5.97	+49.07 -40.25
	-40	+25.33 +47.17	+24.85 +2.79	+33.80 -42.31
		+45	**0**	**-45**
			ROLL (LOS angles with respect to vehicle axes)	

3.5-49

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Gimbal Angles for +7 ° Cant

Geometry I

Extreme Angles		Corresponding LOS Angles (with respect to vehicle axes)	
Roll	Pitch	Roll	Pitch
-41.81		-45	-40
	+23.25	+24	-40
	+80.24	-38	+70
+59.59		-45	+70

PITCH (LOS angles with respect to vehicle axes)	+45	0	-45
+70	+70.80 +59.59	+77.81 +34.65	+80.04 -15.70
+40	+55.07 +52.33	+64.10 +14.65	+64.84 -34.60
+10	+43.39 +49.90	+49.49 +8.26	+53.23 -38.57
0	+39.86 +49.36	+44.57 +6.95	+49.71 -39.36
-40	+24.60 +47.48	+24.80 +3.25	+34.47 -41.81

ROLL (LOS angles with respect to vehicle axes)

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Gimbal Angles for +8 ° Cant

Geometry I

Extreme Angles		**Corresponding LOS Angles (with respect to vehicle axes)**	
Roll	**Pitch**	**Roll**	**Pitch**
-41.29		-45	-40
	+22.77	+27	-40
	+80.31	-42	+70
+60.98		+45	+70

PITCH

(LOS angles with respect to vehicle axes)

+70	+69.93 +60.98	+77.22 +38.28	+80.26 -10.08
+40	+54.28 +53.18	+63.83 +16.62	+65.40 -32.81
+10	+42.62 +50.50	+49.34 +9.42	+53.84 -37.50
0	+39.10 +49.89	+44.45 +7.92	+50.34 -38.43
-40	+23.86 +47.79	+24.74 +3.71	+35.14 -41.29
	+45	0	**-45**

ROLL (LOS angles with respect to vehicle axes)

35-51

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Gimbal Angles for +9° Cant

Geometry I

Extreme Angles		Corresponding LOS Angles (with respect to vehicle axes)	
Roll	Pitch	Roll	Pitch
-40.75		-45	-40
	+22.25	+29	-40
	+80.39	-45	+70
+62.25		+45	+70

PITCH (LOS angles with respect to vehicle axes)

+70	+69.05 +62.25	+76.58 +41.58	+80.39 -4.26
+40	+53.47 +54.00	+63.53 +18.55	+65.93 -30.93
+10	+41.85 +51.08	+49.17 +10.56	+54.45 -36.40
0	+38.33 +50.40	+44.30 +8.89	+50.95 -37.47
-40	+23.12 +48.08	+ 24.67 +4.17	+35.79 -40.75
	+45	0	-45

ROLL (LOS angles with respect to vehicle axes)

3.5-52

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Gimbal Angles for +10° Cant

Geometry I

Extreme Angles		Corresponding LOS Angles (with respect to vehicle axes)	
Roll	Pitch	Roll	Pitch
-40.20		-45	-40
	+21.69	+31	-40
	+80.41	-45	+70
+63.42		+45	+70

PITCH (LOS angles with respect to vehicle axes)

	+45	0	-45
+70	+68.16 +63.42	+75.89 +44.56	+80.41 +1.65
+40	+52.66 +54.77	+63.19 +20.42	+66.43 -28.97
+10	+41.06 +51.63	+48.97 +11.69	+55.03 -35.25
0	+37.56 +50.90	+44.14 +9.85	+51.55 -36.47
-40	+22.37 +48.36	+24.59 +4.63	+36.44 -40.20

ROLL (LOS angles with respect to vehicle axes)

3.5-53

3.5.4.2 Sun Sensor

3.5.4.2.1 Introduction

The sun sensor will consist of a group of illumination sensors arranged to detect the image of the sun.in the sensor field of view.

Two types of light sensors have been considered, photovoltaic and photoconductive. The photovoltaic does not need an external voltage source because it generates its own voltage as a function of the light intensity. The photoconductive sensor (photo transitor) needs an external power source to back bias the diode junction. The incident light intensity tends to cause forward bias, thus lowering the resistance of the device. The sensitivity of the photoconductive sensor is on the order of twice the sensitivity of the photovoltaic type.

3.5.4.2.2 Design Description

Considering the photo transistor as being similar in function to the more common types, a silicon unit seems appropriate in consideration of environmental conditions and contractor imposed requirement banning the use of germanium semiconductors.

The silicon phototransistor is recommended because it can generate a large voltage variation at a low impedance level. The device impedance at 50 mw/cm^2 is about 300Ω. The disadvantage of phototransistor is the variation in gain from unit to unit. If a phototransistor is changed, the system has to be recalibrated. The phototransistor gain will also change with temperature, thus varying the threshold level of the sun sensor.

This sensitivity change is not a problem in this application, since the ultimate output is of an on-off nature. Illumination on the detector surface of 20,000 ft.candles should cause the detector to activate the shutter. This is well within the safety factor for the brightness of the sun above the atmosphere which is approximately 130,000 ft. candles. Parameter variations that cause difficulty in a proportional design will be circumvented by proper signal processing.

The two photoconductive devices chosen for study are the Texas Instrument LS-810 phototransistor and General Electric L14A502. Their characteristics are presented as follows:

PHOTOTRANSISTOR CHARACTERISTICS

	LS-810	L14A502	
Power Dissipation :	75	300	mw max.
Reverse Voltage :	30	45	V_{dc}
Operating Temp. Range:	-65°C to 125°C	-65°C to 150°C	
Sensitivity :	300 a/mw/cm^{2*}	300 a/mw/cm^{2**}	

*Measured with radiation of 9 mw/cm^2 in wave lengths of .7 to 1.0 microns

**Radiation source is an unfiltered tungsten filament bulb at 2870°K

3.5.4.2.3 Conclusions

Although the basic design of the sensors has been investigated the parameters such as sensor type (optical or non-optical), location, wiring, weight, field of view etc., must still be decided. Following trade-off discussions, the operating parameters will be crystalized and then an appropriate sensor chosen. The field of view will be dependent upon sensor location.

3.5.4.3

BOS-COR-9300-67-089

COPY NO.______

[redacted]

To: R. Heath DATE: 29 March 1967

From: J. Galligan

Subject: Slant Range Focus Shift

1.0 Introduction

The telescope must operate over wide slant range excursions. These changes in range result in a shift in the location of the objective lens focal plane. For the present optical design, the focal plane shifts as a function of roll and pitch angles are depicted in Figures 1 - 5.

2.0 Method of Calculation

2.1 Assumptions

The defocus values in the figures are predicated on the following assumptions:

a. The slant range was calculated for a flat earth.

b. The pitch and roll angles are referenced to the vehicle; crab angle changes were not considered.

c. The reference object distance for the infocus condition is the vertical altitude of the telescope.

d. Any defocus due to power changing or zooming will add directly to the values in the curves.

2.2 Slant Range Defocus

The following equation was used to evaluate the magnitude of the slant range defocus errors:

3.5-56

$$\Delta f_{SL} = \frac{f^2}{h}(1 - \cos\phi\cos\theta)$$ where

Δf_{SL} = slant range defocus error

f = focal length

h = altitude

ϕ = pitch angle

θ = roll angle

A derivation of this equation is in an appendix. Defocus errors were calculated for nadir altitudes of: 70, 80, 100, 150, and 230 nautical miles. The pitch angle variation is from 0° to 70° and the roll angle increments are 0°, 20° and 45°. The curves are valid only if the system was focussed at nadir. If an object distance greater than nadir height is used, the values must be recalculated.

3.0 Discussion of Results

Taking the 80 n.mi. case as a typical example, the worst case slant range defocus is .0007 inches in the high power mode at the objective lens focal plane. At the eyepiece object plane this corresponds to approximately .003 inches. The low power mode worst case is negligible. Thus the separation between the reticle and the scene planes is approximately .003 inches in front of the eyepiece.

The possible effects of such a displacement can be discussed qualitatively. First, the reticle may appear to lose some of its definition causing the observer's eye to have to refocus as he concentrates either on the reticle or the scene. This will not be a cause for concern in the present design since the eye has a depth of field of .5 diopters and the .003 inches separation corresponds to .13 diopters. In summary, at the present time, the

3.5-57

reticle/scene defocus should not be considered a problem area, but it should be further studied if the magnitude of the defocus becomes significantly greater due to other defocus causes.

The second effect of the slant range focus shift is one of parallax. If the reticle and objective lens focal plane are coplanar, then the reticle can be used as an aid in aiming and tracking any part of the field. However, if reticle and focal plane are not coplanar, then the reticle could appear to be centered on a target at the edge of the field while in fact it is not. This could introduce aiming and tracking rate errors. At the highest power, the outer ring of the reticle subtends an angle of 15° in the eyepiece field. If the reticle and scene are separated by .0035 inches, as in the case below, the angular parallax will be approximately three arc-minutes. The acuity of the eye is sufficient to detect this angle. Figure 6 shows the relationship of the angle of parallax to the apparent semi-field angle at highest magnification out to the location of the outer ring of the reticle.

In summary, a worst possible case will be discussed. If the system was focussed for an 80 n.mi. object distance and was then taken to a 230 n.mi. altitude and used on a target located at +70° pitch angle and +45° roll angle, the defocus would be .0008 inches at the objective focal plane. This corresponds to approximately .0035 inches at the eyepiece object plane. Therefore, the worst case for slant range defocus results in a .15 diopter shift which is well within the limit of the eye's depth of focus.

J. Galligan
J. Galligan

Approved:

RRA

A. Van Sickel
A. Van Sickel

Dist: F. Bean
P. Clifford
S. Robinson
A. Van Sickel
A. L. Wright

3.5-58

APPENDIX

1. Slant Range: $SR = h \sec \phi \sec \theta = h + \Delta h$

   (Flat Earth)

   (See Figure a)

2. Image Distance for a nadir in-focus condition:

$$S_N = \frac{h + f}{h - f}$$

3. Image distance for a slant range change:

$$S_C = \frac{(h + \Delta h)\, f}{(h + \Delta h) - f}$$

4. Defocus:

$$S_N - S_C = \Delta f = \frac{h\, f}{h - f} - \frac{(h + \Delta h)\, f}{(h + \Delta h) - f}$$

5. After algebraic manipulation:

$$\frac{\Delta f}{f} = h \left[\frac{h \sec \phi \sec \theta - f - \left[(h - f)(\sec \phi \sec \theta) \right]}{(h - f)(h \sec \phi \sec \theta - f)} \right]$$

$$\frac{\Delta f}{f^2} \qquad \frac{h (\sec \phi \sec \theta - 1)}{h^2 \sec \phi \sec \theta - f\, h\, (1 + \sec \phi \sec \theta) + f^2}$$

6. Approximation:

   The last two terms in the denominator can be neglected since the worst case error that would be introduced is one part in seventy (1/70) or .0001%.

3.5-59

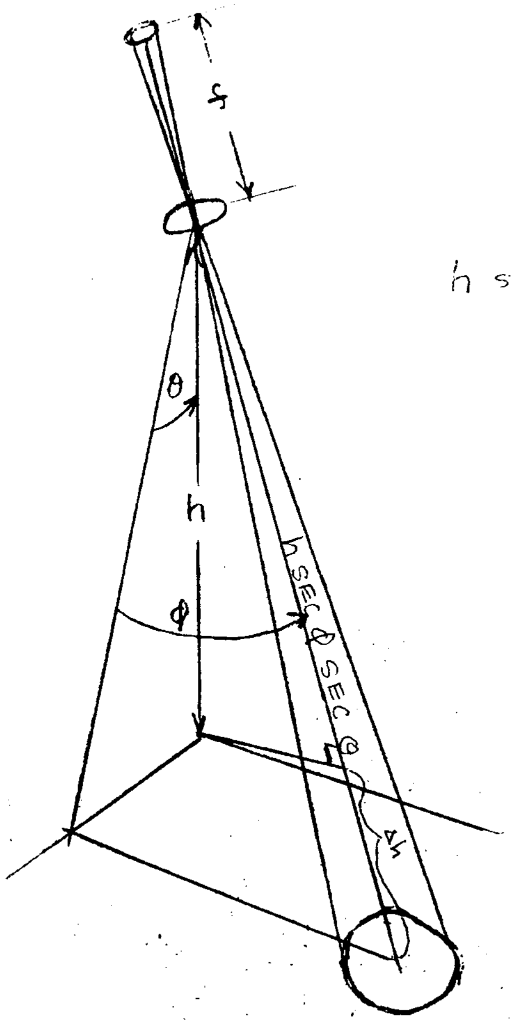
Therefore: $$\frac{\Delta f}{f^2} = \frac{(\sec \phi \sec \theta - 1)}{h \quad \sec \phi \sec \theta}$$

$$\frac{\Delta f}{f^2} = \frac{1 - \cos \phi \cos \theta}{h}$$

$$\Delta f = \frac{f^2}{h} \left[1 - \cos \phi \cos \theta\right]$$

7. The results were evaluated for this expression.

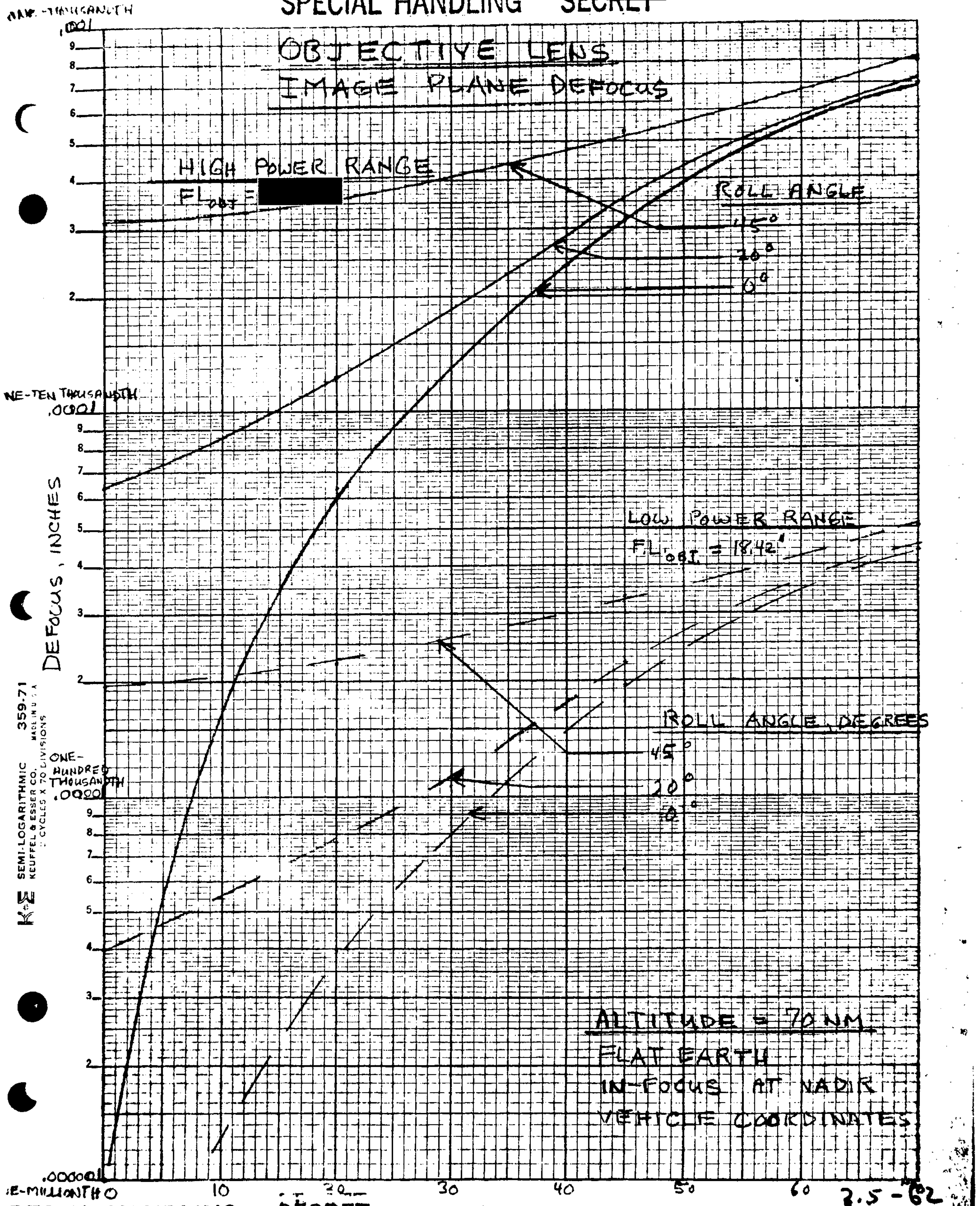
3.5-60



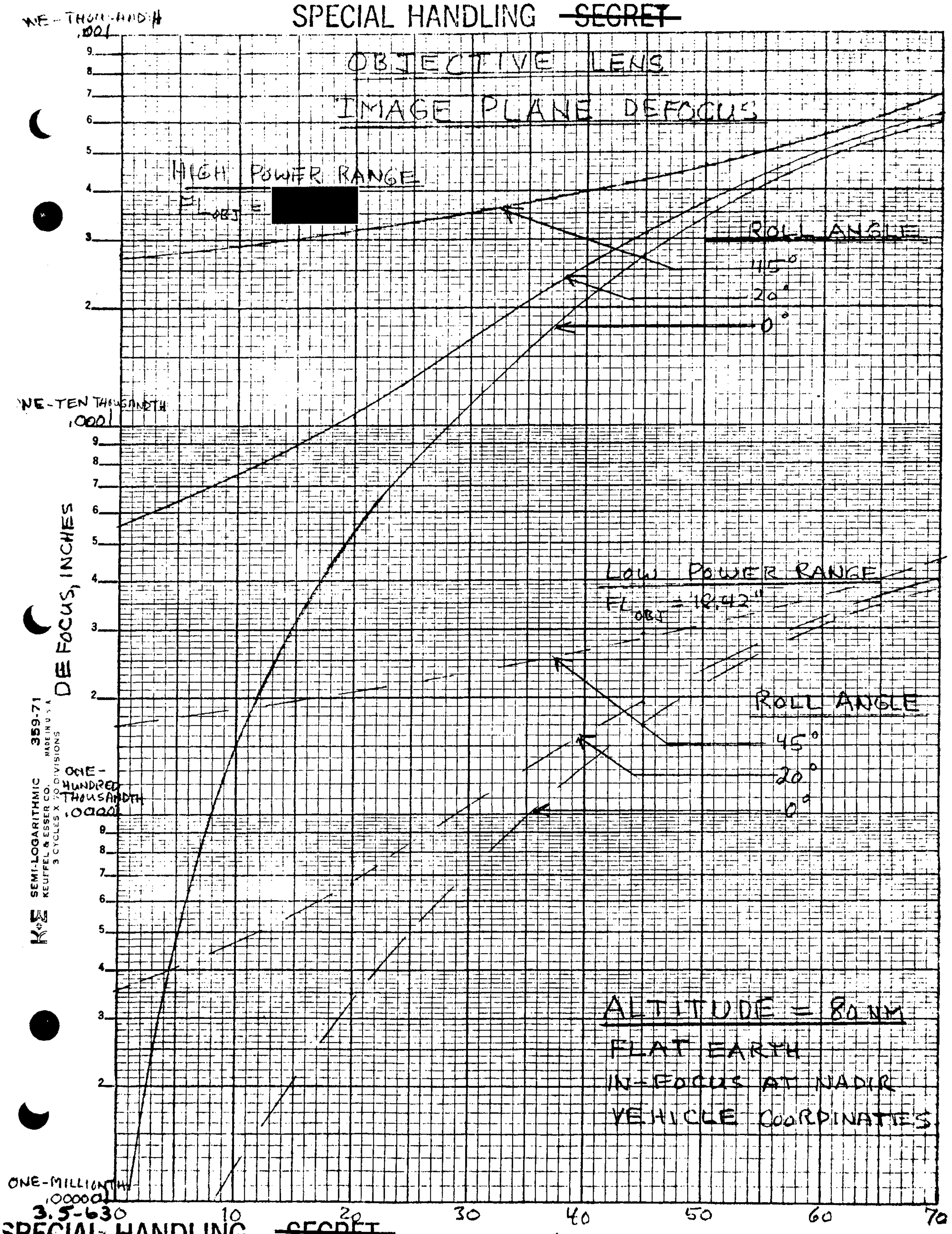
$h \sec\phi \sec\theta = h + \Delta h$

FIGURE a.

SLANT RANGE DEFOCUS GEOMETRY


OBJECTIVE LENS
IMAGE PLANE DEFOCUS
HIGH POWER RANGE
FL_OBJ = [redacted]
ROLL ANGLE
45°
20°
0°
LOW POWER RANGE
FL_OBJ = 18.42"
ROLL ANGLE, DEGREES
45°
20°
0°
ALTITUDE = 70 NM.
FLAT EARTH
IN-FOCUS AT NADIR
VEHICLE COORDINATES
DEFOCUS, INCHES
ONE-THOUSANDTH .001
ONE-TEN THOUSANDTH .0001
ONE-HUNDRED THOUSANDTH .00001
ONE-MILLIONTH .000001
9
8
7
6
5
4
3
2
0
10
20
30
40
50
60
CH ANGLE DEGREES
SEMI-LOGARITHMIC 359-71
KEUFFEL & ESSER CO. MADE IN U.S.A.
3 CYCLES X 70 DIVISIONS

3.5-62



OBJECTIVE LENS

IMAGE PLANE DEFOCUS

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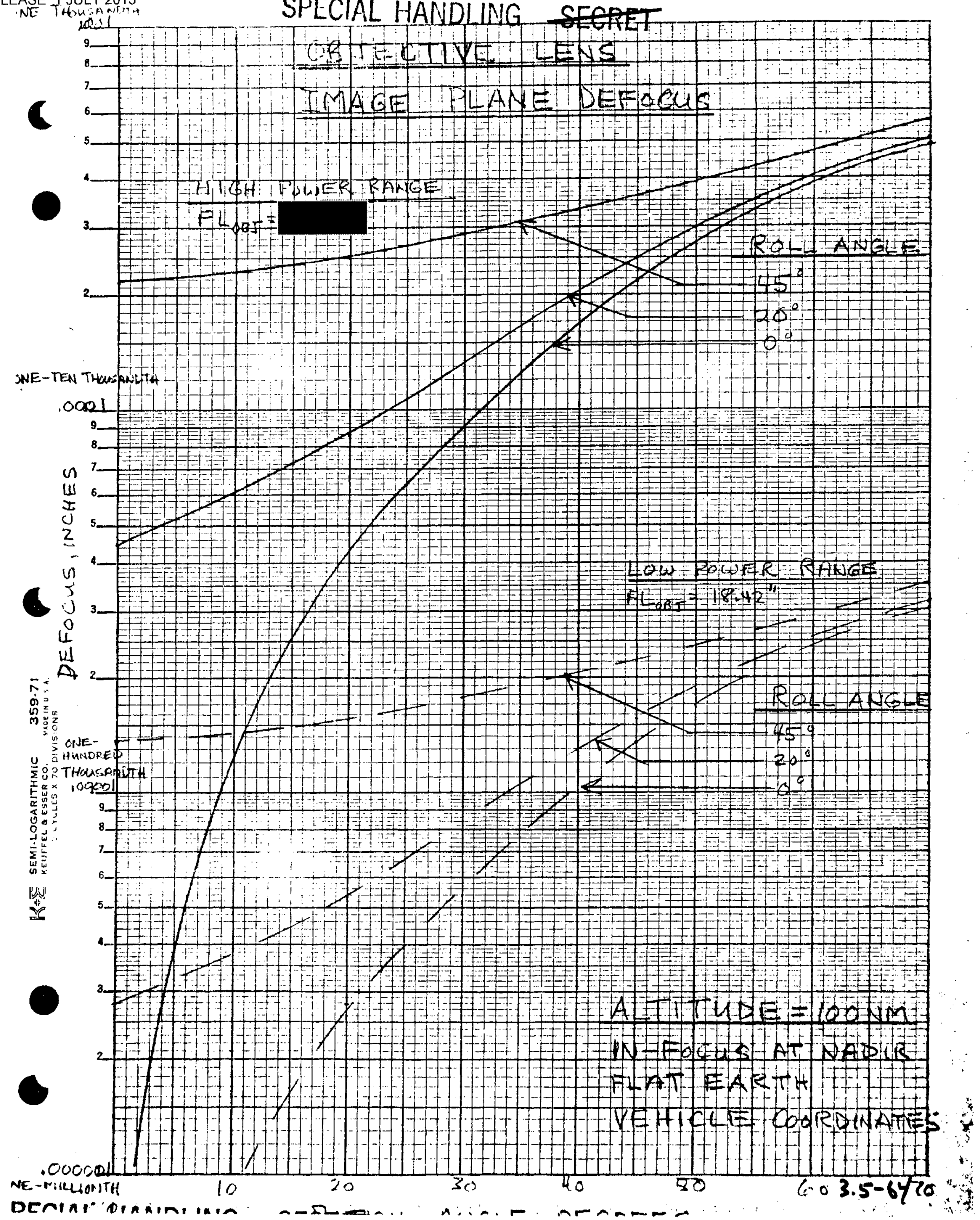

3.5-64/70

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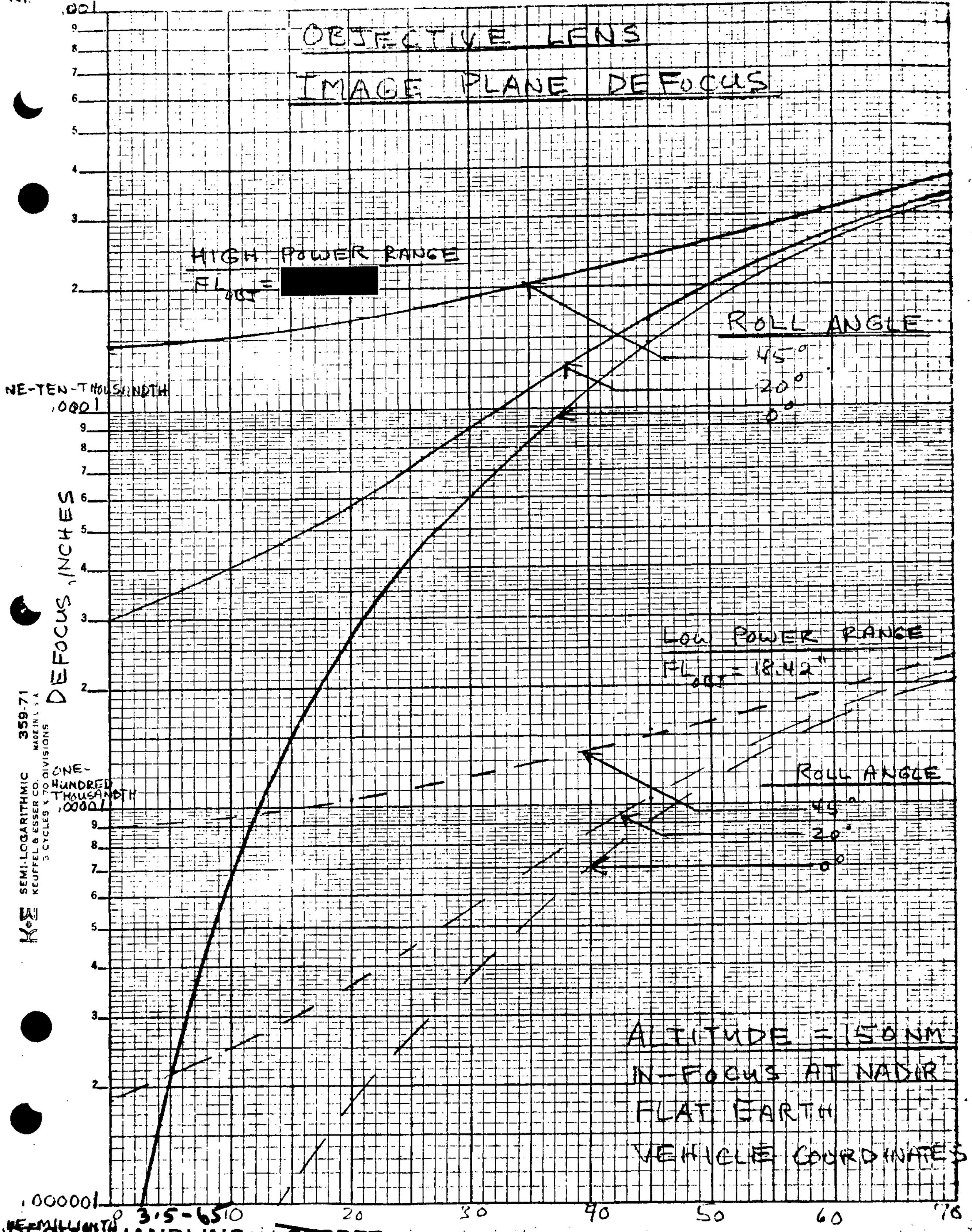
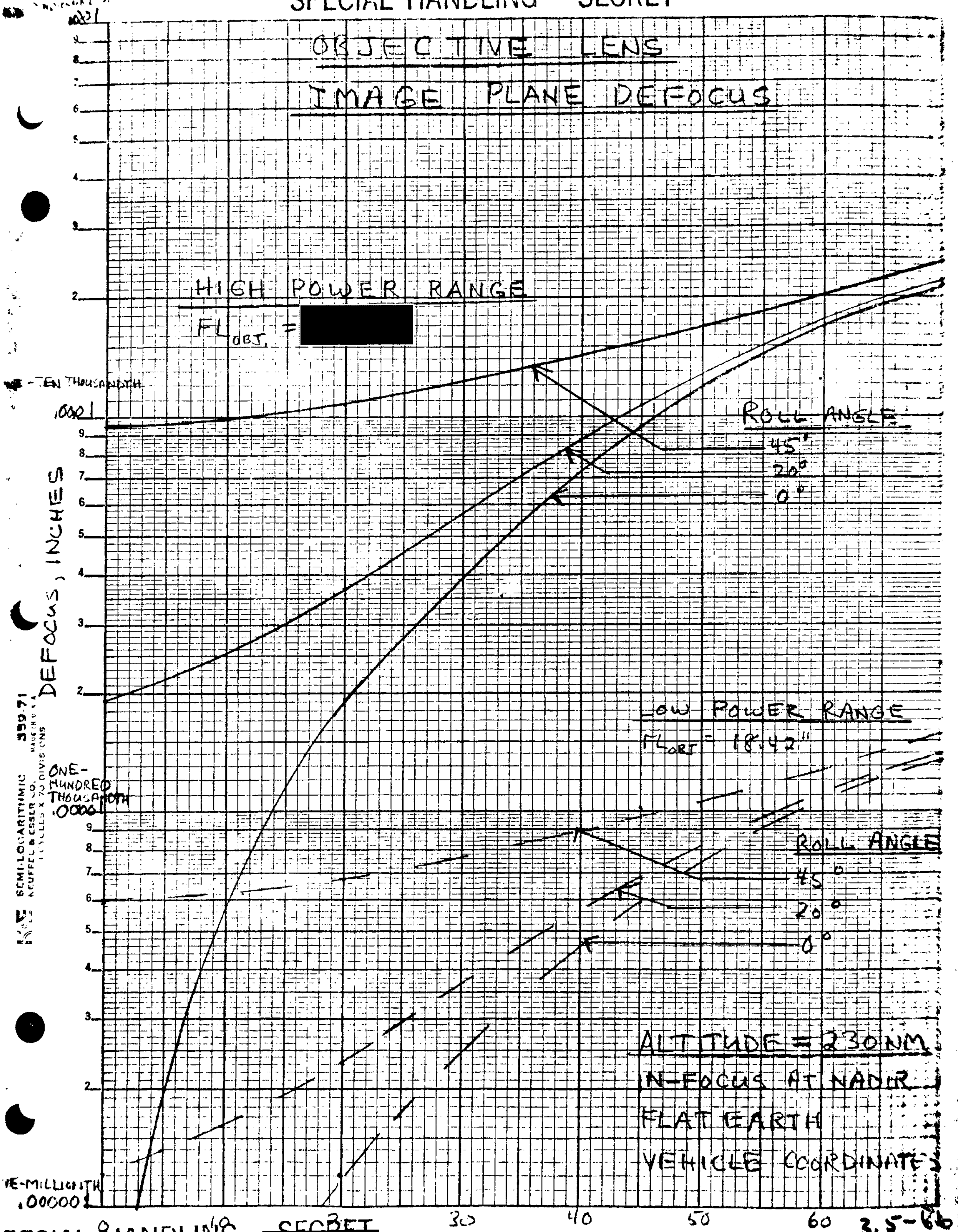
OBJECTIVE LENS
IMAGE PLANE DEFOCUS



SPECIAL HANDLING ~~SECRET~~


OBJECTIVE LENS
IMAGE PLANE DEFOCUS
HIGH POWER RANGE
FL$_{OBJ}$ = [redacted]
ROLL ANGLE
45°
20°
0°
LOW POWER RANGE
FL$_{OBJ}$ = 18.42"
ROLL ANGLE
45°
20°
0°
ALTITUDE = 230 NM
IN-FOCUS AT NADIR
FLAT EARTH
VEHICLE COORDINATES
DEFOCUS, INCHES
.0001
TEN THOUSANDTH
ONE-HUNDRED THOUSANDTH
.00001
ONE-MILLIONTH
.000001
0
10
20
30
40
50
60
K&E SEMI-LOGARITHMIC 359-71
KEUFFEL & ESSER CO. MADE IN U.S.A.
3 CYCLES X 70 DIVISIONS

3.5-66

NRO APPROVED FOR [redacted]
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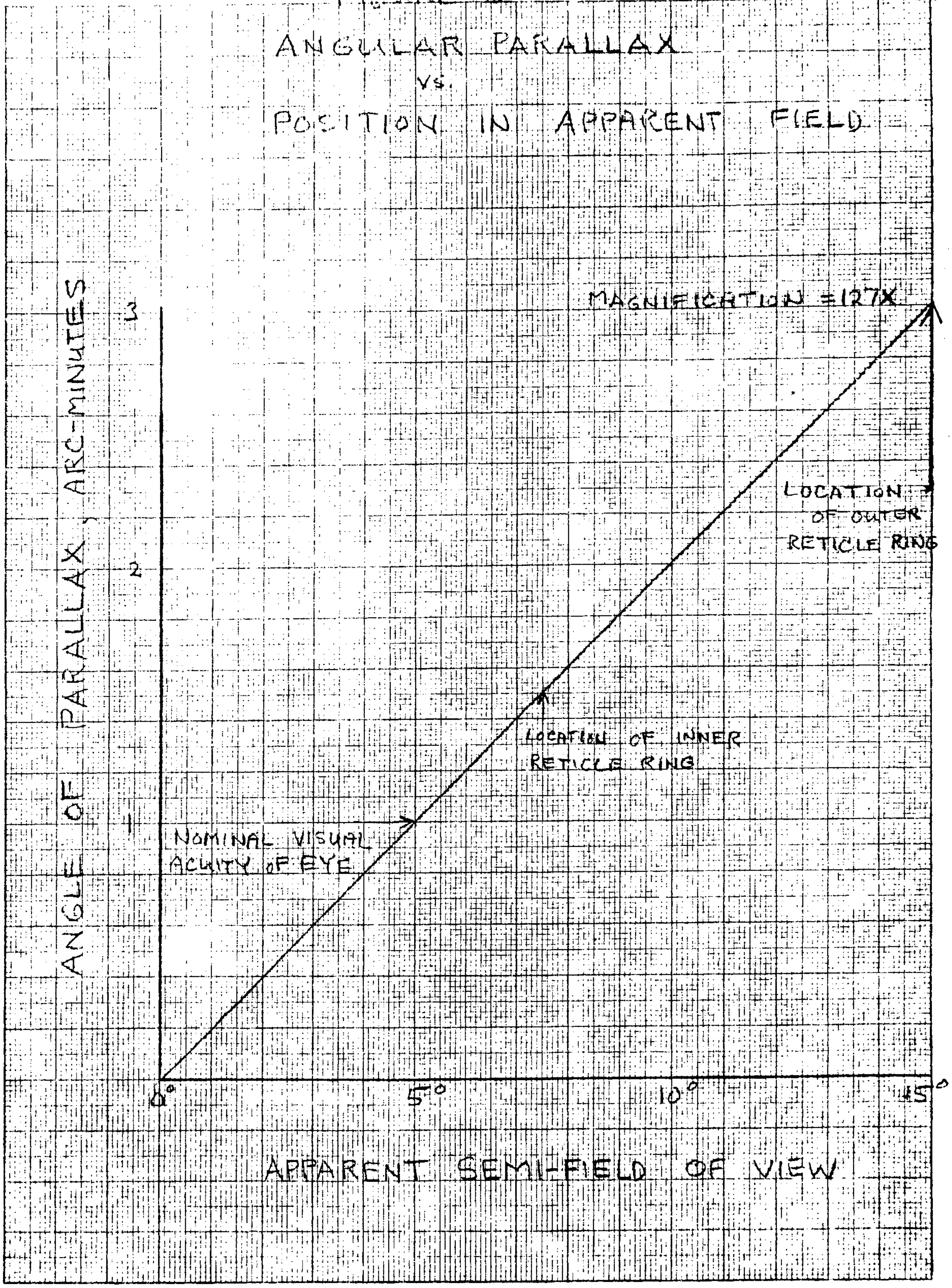
[redacted]

Figure 6 SPECIAL HANDLING ~~SECRET~~



K+E 10 X 10 TO THE CENTIMETER 46 1513
18 X 25 CM. MADE IN U.S.A.
KEUFFEL & ESSER CO.

3.5-67

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July, August
1968 Experiment

OBJECTIVES

PRIMARY

- DETERMINE CREW STATIC VISUAL THRESHOLD CHARACTERISTIC
- EVALUATE RESOLUTION DEGRADATION CAUSED BY SINGLE FREQUENCY SINUSOIDAL JITTER

SECONDARY

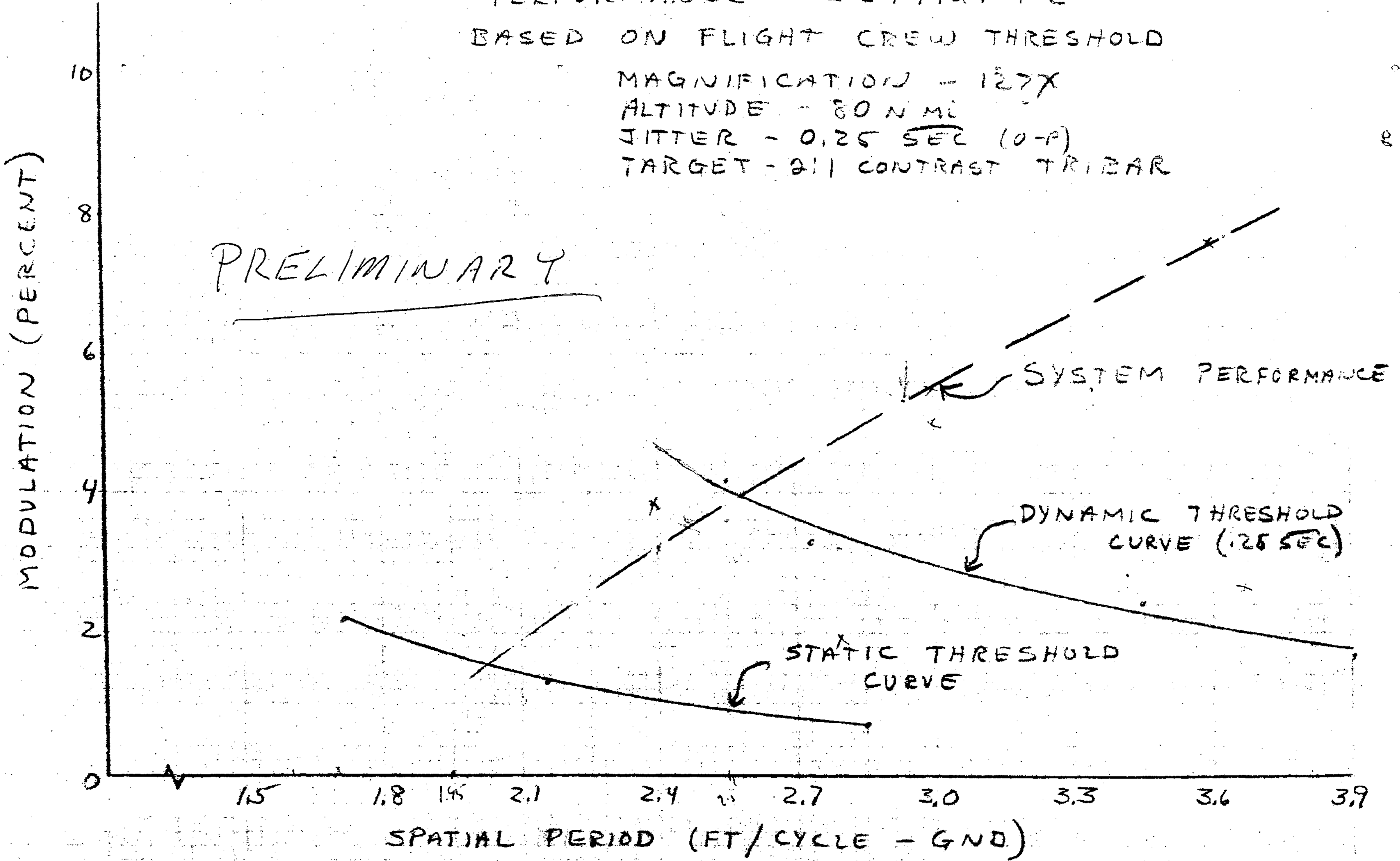
- EVALUATE THE EFFECT OF SCENE BRIGHTNESS ON RESOLUTION
- DEVELOP A WEIGHTING FUNCTION FOR APPLICATION TO THE SERVO DESIGN AREA

EXTENSIONS

- EVALUATE RESOLUTION DEGRADATION CAUSED BY RANDOM JITTER
- EVALUATE RESOLUTION DEGRADATION FROM EYE FATIGUE

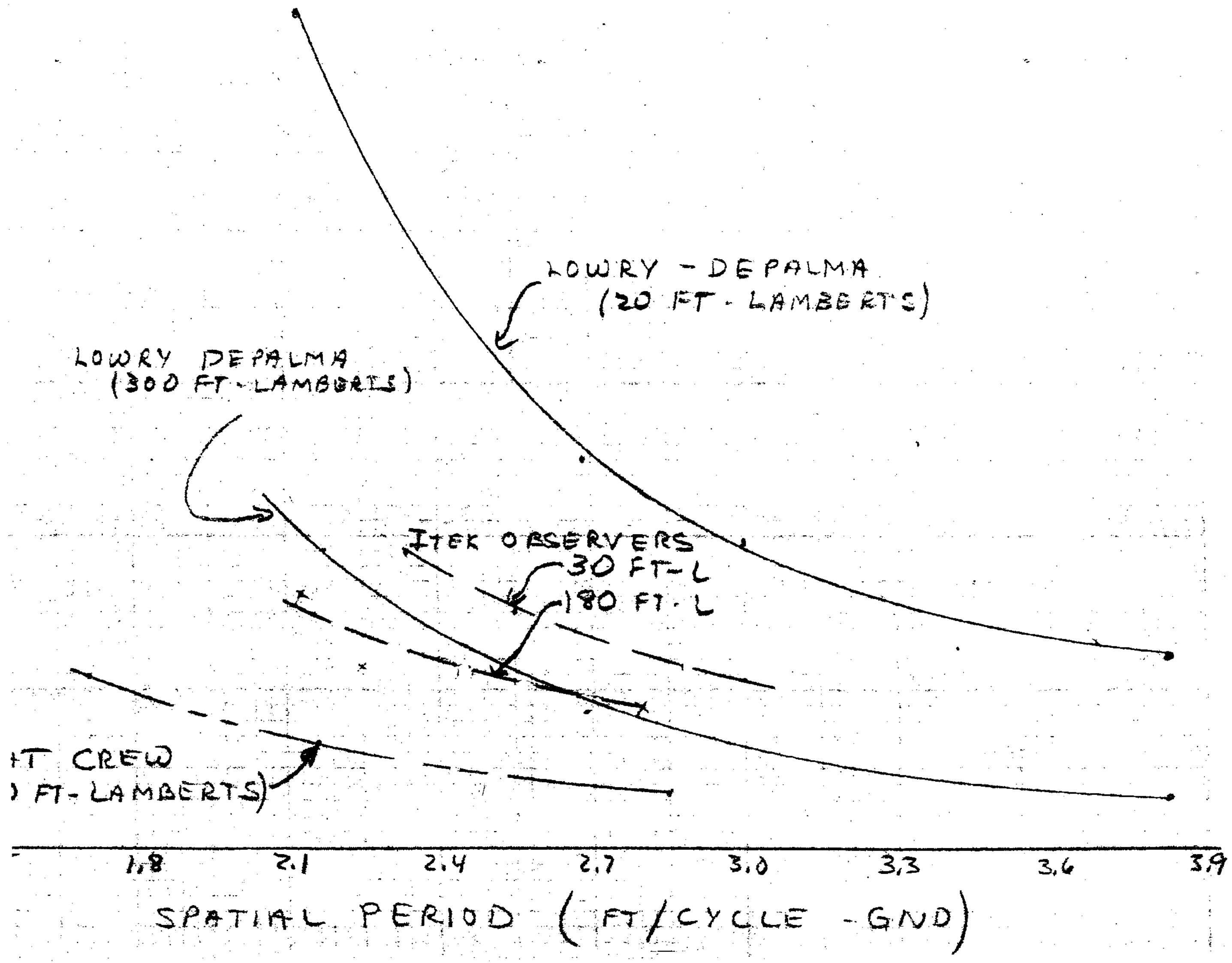
ACQUISITION SUBSYSTEM
PERFORMANCE ESTIMATE
BASED ON FLIGHT CREW THRESHOLD

MAGNIFICATION - 127X
ALTITUDE - 80 N MI
JITTER - 0.25 SEC (0-P)
TARGET - 2:1 CONTRAST TRIBAR



PRELIMINARY ~~SECRET~~ SPECIAL HANDLING ROUGH DRAFT

COMPARISON OF VISUAL THRESHOLDS

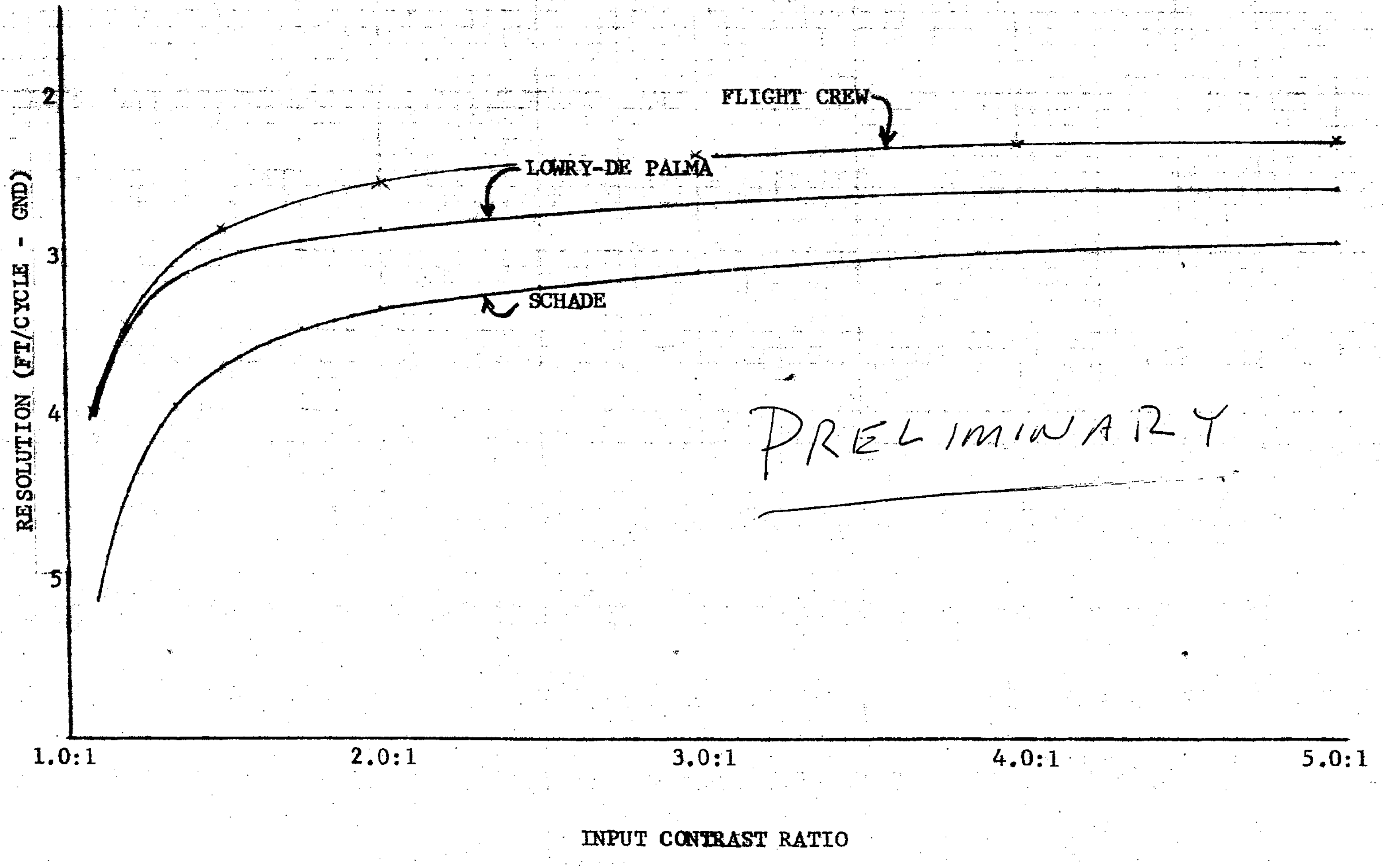


~~SECRET~~ SPECIAL HANDLING ROUGH DRAFT

~~SECRET~~ SPECIAL HANDLING
ROUGH DRAFT

ACQUISITION SUBSYSTEM RESOLUTION
VS
INPUT CONTRAST RATIO

MAGNIFICATION - 127X
JITTER - 0.25 ARC SEC (O-P)
ON-AXIS
NADIR (80 N.MI.)



PRELIMINARY

ROUGH DRAFT
~~SECRET~~ SPECIAL HANDLING

3.5.4.4 Image Motion Experiment

Since image motion will undoubtedly be introduced into the AO image plane by the scanner, a preliminary study of the effects of image motion on resolution was conducted. The results of this study and recommendations for further effort are stated in this section.

A standard Air Force Tri-Bar target with a 2:1 contrast and illuminated by 180 foot-lamberts was mounted on a slide. This slide was then placed in a tray which was sinusoidally vibrated by a speaker cone. For various combinations of frequency (4,6,8,10,20 and 50 cycles per second) and amplitude (± 0.25, ± 0.5, ± 1.0 and 2.5 arc-seconds, five observers recorded the maximum resolution they could perceive in the target. The results of this experiment are shown in Figure 3.5.4.4-1.

The trends in the data shown in the figure are as follows:

a. The 6-8 CPS region appears to be the place where the curve slope changes most abruptly, indicating a higher tolerance in motion amplitude for resolving the same target, for lower frequencies.

b. One observation - for an individual who passed a physical examination for pilot training - indicated a higher amplitude tolerance in the 8-10 CPS region.

c. All observers, whose eyes were capable of resolving 3.5' equivalent GRD, managed to do so at motion amplitudes greater than ± 0.25 arc seconds.

The significance of the aforementioned trends is this if further experiments show that image motion does not degrade resolution as severely as was first postulated by sine wave response analysis, the scanner servo design criteria may be relaxed. Thus it is imperative to perform this experiment in a very rigorous manner, adhering to the design criteria for the AO as much as possible and varying the motion input (random, sinusoidal, and linear superimposed on a sinusoid) in order to determine the magnitude of the image motion effects. The preliminary investigation showed trends which were favorable to a relaxation of the scanner servo tolerances. Now further analysis must be done to reinforce this conclusion and to determine the magnitude of the effect. Only a limited amount of in- scope additional experimentation is planned.

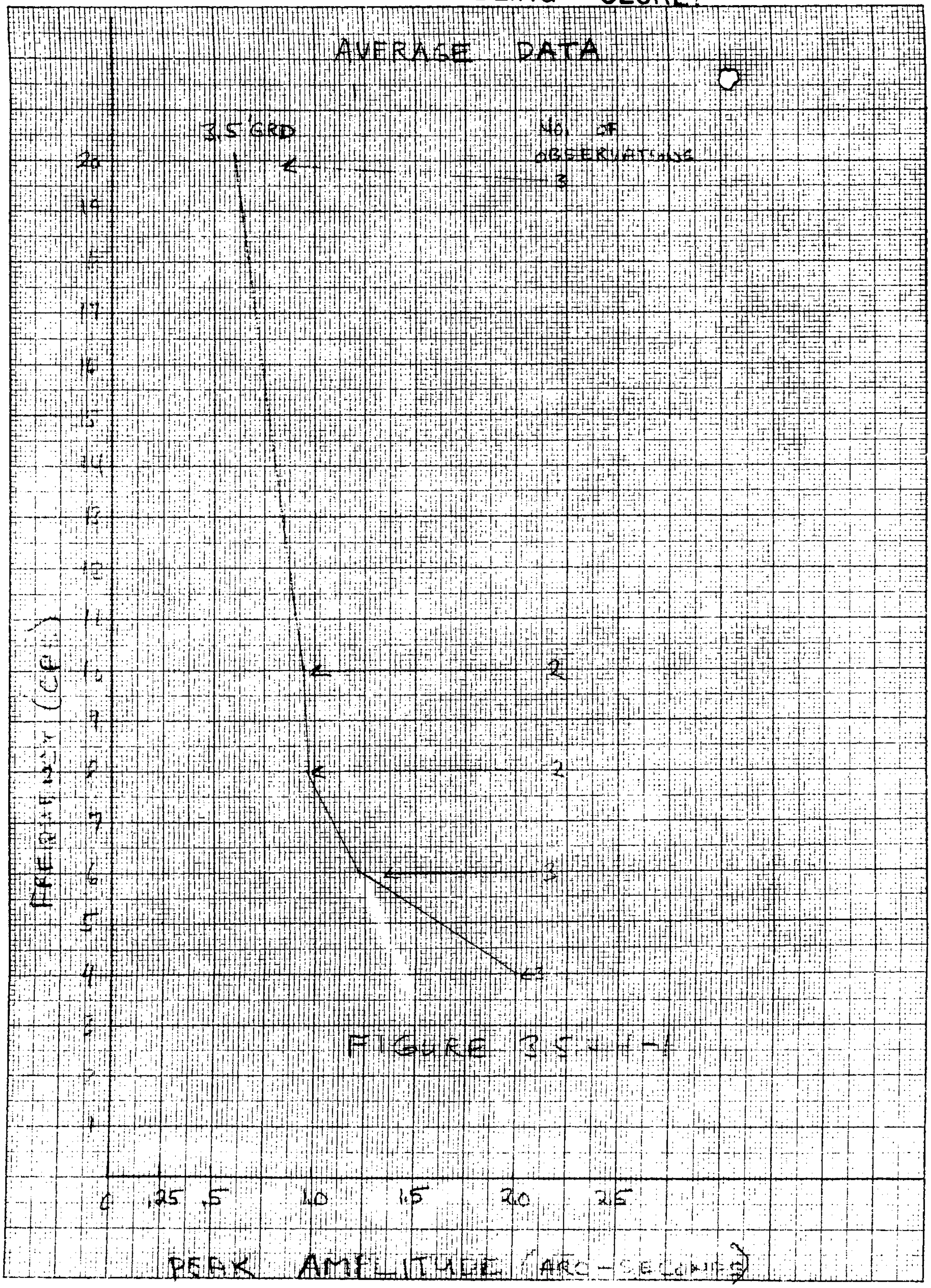

AVERAGE DATA
3.5 GRD
NO. OF
OBSERVATIONS
3
2
2
3
3
FREQUENCY (CPS)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
0
.25
.5
1.0
1.5
2.0
2.5
PEAK AMPLITUDE (ARC-SECONDS)

FIGURE 3.5-4-1

[redacted]

[redacted]

3.6 Optical Design

3.6.1 Design of Optics - This section provides the parameters of the optical design from which the design can be simulated analytically for evaluation. This report conforms to form MSM-S-201, 22 December 1966.

The following items except as noted, are required by the above form and are given in Table 3.6.1-1, Lens Specification Data.

Item 1. Curvature or radius of each surface

Item 2. Aspheric Curvature Coefficients. All surfaces in the A/O telescope are spherical, therefore this does not apply.

Item 3. Surface separations. This includes glass thickness, air spacings, pupil and stop locations, image or focal positions and other available cardinal points.

Item 4. Glass types and/or indices of refraction. Note: the specified spectral wavelengths are given in Table 3.6.1-2 and 3.6.1-3 (CLOC Specification).

Item 5. Clear apertures and obscurations for each optical surface. Note: obscurations do not apply to the A/O telescope.

Item 6. All angular and linear dimensions on all prisms and mirrors are shown in Figures 3.6.1-1 through 3.6.1-4.

Item 7. Optical dimensions, spectral data for all windows and filters - absorption or interference type, is presently under study. The dimensions for the window are shown in Figure 3.6.1-5 and those for the filter are listed in Table 3.6.1-1. However, the spectral data for the filters is to be determined by the Contractor.

Item 8. Specification for coatings on each surface can be summed up as follows:

a. On all refracting surfaces, single layer magnesium fluoride $\lambda/4$ thick, where λ equals 0.56 microns.

b. Internal folding mirror, aluminized plus enhanced coating for 98.5 percent reflectivity.

c. External folding mirror, aluminized plus enhanced coating for 93 percent reflectivity.

d. External scanning mirror, aluminized plus a SiO coating for 87 percent reflectivity.

e. Reflecting surfaces of the Pechan prism, aluminized plus SiO coating for 87 percent reflectivity.

Item 10. The system optical layout is shown in Figures 3.6.1-6 and 3.6.1-7.

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Itek **DESIGN SPECIFICATION SHEET**

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Element Number	Surface Number	Radius	Radius Tolerance	Thickness	Thickness Tolerance	Airspace	Airspace Tolerance	Clear Aperture	n*	v**	Glass Type & Melt
DESIGN NO. 67-015	1	40.1302	±0.080	1.3544	+0.000 -0.005			10.00	1.62041	60.33	SK-16
	2	-18.4179	±0.005			0.2656	±0.002	9.98			
	3	-17.8183	±0.005	0.6000	+0.000 -0.005			9.84	1.61340	44.30	KzFSN-4
	4	273.6105	±3.000			28.8180	±0.030	9.73			
DESIGN NO. 67-0064	5	-8.9940	±0.036	0.3613	±0.005			2.79	1.62041	60.33	SK-16
	6	10.7028	±0.050			0.0200	±0.005	2.79			
	7	7.6130	±0.026	0.2934	±0.005			2.80	1.62004	36.37	F-2
	8	486.4318	±105.000			13.9069	±0.010	2.79			
	9	∞				10.0873	±0.010	2.06			Aperture
	10	-5.4627	±0.010	0.4468	±0.005			3.28	1.62041	60.33	SK-16
	11	-3.1057	±0.003			0.1337	±0.005	3.35			
	12	-3.0157	±0.003	0.4516	±0.005			3.32	1.62004	36.37	F-2
	13	-6.7970	±0.013			0.0200	±0.005	3.55			
	14	11.9795	±0.038	0.5711	±0.005			3.63	1.62041	60.33	SK-16
	15	-18.5349	±0.090			12.0696	±0.010	3.63			
DESIGN NO. 67-015	16	∞		9.1391 Unfolded				2.22	1.51680	64.17	BK-7
	17	∞				0.1017	±0.005	1.55			
	18	2.2310	±0.008	0.2391	±0.005			1.53	1.51680	64.17	BK-7
	19	2.2002	±0.008			0.7916	±0.005	1.46			

SYSTEM: 67-0075 **UNIT:** Inch

APPROVED: E. Hagerott **LENS DESIGNER** **DATE:** 6/22/67

R. Hilbert 6/22/67

R. Wientzen 6/22/67

*** n = refractive index at** 5876 **Angstrom units**

**** v = reciprocal disper - sive power at** 5876 **Å**

Table 3.6.1-1 Lens Specification Data

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3-4

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Itek

DESIGN SPECIFICATION SHEET

Element Number	Surface Number	Radius	Radius Tolerance	Thickness	Thickness Tolerance	Airspace	Airspace Tolerance	Clear Aperture	n*	v**	Glass Type & Melt
	20	∞		0.2000	±0.005			1.36	1.51680	64.17	BK-7
	21	∞				0.3229	±0.005	1.37			Reticle
	22	2.5493	±0.011	0.3959	±0.005			1.39	1.62041	60.33	SK-16
	23	-1.8689	±0.006			0.0837	±0.005	1.36			
	24	-1.3669	±0.004	0.2310	±0.005			1.33	1.68893	31.18	SF-8
	25	1.3808	±0.004	0.4500	±0.005	0.2274	±0.005 High	1.35	1.62041	60.33	SK-16
	26	-2.2523	±0.009			0.5215	Mid	1.37			
	27	2.9031	±0.022	0.3200	±0.005	0.9993	Low	1.09	1.51680	64.17	BK-7
	28	-1.4431	±0.006			0.3750		1.05			
	29	-0.6161	±0.002	0.3996	±0.005	0.3342	±0.005 High	0.66	1.62004	36.37	F-2
	30	-0.8979	±0.005			1.1384	Mid	0.67			
	31	1.7353	±0.015	0.3246	±0.005	1.3933	Low	0.75	1.51680	64.17	BK-7
	32	-0.8258	±0.003			0.0500		0.79			
	33	-0.7985	±0.003	0.3933	±0.005	1.8578	±0.005 High	0.78	1.62004	36.37	F-2
	34	-3.4038	±0.041			0.7597	Mid	0.91			
	35	1.7311	±0.009	0.2072	±0.005	0.0266	Low	0.98	1.62004	36.37	F-2
	36	1.0715	±0.004			0.3178	±0.005	0.98			
	37	1.2965	±0.004	0.3000	±0.005			1.18	1.62041	60.33	SK-16
	38	5.4668	±0.069			0.1500	±0.005	1.18			

Design No. 67-0075

PRIVATE

SYSTEM: 67-0075 **UNIT:** Inch

APPROVED: E. Hagerott **LENS DESIGNER** **DATE:** 6/22/67
R. Hilbert 6/22/67
R. Wientzen 6/22/67

* n = refractive index at 5876 Angstrom units

** v = reciprocal dispersive power at 5876 Å

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Table 3.6.1-1 Continued

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Itek

DESIGN SPECIFICATION SHEET

Element Number	Surface Number	Radius	Radius Tolerance	Thickness	Thickness Tolerance	Airspace	Airspace Tolerance	Clear Aperture	n*	v**	Glass Type & Melt
DESIGN NO 67-0075	39	∞ Filter		0.1700	±0.005			1.18	1.51680	64.17	BK-7
	40	∞				0.1500	±0.005	1.18			
	41	-1.9993	±0.009	0.2001	±0.005			1.18	1.51680	64.17	BK-7
	42	-4.1623	±0.035			1.0426	±0.005	1.24			
	43	∞				0.2000	±0.005	1.50			Image Plane
	44	-7.4978	±0.084	0.1670	±0.005			1.54	1.68893	31.18	SF-8
	45	1.1851	±0.002	0.7560	±0.005			1.67	1.62041	60.33	SK-16
	46	-1.7750	±0.004			0.7504	±0.005	1.74			
	47	2.1978	±0.006	0.2100	±0.005			1.78	1.64831	33.84	SF-12
	48	1.1552	±0.002	0.5880	±0.005			1.67	1.62041	60.33	SK-16
	49	-30.2177	±1.253			0.0150	±0.005	1.61			
	50	0.9348	±0.002	0.5000	±0.005			1.44	1.62041	60.33	SK-16
	51	-11.9989	±0.300	0.1490	±0.005			1.29	1.68893	31.18	SF-8
	52	1.3461	±0.006			0.7716	±0.005	1.02			
	53										Eye Point

PRIVATE

SYSTEM: 67-0075 UNIT: Inch

APPROVED: E. Hagerott LENS DESIGNER DATE: 6/22/67
R. Hilbert 6/22/67
R. Wientzen 6/22/67

* n = refractive index at 5876 Angstrom units

** v = reciprocal dispersive power at 5876 Å

PROJECT

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Table 3.6.1-1 Continued

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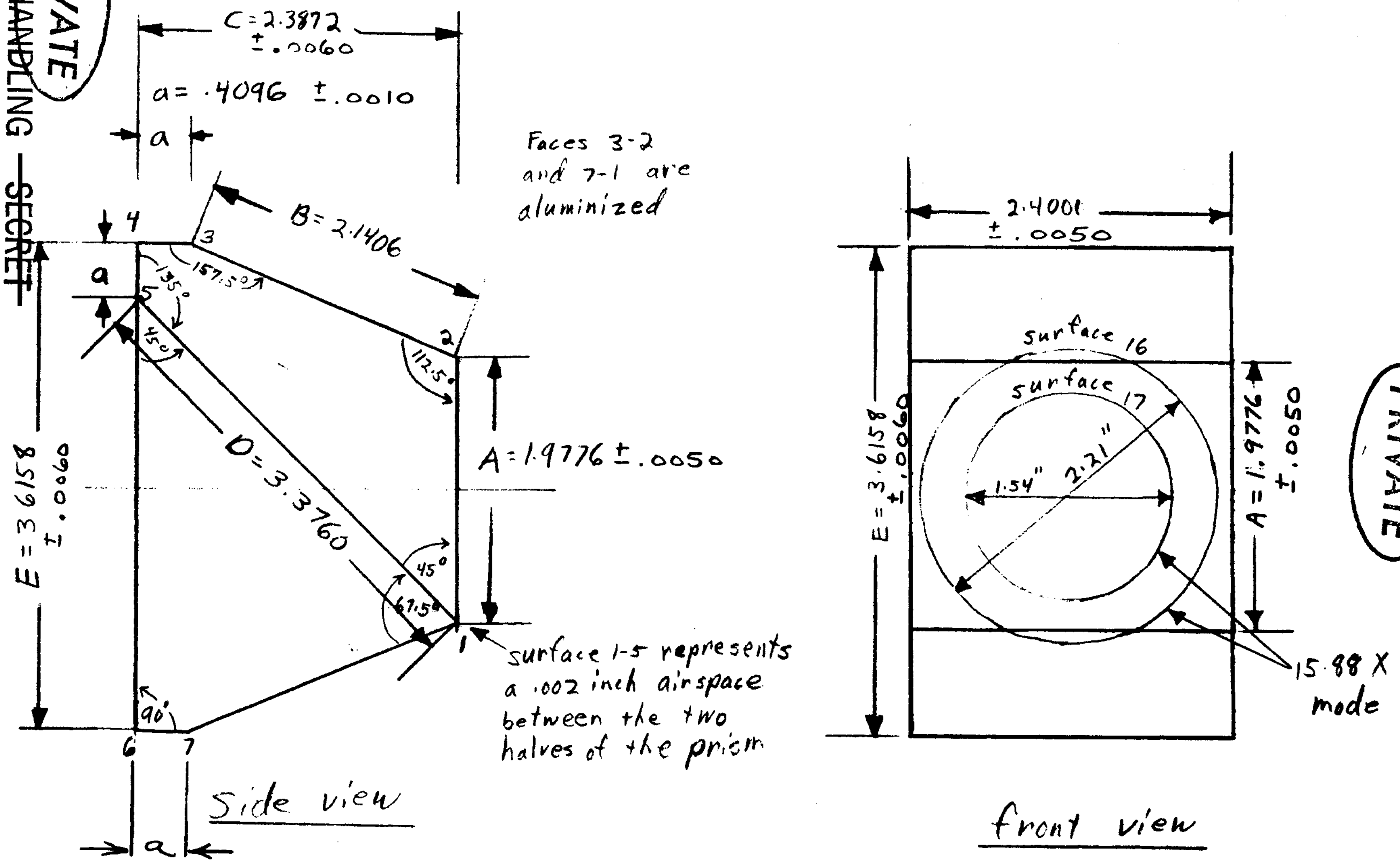
Schematic Drawing of Pechan Prism- A/O telescope



Faces 3-2 and 7-1 are aluminized

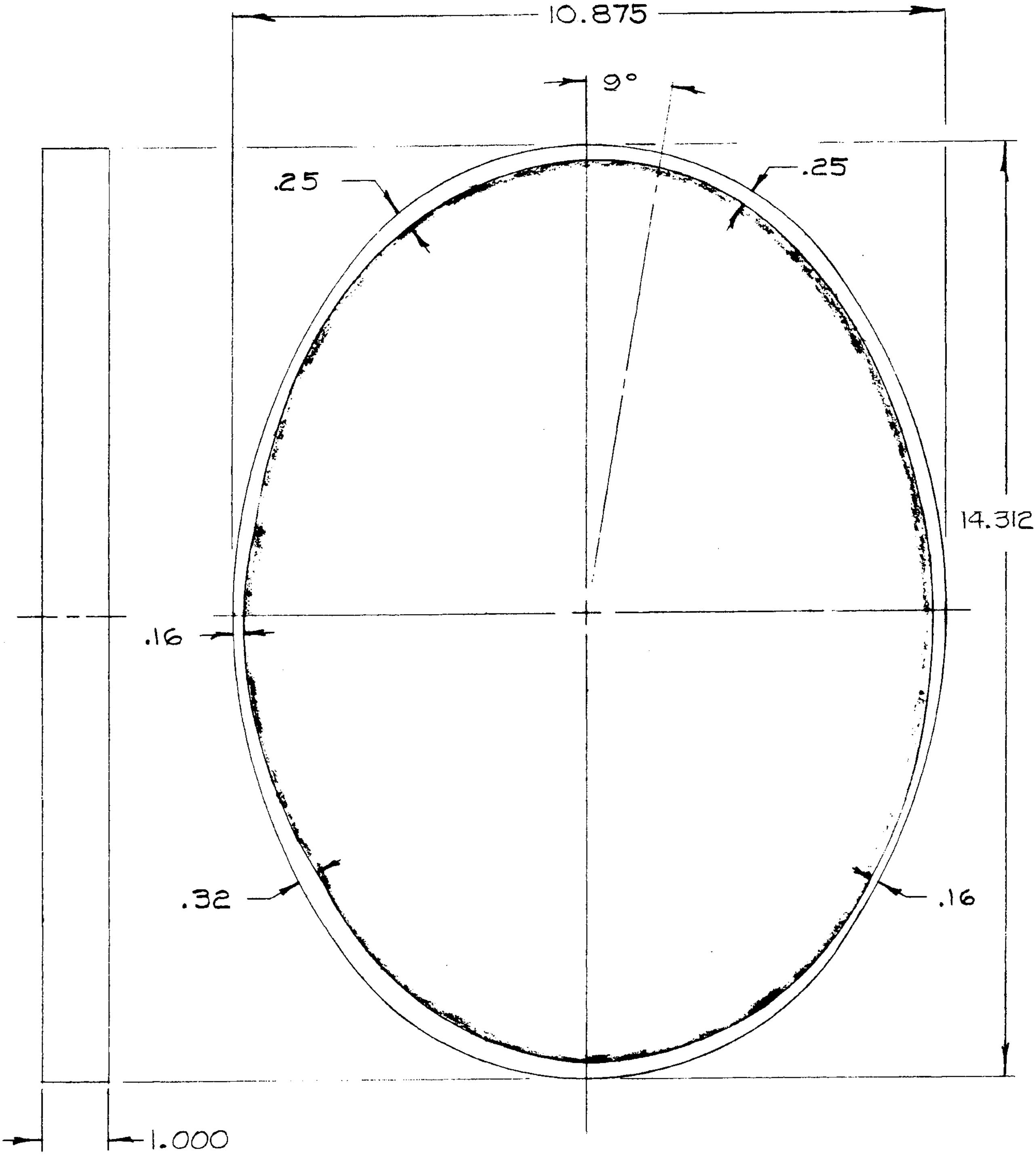
surface 1-5 represents a .002 inch airspace between the two halves of the prism

Side view

front view

ALL DIMS INCHES

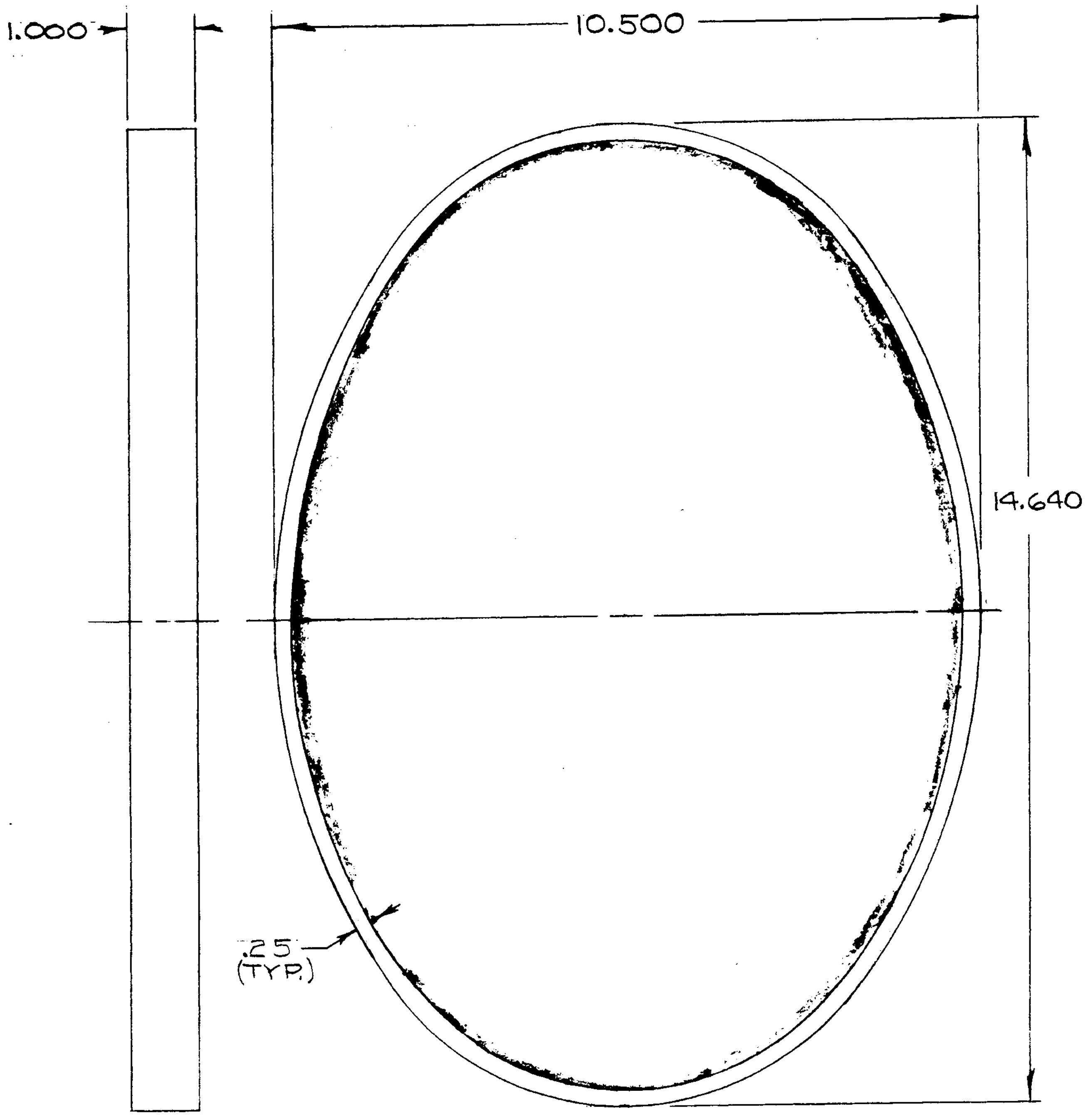
Figure 3.6.1-1



ASTIGMATISM – $\frac{1}{20}\lambda$ P.P.
SPHERICAL POWER $\frac{1}{10}\lambda$ P.P.

SCAN MIRROR
–FOOTPRINT– 3.6-7
SCALE- 1/2 9300
TOL. –.000 – ±.005

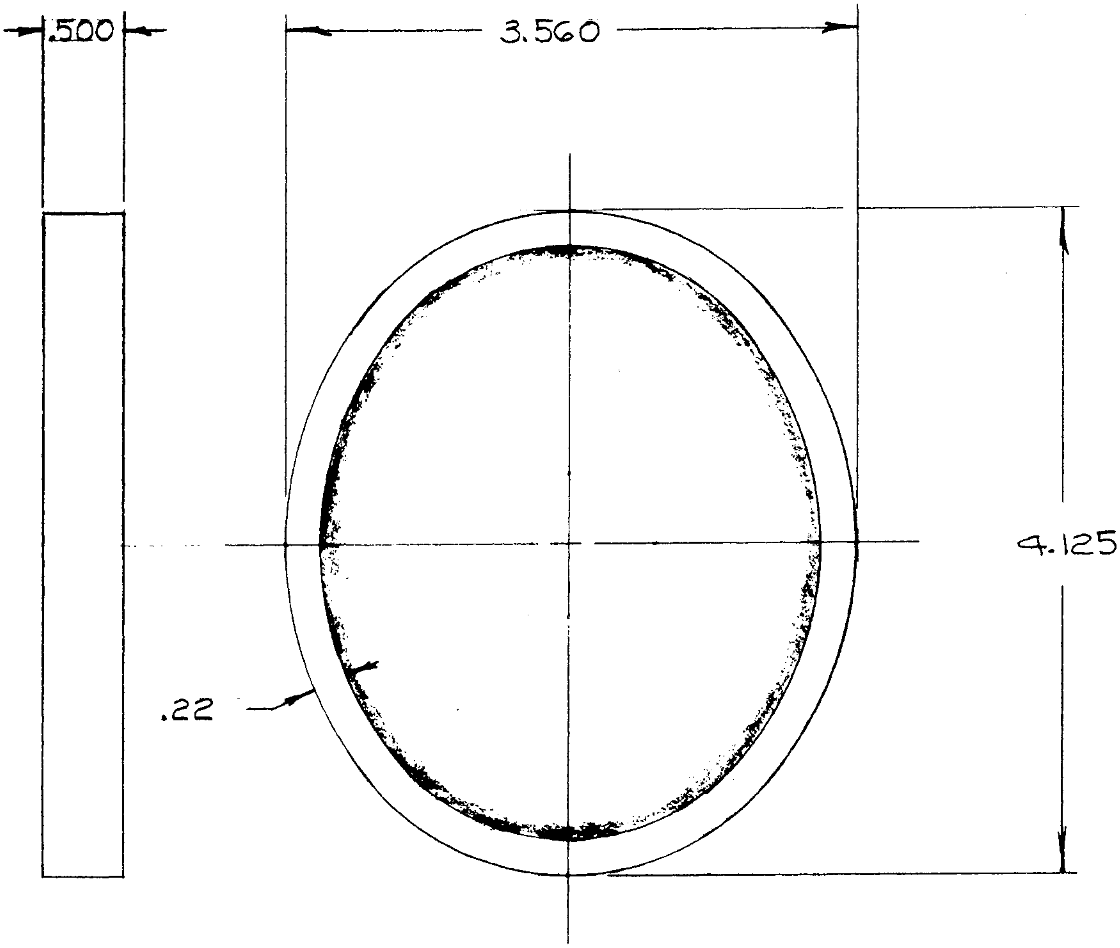
Figure 3.6.1-2



ASTIGMATISM - $\frac{1}{20}\lambda$ P.P.
SPHERICAL POWER $\frac{1}{10}\lambda$ P.P.

FOLD MIRROR - EXT.
- FOOT PRINT -
TOL - .000 - ±.005
SCALE - 1/2 9300

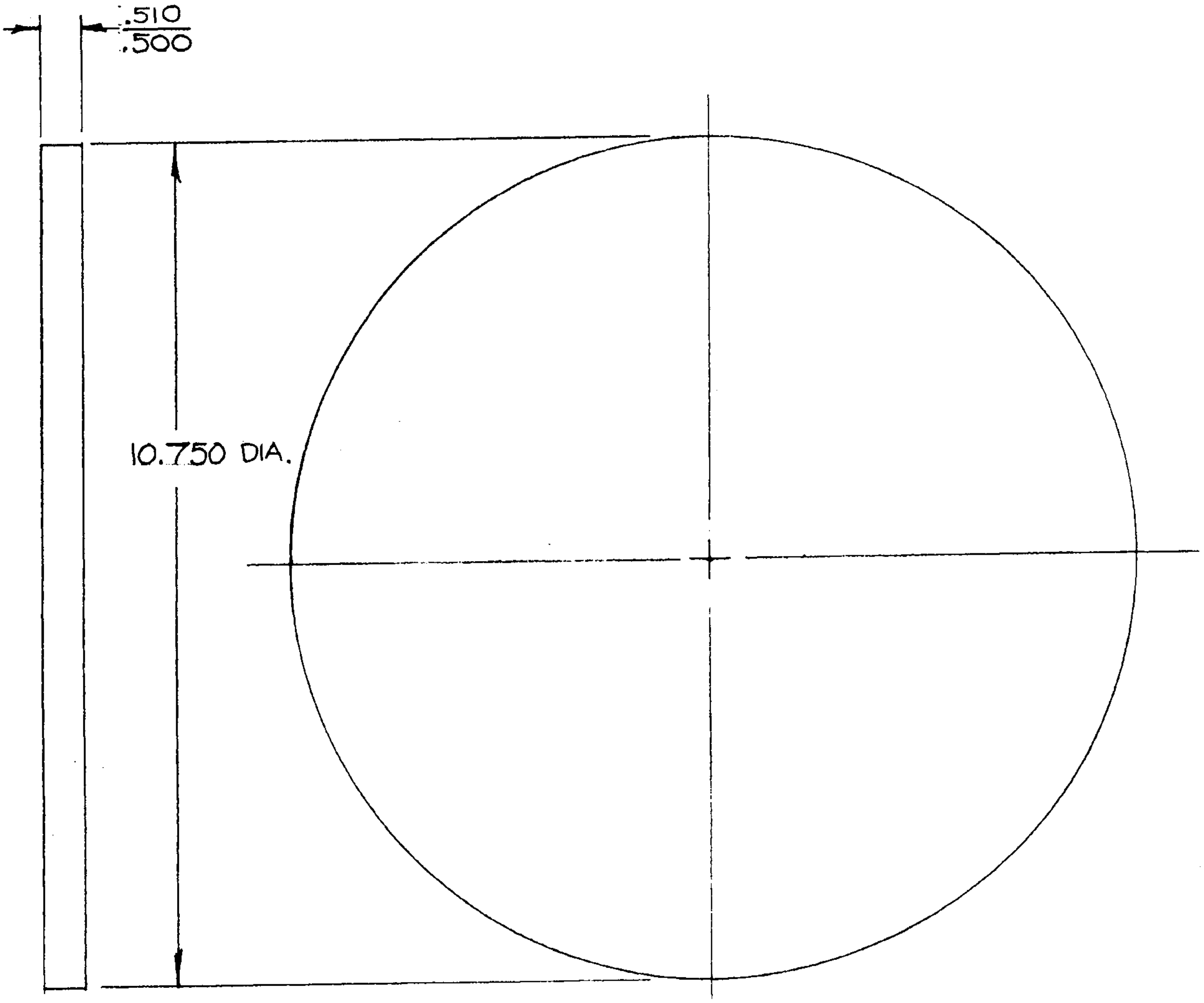
Figure 3.6.1-3



ASTIGMATISM – $\frac{1}{20}\lambda$ P.P.
SPHERICAL POWER $\frac{1}{16}\lambda$ P.P.

FOLD MIRROR, INTERIOR
– FOOT PRINT
SCALE – FULL
TOL –.000 – ±.005

Figure 3.6.1-4



FIRST SURFACE POWER & IRREGULARITY $\lambda/10$ WITHIN 10.10 C.A.
TRANSMITTED WAVE FRONT POWER & IRREGULARITY $\lambda/20$ WITHIN 10.10 C.A.

WINDOW
SCALE - 1/2
TOL - .000 - ±.005

Figure 3.6.1-5

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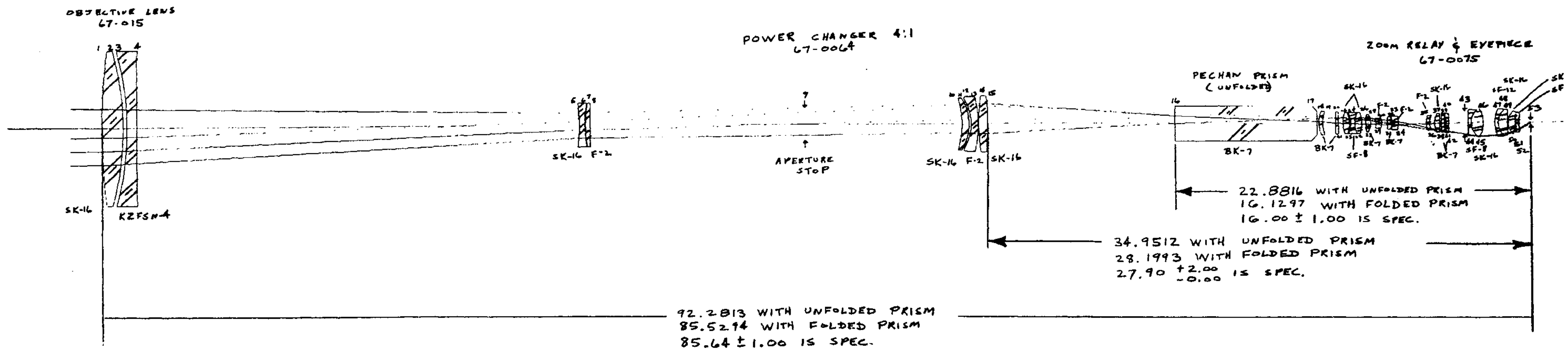
PRIVATE

9900.62P HILB SEQ 999 SER 0002 06/09/67 PLOT NO. 1



ALL DIMS, INCHES
LENS NO. 659 SCALE FACTOR = 250000

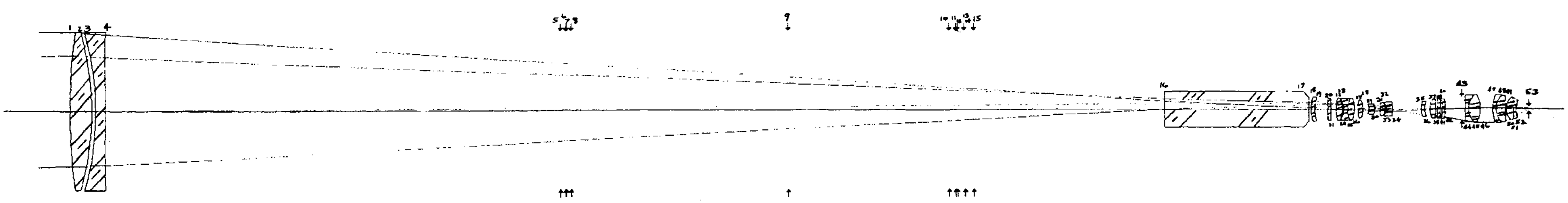
FIGURE 3.6.1-6 FINAL A/O TELESCOPE DESIGN AT 31.75X

PRIVATE

SPECIAL HANDLING ~~SECRET~~

9300 62P HILB SEQ 999 SER 0027 06/09/67 PLOT NO. 2

PRIVATE



LENS NO. 659 SCALE FACTOR = 250000

FIGURE 3.6.1-7 FINAL PRIVATE A/O TELESCOPE DESIGN AT 127 X

PRIVATE

```
• CLIC P

ID HIPOW    PJN 9300.62 DAT

             DRAT  9 3 5 1 0 0
CS 3 5 3 5 1 3
APS  1
WV 6.5000000E-01 6.0500000E-01 5.6000000E-01 5.1500000E-01 4.7000000E-01
OBJ B   5.0000000E-11   4.5461000E-03   5.0000000E+00       .000000000
CF  2.540000E+04 SF  5.000000E-03
VIG1     .700
  0 CV       .000000000 TH   1.0000000E+11 AIR
  1 CAO   5.0000000E+00
  1 N15    1.61752377     1.61952119     1.62198386     1.62509838     1.62915413
  1 CV   2.4918900E-02 TH   1.3544000E+00
  2 CAO   4.9900000E+00
  2 CV  -5.4295000E-02 TH   2.6560000E-01 AIR
  3 CAO   4.9200000E+00
  3 N15    1.60956876     1.61221404     1.61550439     1.61971365     1.62528070
  3 CV  -5.6122100E-02 TH   6.0000000E-01
  4 CAO   4.8650000E+00
  4 TH   2.8818000E+01 AIR
  4 RD   2.7361050E+02
  5 CAS       .000000000   3.6131000E-01
  5 CAO   5.0000000E+00
  5 AIR
  5 CV       .000000000
  6 CAO   5.0000000E+00
  6 CV       .000000000 TH   2.0000000E-02 AIR
  7 CAS       .000000000   2.9343094F-01
  7 CAO   5.0000000E+00
  7 AIR
  7 CV       .000000000
  8 CAO   5.0000000E+00
  8 CV       .000000000 TH   1.3906900F+01 AIR
  9 CAO   5.0000000F+00
  9 CV       .000000000 TH   1.0087256E+01 AIR
 10 CAS       .000000000   4.4682650E-01
 10 CAO   5.0000000E+00
 10 AIR
 10 CV       .000000000
 11 CAO   5.0000000F+00
 11 CV       .000000000 TH   1.3374202E-01 AIR
 12 CAS       .000000000   4.5161000E-01
 12 CAO   5.0000000F+00
 12 AIR
 12 CV       .000000000
 13 CAO   5.0000000F+00
 13 CV       .000000000 TH   2.0000000E-02 AIR
 14 CAO   5.0000000E+00
 14 CV       .000000000 TH   5.7110000E-01 AIR
 15 CAO   5.0000000F+00
 15 CV       .000000000 TH   1.2069578E+01 AIR
 16 CAO   1.1100000F+00
 16 N15    1.51451425     1.51608889     1.51801874     1.52044653     1.52359228
```

TABLE 3.6.1-2 "CLOC" SPECIFICATION AT 127X

PRIVATE

(LENS DESIGN REFERENCE ONLY)

PRIVATE

```
16 CV 0.0 TH   9.1391000E+00
17 CAO    7.7000000E-01
17 CV       .000000000 TH   1.0170000E-01 AIR
18 CAO    7.6000000E-01
18 N15      1.51451425     1.51608889     1.51801874     1.52044653     1.52359228
18 CV    4.4823760E-01 TH   2.3910000E-01
19 CAO    7.3000000E-01
19 CV    4.5450700E-01 TH   7.9157890E-01 AIR
20 CAO    6.8000000E-01
20 N15      1.51451425     1.51608889     1.51801874     1.52044653     1.52359228
20 CV 0.0 TH   2.0000000E-01
21 CAO    6.8000000E-01
21 CV       .000000000 TH   3.2289388E-01 AIR
22 CAO    6.9150000E-01
22 N15      1.61752377     1.61952119     1.62198386     1.62509838     1.62915413
22 CV    3.9226366E-01 TH   3.9593292E-01
23 CAS    8.0000000E-01   5.0000000E-03
23 CAO    6.7900000E-01
23 AIR
23 CV   -5.3506604E-01
24 CAO    6.6200000E-01
24 N15      1.68299586     1.68707398     1.69226203     1.69905453     1.70827343
24 CV   -7.3156413E-01 TH   2.3100000E-01
25 CAO    6.7400000E-01
25 N15      1.61752377     1.61952119     1.62198386     1.62509838     1.62915413
25 CV    7.2421613E-01 TH   4.5000000E-01
26 CAO    6.8250000E-01
26 CV   -4.4399182E-01 TH   2.2738250E-01 AIR
27 CAO    5.4500000E-01
27 N15      1.51451425     1.51608889     1.51801874     1.52044653     1.52359228
27 CV    3.4445848E-01 TH   3.2000000E-01
28 CAO    5.2050000E-01
28 CV   -6.9295932E-01 TH   3.7496183E-01 AIR
29 CAO    3.2700000E-01
29 N15      1.61543933     1.61861263     1.62262630     1.62784951     1.63488689
29 CV   -1.6232146E+00 TH   3.9957652E-01
30 CAO    3.3050000E-01
30 CV   -1.1136856E+00 TH   3.3423286E-01 AIR
31 CAO    3.7200000E-01
31 N15      1.51451425     1.51608889     1.51801874     1.52044653     1.52359228
31 CV    5.7628414E-01 TH   3.2457630E-01
32 CAO    3.9250000E-01
32 CV   -1.2109148E+00 TH   5.0000000E-02 AIR
33 CAO    3.8750000E-01
33 N15      1.61543933     1.61861263     1.62262630     1.62784951     1.63488689
33 CV   -1.2523078E+00 TH   3.9331069E-01
34 CAO    4.5350000E-01
34 CV   -2.9379213E-01 TH   1.8578450E+00 AIR
35 CAO    4.9000000E-01
35 N15      1.61543933     1.61861263     1.62262630     1.62784951     1.63488689
35 CV    5.7765995E-01 TH   2.0723648E-01
36 CAO    4.9000000E-01
36 CV    9.3330300E-01 TH   3.1781358E-01 AIR
37 CAO    5.9000000E-01
37 N15      1.61752377     1.61952119     1.62198386     1.62509838     1.62915413
37 CV    7.7129187E-01 TH   3.0000000E-01
```

PRIVATE

TABLE 3.6.1-2 CONTINUED

```
38 CAO    5.8600000E-01
38 CV   1.8292381E-01 TH   1.5000000E-01 AIR
39 CAO    5.9000000E-01
39 N15     1.51451425     1.51608889     1.51801874     1.52044653     1.52359228
39 CV 0.0 TH   1.7000000E-01
40 CAO    5.9000000E-01
40 CV       .000000000 TH   1.5000000E-01 AIR
41 CAO    5.9000000E-01
41 N15     1.51451425     1.51608889     1.51801874     1.52044653     1.52359228
41 CV  -5.0017106E-01 TH   2.0005154E-01
42 CAO    6.2000000E-01
42 CV  -2.4024916E-01 TH   1.0425652E+00 AIR
43 CAO    7.5000000E-01
43 CV       .000000000 TH   2.0000000E-01 AIR
44 CAO    7.7000000E-01
44 N15     1.68299586     1.68707398     1.69226203     1.69905453     1.70827343
44 CV  -1.3337190E-01 TH   1.6700000E-01
45 CAO    8.3500000E-01
45 N15     1.61752377     1.61952119     1.62198386     1.62509838     1.62915413
45 CV   8.4379514E-01 TH   7.5600000E-01
46 CAO    8.7000000E-01
46 CV  -5.6336878E-01 TH   7.5040185E-01 AIR
47 CAO    8.8600000E-01
47 N15     1.64312043     1.64668350     1.65119990     1.65709009     1.66505028
47 CV   4.5499823E-01 TH   2.1000000E-01
48 CAO    8.3200000E-01
48 N15     1.61752377     1.61952119     1.62198386     1.62509838     1.62915413
48 CV   8.6566261E-01 TH   5.8800000E-01
49 CAO    8.0350000E-01
49 CV  -3.3093167E-02 TH   1.5000000E-02 AIR
50 CAO    7.2050000E-01
50 N15     1.61752377     1.61952119     1.62198386     1.62509838     1.62915413
50 CV   1.0697825E+00 TH   5.0002125E-01
51 CAO    6.4300000E-01
51 N15     1.68299586     1.68707398     1.69226203     1.69905453     1.70827343
51 CV  -8.3341200E-02 TH   1.4900000E-01
52 CAO    5.0850000E-01
52 CV   7.4291318E-01 TH   7.7157971E-01 AIR
53 CAO    1.5000000E-01
53 CV       .000000000 TH       .000000000 AIR
54 CV 0.0 TH   1.0000000E+00
END
* PUPL REAL

* SPEC
```

TABLE 3.6.1-2 CONTINUED

PRIVATE

```
* CLIC P
            LOW POWER MODE
ID HIPOW     PJN 9300.62 DAT
            LENS NO.  660
            DRAT  9 3 5 1 0 0
CS 3 5 3 5 1 3
APS  9
WV 6.5000000E-01 6.0500000E-01 5.6000000E-01 5.1500000E-01 4.7000000E-01
OBJ B   1.2500000E-11   1.8180000E-02   1.2500000E+00  -1.4802315E+00
CF  2.5400000E+04 SF  5.000000E-03
VIG1     .700
  0 CV       .000000000 TH   1.0000000E+11 AIR
  1 CAO   5.0000000E+00
  1 N15    1.61752377    1.61952119    1.62198386    1.62509838    1.62915413
  1 CV   2.4918900E-02 TH   1.3544000E+00
  2 CAO   4.9900000E+00
  2 CV  -5.4295000E-02 TH   2.6560000E-01 AIR
  3 CAO   4.9200000E+00
  3 N15    1.60956876    1.61221404    1.61550439    1.61971365    1.62528070
  3 CV  -5.6122100E-02 TH   6.0000000E-01
  4 CAO   4.8650000E+00
  4 TH   2.8818000E+01 AIR
  4 RD   2.7361050E+02
  5 CAS       .000000000   3.6131000E-01
  5 CAO   1.3950000E+00
  5 N15    1.61752377    1.61952119    1.62198386    1.62509838    1.62915413
  5 CV  -1.1118486E-01
  6 CAO   1.3950000E+00
  6 CV   9.3433654E-02 TH   2.0000000E-02 AIR
  7 CAS       .000000000   2.9343094E-01
  7 CAO   1.4000000E+00
  7 N15    1.61543933    1.61861263    1.62262630    1.62784951    1.63488689
  7 CV   1.3135445E-01
  8 CAO   1.3950000E+00
  8 CV   2.0557867E-03 TH   1.3906900E+01 AIR
  9 CAO   1.0300000E+00
  9 CV       .000000000 TH   1.0087256E+01 AIR
 10 CAS       .000000000   4.4682650E-01
 10 CAO   1.6400000E+00
 10 N15    1.61752377    1.61952119    1.62198386    1.62509838    1.62915413
 10 CV  -1.8305845E-01
 11 CAO   1.6750000E+00
 11 CV  -3.2199174E-01 TH   1.3374202E-01 AIR
 12 CAS       .000000000   4.5161000E-01
 12 CAO   1.6600000E+00
 12 N15    1.61543933    1.61861263    1.62262630    1.62784951    1.63488689
 12 CV  -3.3160338E-01
 13 CAO   1.7750000E+00
 13 CV  -1.4712288E-01 TH   2.0000000E-02 AIR
 14 CAO   1.8150000E+00
 14 N15    1.61752377    1.61952119    1.62198386    1.62509838    1.62915413
 14 CV   8.3476098E-02 TH   5.7110000E-01
 15 CAO   1.8150000E+00
 15 CV  -5.3952257E-02 TH   1.2069578E+01 AIR
 16 CAO   1.1150000E+00
```

PRIVATE

TABLE 3.6.1-3 "CLOC SPECIFICATION AT 31.75X
(LENS DESIGN REFERENCE ONLY)

```
16 N15     1.51451425     1.51608889     1.51801874     1.52044653     1.52359228
16 CV 0.0 TH   9.1391000E+00
17 CAO   7.7500000E-01
17 CV       .000000000 TH   1.0170000E-01 AIR
18 CAO   7.6500000E-01
18 N15     1.51451425     1.51608889     1.51801874     1.52044653     1.52359228
18 CV    4.4823760F-01 TH   2.3910000E-01
19 CAO   7.2500000E-01
19 CV    4.5450700F-01 TH   7.9157890E-01 AIR
20 CAO   6.8000000E-01
20 N15     1.51451425     1.51608889     1.51801874     1.52044653     1.52359228
20 CV 0.0 TH   2.0000000E-01
21 CAO   6.8500000E-01
21 CV       .000000000 TH   3.2289388E-01 AIR
22 CAO   6.9150000E-01
22 N15     1.61752377     1.61952119     1.62198386     1.62509838     1.62915413
22 CV    3.9226366F-01 TH   3.9593292E-01
23 CAS   8.0000000E-01   5.0000000E-03
23 CAO   6.7900000E-01
23 AIR
23 CV   -5.3506604F-01
24 CAO   6.6200000E-01
24 N15     1.68299586     1.68707398     1.69226203     1.69905453     1.70827343
24 CV   -7.3156413F-01 TH   2.3100000E-01
25 CAO   6.7400000E-01
25 N15     1.61752377     1.61952119     1.62198386     1.62509838     1.62915413
25 CV    7.2421613F-01 TH   4.5000000E-01
26 CAO   6.8250000E-01
26 CV   -4.4399182F-01 TH   2.2738000F-01 AIR
27 CAO   5.4500000E-01
27 N15     1.51451425     1.51608889     1.51801874     1.52044653     1.52359228
27 CV    3.4445848F-01 TH   3.2000000E-01
28 CAO   5.2050000E-01
28 CV   -6.9295932F-01 TH   3.7496183E-01 AIR
29 CAO   3.2700000E-01
29 N15     1.61543933     1.61861263     1.62262630     1.62784951     1.63488689
29 CV   -1.6232146E+00 TH   3.9957652E-01
30 CAO   3.3050000E-01
30 CV   -1.1136856F+00 TH   3.3423000E-01 AIR
31 CAO   3.7200000E-01
31 N15     1.51451425     1.51608889     1.51801874     1.52044653     1.52359228
31 CV    5.7628414F-01 TH   3.2457630E-01
32 CAO   3.9250000E-01
32 CV   -1.2109148F+00 TH   5.0000000E-02 AIR
33 CAO   3.8750000E-01
33 N15     1.61543933     1.61861263     1.62262630     1.62784951     1.63488689
33 CV   -1.2523078F+00 TH   3.9331069E-01
34 CAO   4.5350000E-01
34 CV   -2.9379213F-01 TH   1.8578400E+00 AIR
35 CAO   4.9000000E-01
35 N15     1.61543933     1.61861263     1.62262630     1.62784951     1.63488689
35 CV    5.7765995F-01 TH   2.0723648E-01
36 CAO   4.9000000E-01
36 CV    9.3330300F-01 TH   3.1781358E-01 AIR
37 CAO   5.9000000E-01
37 N15     1.61752377     1.61952119     1.62198386     1.62509838     1.62915413
```

TABLE 3.6.1-3 CONTINUED

PRIVATE

SPECIAL HANDLING ~~SECRET~~

```
 37 CV    7.7129187E-01 TH    3.0000000E-01
 38 CAO    5.8600000E-01
 38 CV    1.8292381E-01 TH    1.5000000E-01 AIR
 39 CAO    5.9000000E-01
 39 N15     1.51451425      1.51608889      1.51801874      1.52044653      1.52359228
 39 CV 0.0 TH    1.7000000E-01
 40 CAO    5.9000000E-01
 40 CV       .000000000 TH    1.5000000E-01 AIR
 41 CAO    5.9000000E-01
 41 N15     1.51451425      1.51608889      1.51801874      1.52044653      1.52359228
 41 CV   -5.0017106E-01 TH    2.0005154E-01
 42 CAO    6.2000000E-01
 42 CV   -2.4024916E-01 TH    1.0425652E+00 AIR
 43 CAO    7.5000000E-01
 43 CV       .000000000 TH    2.0000000E-01 AIR
 44 CAO    7.7000000E-01
 44 N15     1.68299586      1.68707398      1.69226203      1.69905453      1.70827343
 44 CV   -1.3337190E-01 TH    1.6700000E-01
 45 CAO    8.3500000E-01
 45 N15     1.61752377      1.61952119      1.62198386      1.62509838      1.62915413
 45 CV    8.4379514E-01 TH    7.5600000E-01
 46 CAO    8.7000000E-01
 46 CV   -5.6336878E-01 TH    7.5040185E-01 AIR
 47 CAO    8.8600000E-01
 47 N15     1.64312043      1.64668350      1.65119990      1.65709009      1.66505028
 47 CV    4.5499823E-01 TH    2.1000000E-01
 48 CAO    8.3200000E-01
 48 N15     1.61752377      1.61952119      1.62198386      1.62509838      1.62915413
 48 CV    8.6566261E-01 TH    5.8800000E-01
 49 CAO    8.0350000E-01
 49 CV   -3.3093167E-02 TH    1.5000000E-02 AIR
 50 CAO    7.2050000E-01
 50 N15     1.61752377      1.61952119      1.62198386      1.62509838      1.62915413
 50 CV    1.0697825E+00 TH    5.0002125E-01
 51 CAO    6.4300000E-01
 51 N15     1.68299586      1.68707398      1.69226203      1.69905453      1.70827343
 51 CV   -8.3341200E-02 TH    1.4900000E-01
 52 CAO    5.0850000E-01
 52 CV    7.4291318E-01 TH    7.7157971E-01 AIR
 53 CAO    1.5000000E-01
 53 CV       .000000000 TH       .000000000 AIR
 54 CV 0.0 TH    1.0000000E+00
END
* PUPL REAL

* SPEC
```

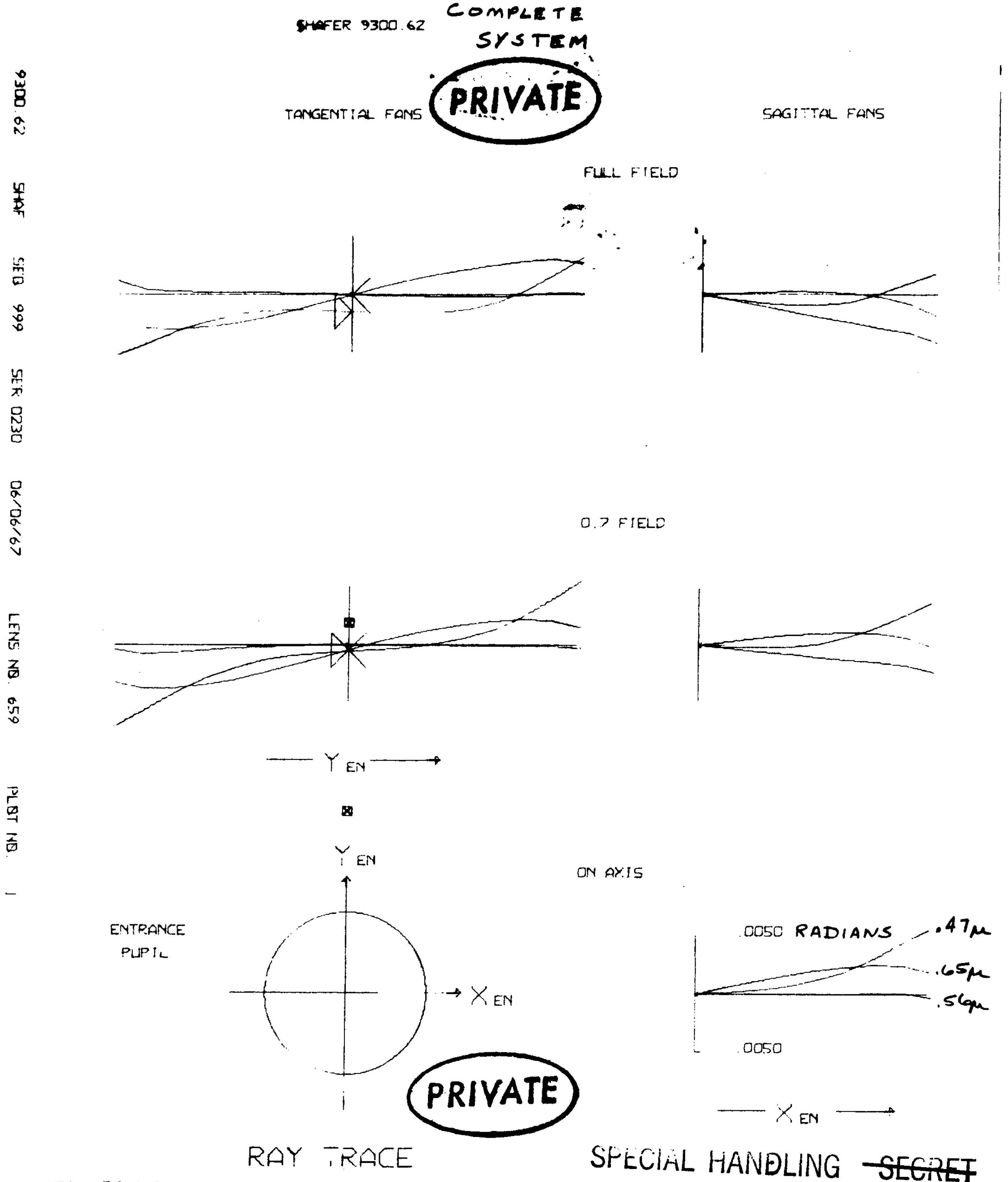
PRIVATE

SPECIAL HANDLING ~~SECRET~~

TABLE 3.6.1-3 CONTINUED

127.0 X
COMPLETE
SYSTEM

PRIVATE



PRIVATE

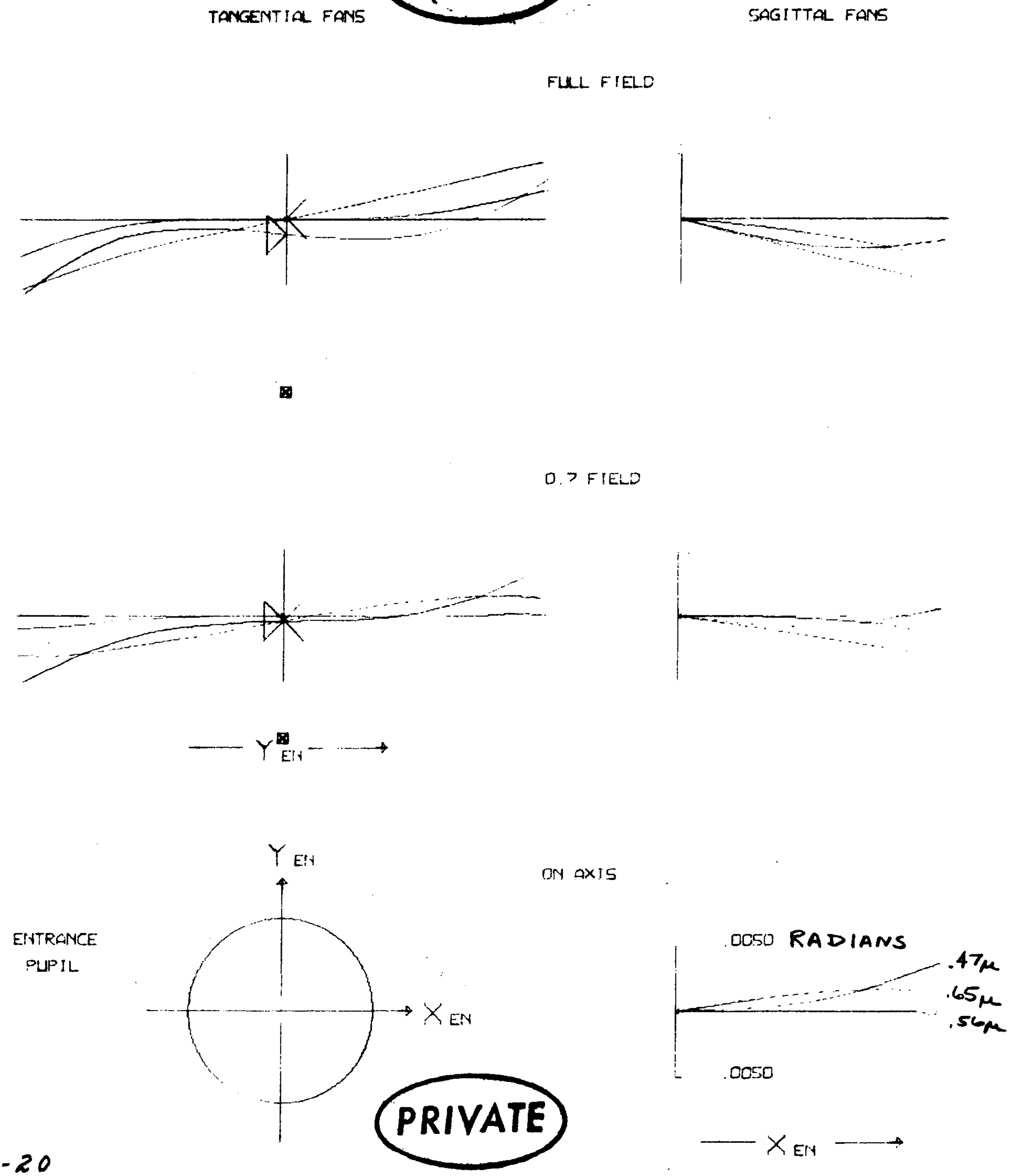
Fig. 36.1-8. ANGULAR ABERRATION AT 127X

84.67X
COMPLETE
SYSTEM

SHAFER 9300.62 06/06/67

PRIVATE

9300.62 SHAF SEQ 999 SER 0230 06/06/67 LENS NO. 660 PLOT NO. 3



PRIVATE

RAY TRACE

Fig. 36.1-5 ANGULAR ABERRATION AT 84.67X

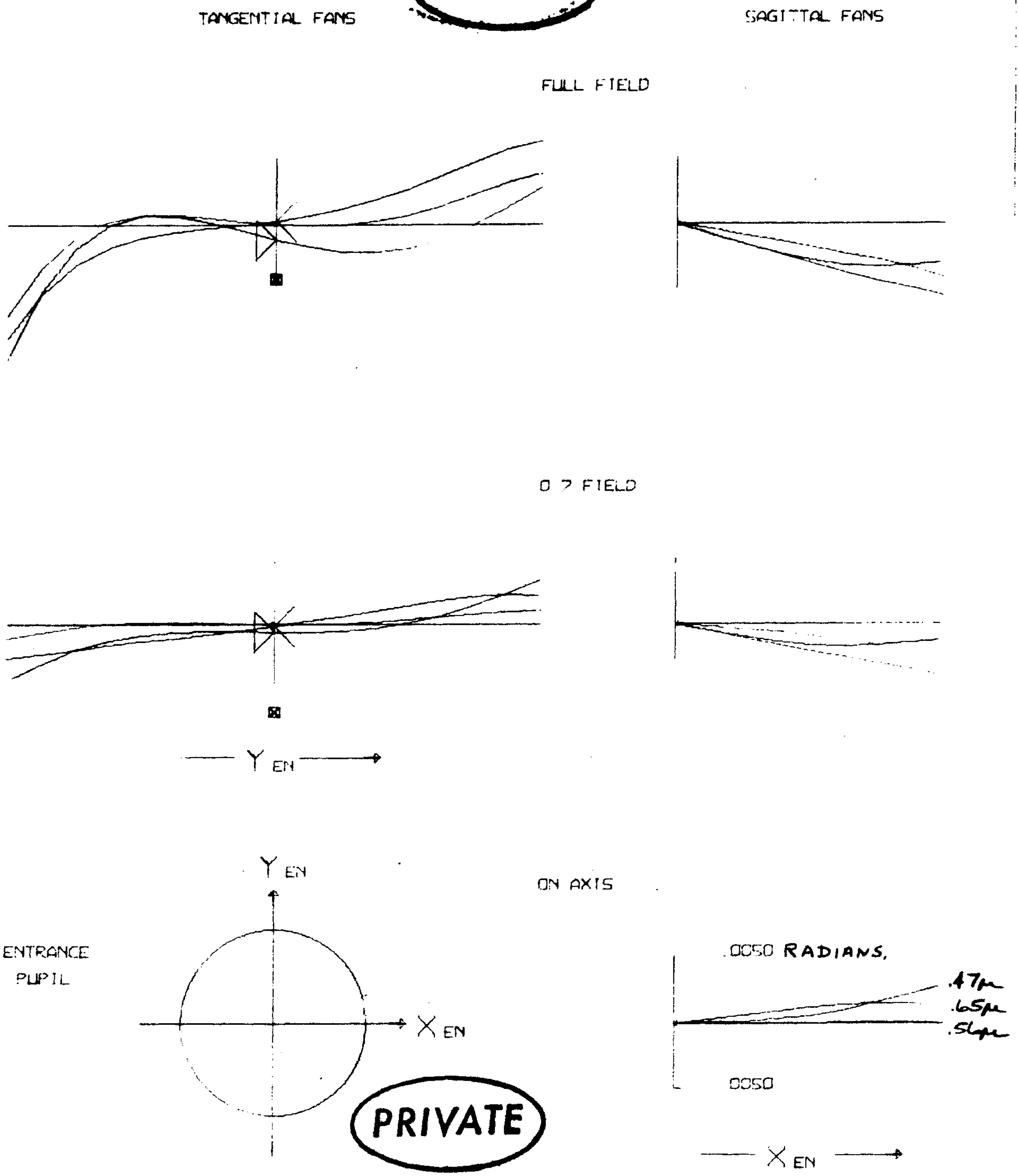
63.5x SPECIAL HANDLING ~~SECRET~~

COMPLETE SYSTEM

SHAFER 9300.62 06/06/67

PRIVATE

9300.62 SHAF SED 999 SER 0230 06/06/67 LENS NO. 661 PLOT NO. 5



PRIVATE

SPECIAL HANDLING ~~SECRET~~

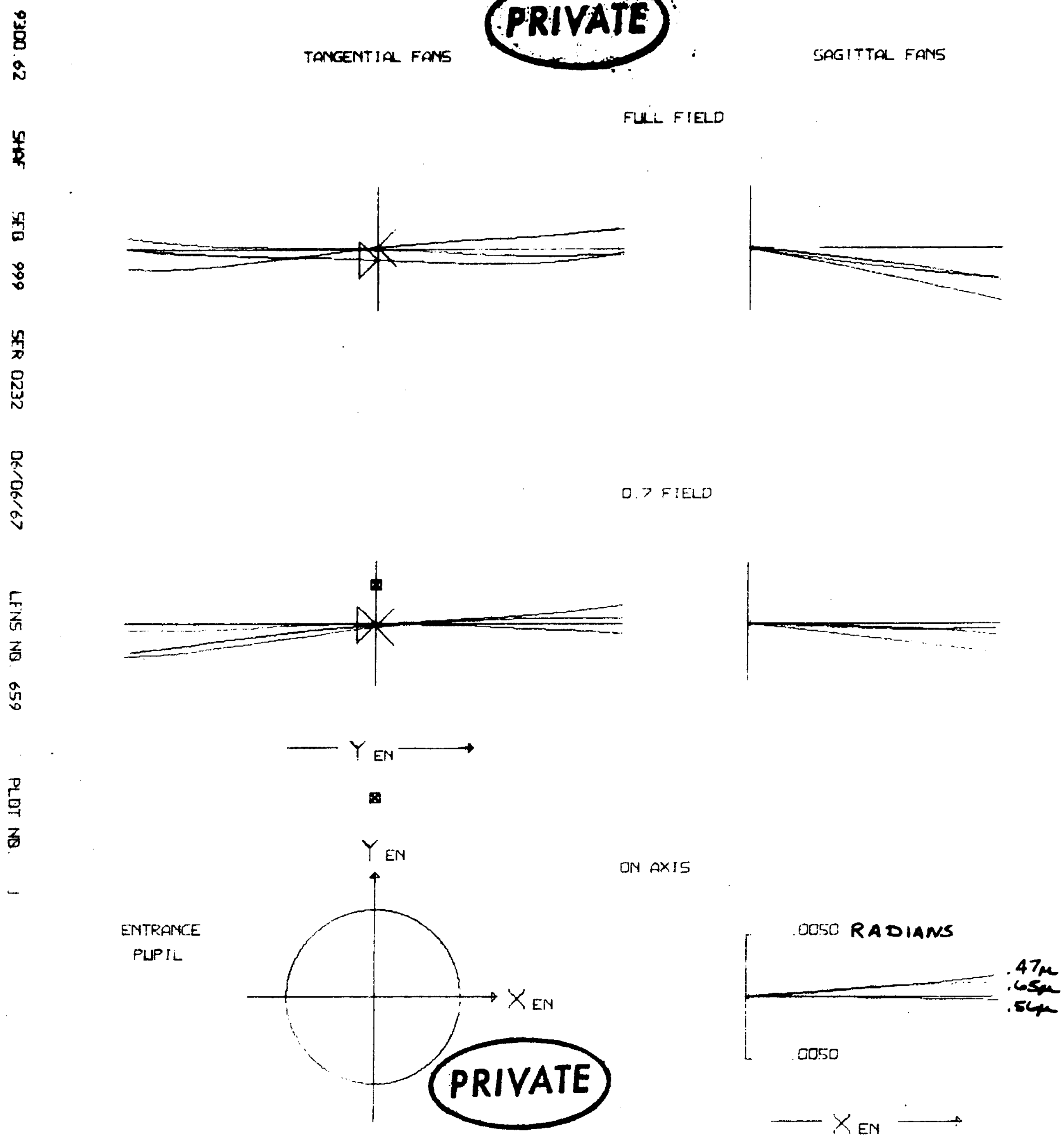
RAY TRACE

Fig. 36.1-10 ANGULAR ABERRATION AT 63.5X

31.75X
COMPLETE SYSTEM

SHAFER 9300.62 06/06/67*

PRIVATE



PRIVATE

RAY TRACE
Fig. 36.1-11 ANGULAR ABERRATION AT 31.75X

NRO APPROVED FOR
RELEASE 1 JULY 2015

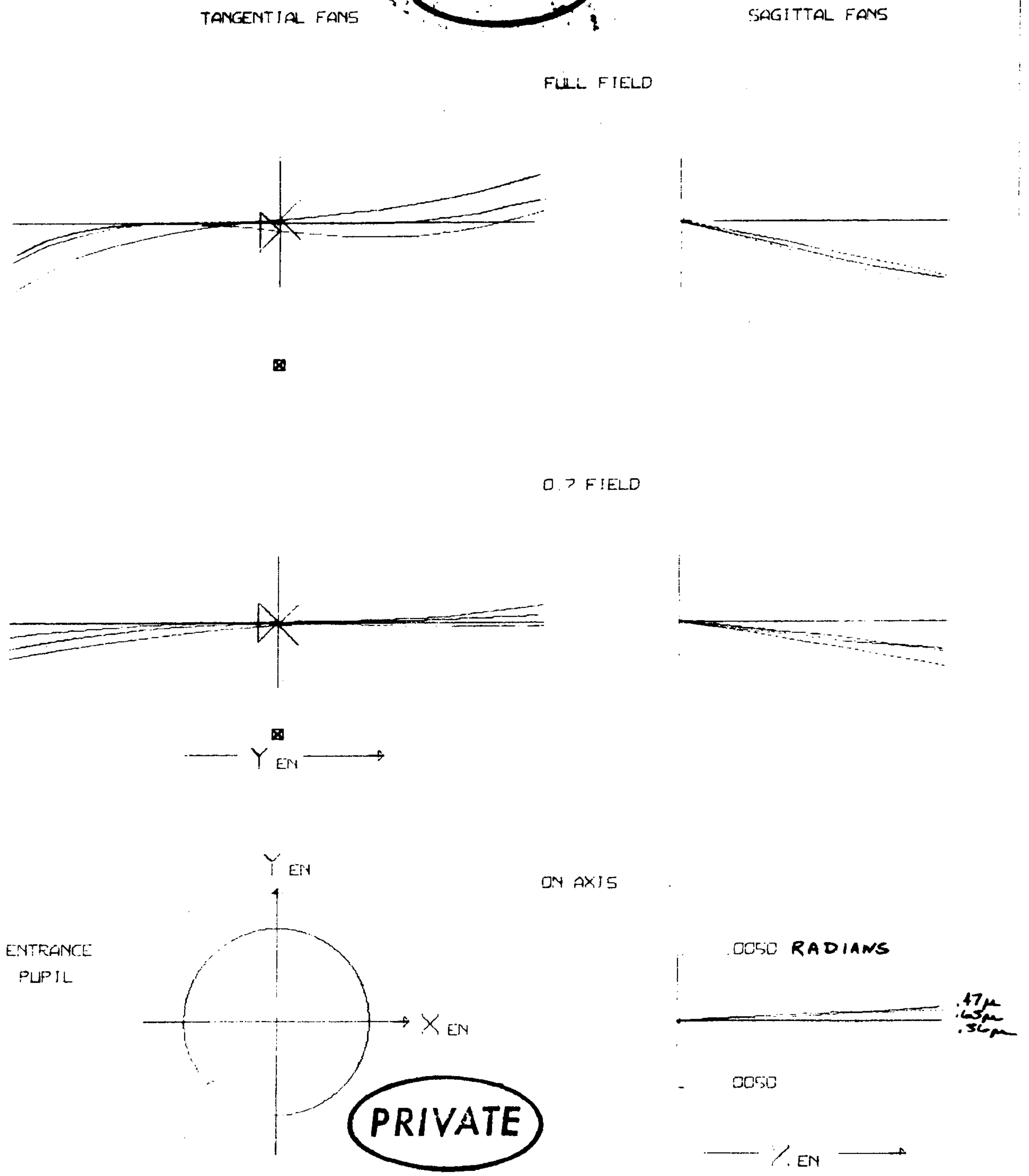
SPECIAL HANDLING ~~SECRET~~

21.17X
COMPLETE
SYSTEM

SHAFER 9300.62 06/06/67*

PRIVATE

9300.62 SHAF SFQ 999 SER 0232 06/06/67 LENS NO. 660 PLOT NO. 3



PRIVATE

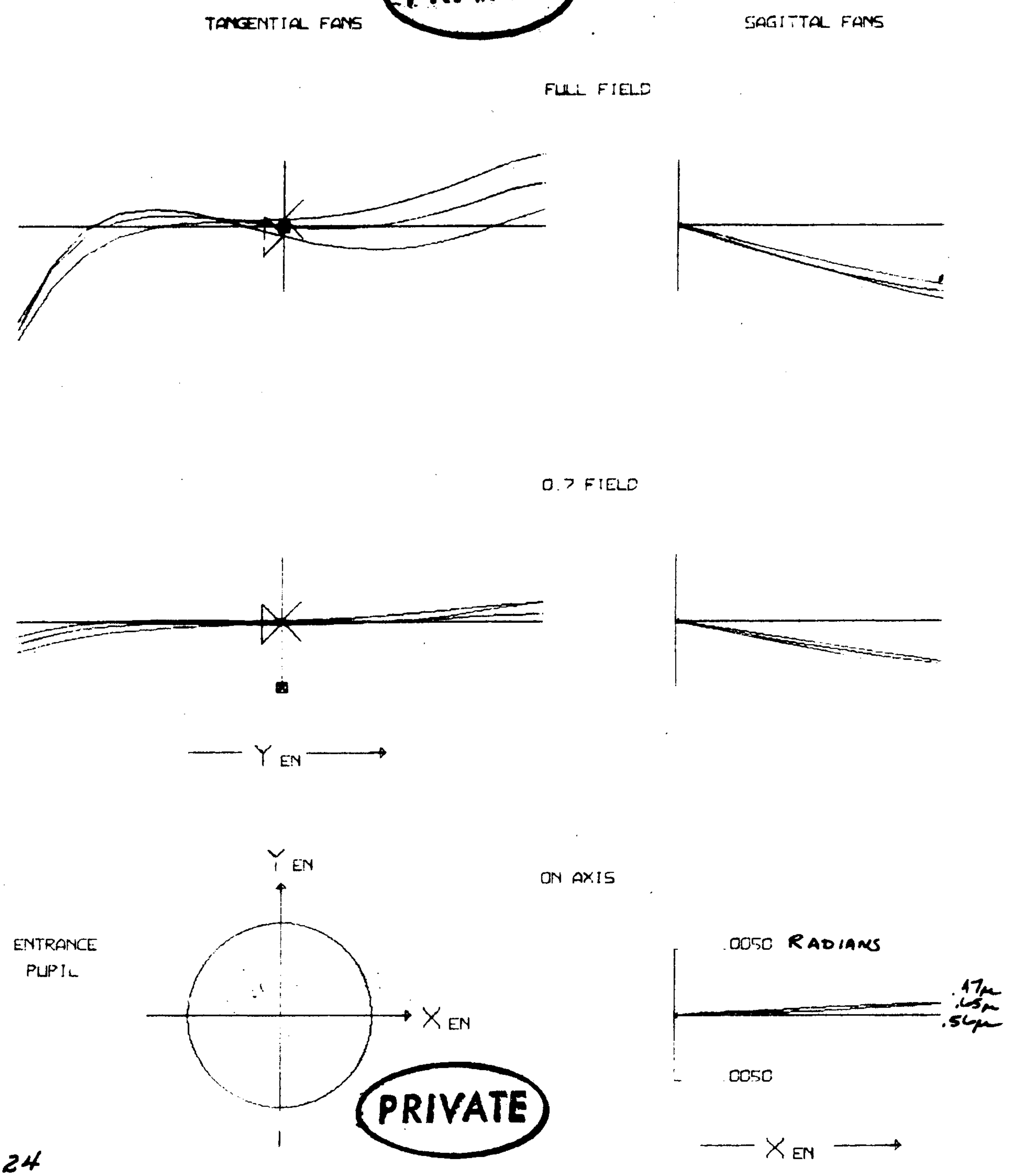
RAY TRACE .SPECIAL HANDLING ~~SECRET~~ 3.6-23

Fig. 36.1-12 - ANGULAR ABERRATION AT 21.17X

15.88x
COMPLETE
SYSTEM

SHAFER 9300.62 06/06/67

PRIVATE



9300.62 SHAF SED 999 SER 0232 06/06/67 LENS NO 661 PLOT NO. 5

PRIVATE

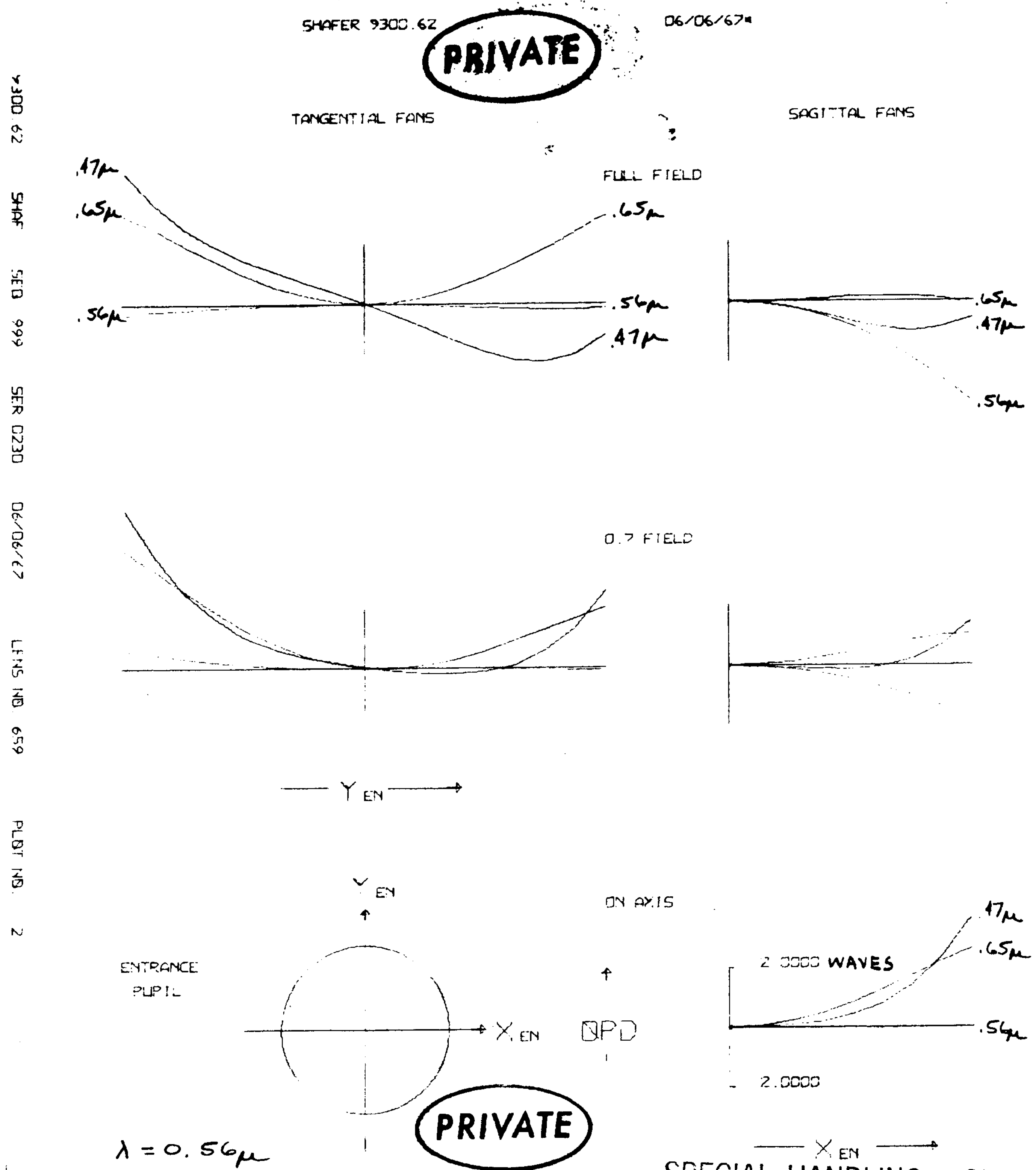
3.6-24

RAY TRACE

Fig. 36.1-13 -ANGULAR ABERRATION AT 15.88 X

127.0 X

PRIVATE



PRIVATE

RAY TRACE OPD - OPTICAL PATH DIFFERENCE

Fig. 36.1-14 · OPTICAL PATH DIFFERENCE AT 127 X

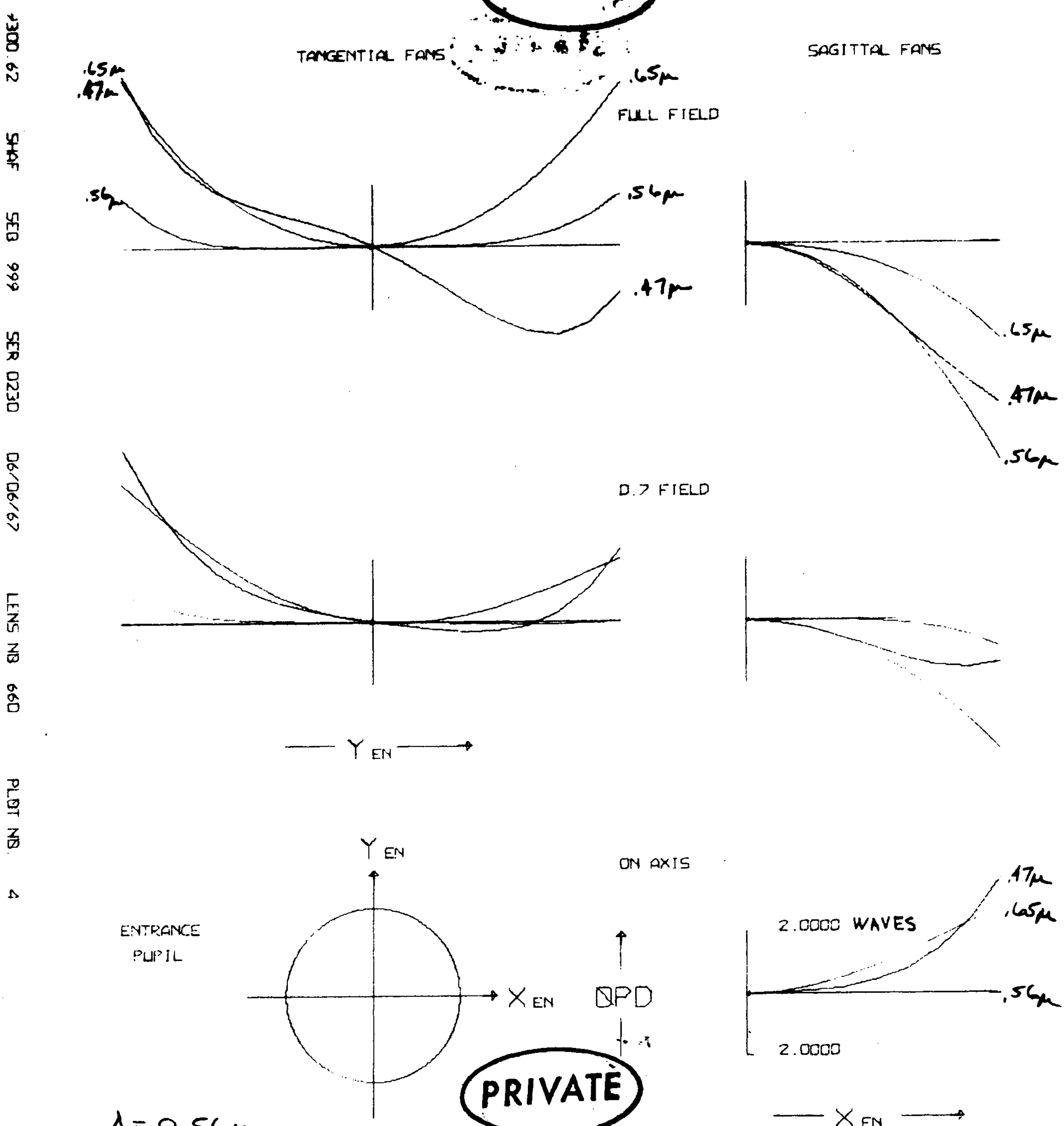
3.6-25

84.67X

SHAFER 9300.62

PRIVATE

06/06/67



PRIVATE

λ = 0.56μ

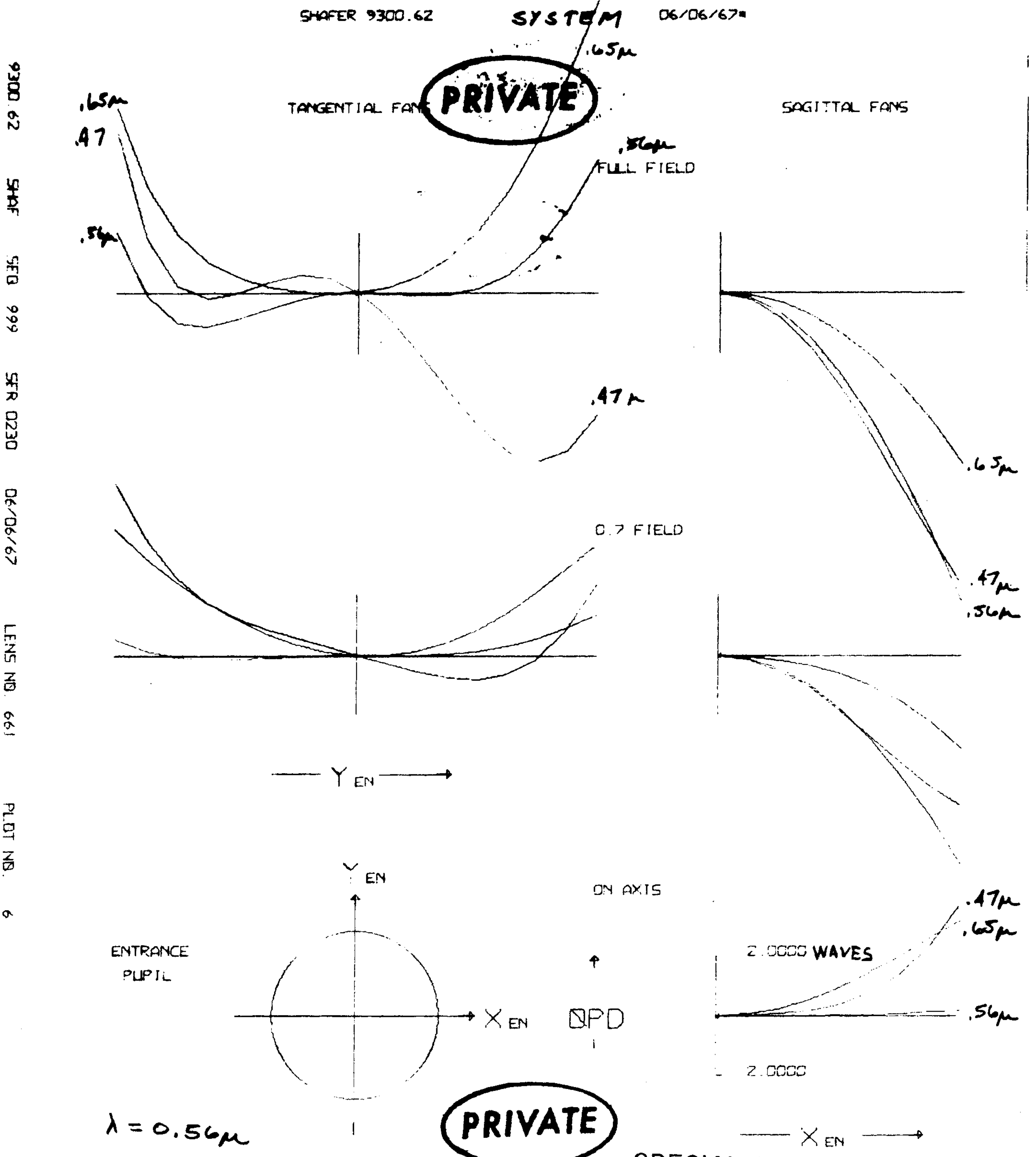
3.6-26

RAY TRACE (OPD = OPTICAL PATH DIFFERENCE)

Fig. 36.1-15 - OPTICAL PATH DIFFERENCE AT 84.67 X

63.5 x
COMPLETE
SYSTEM

PRIVATE



PRIVATE

RAY TRACE (OPD = OPTICAL PATH DIFFERENCE)

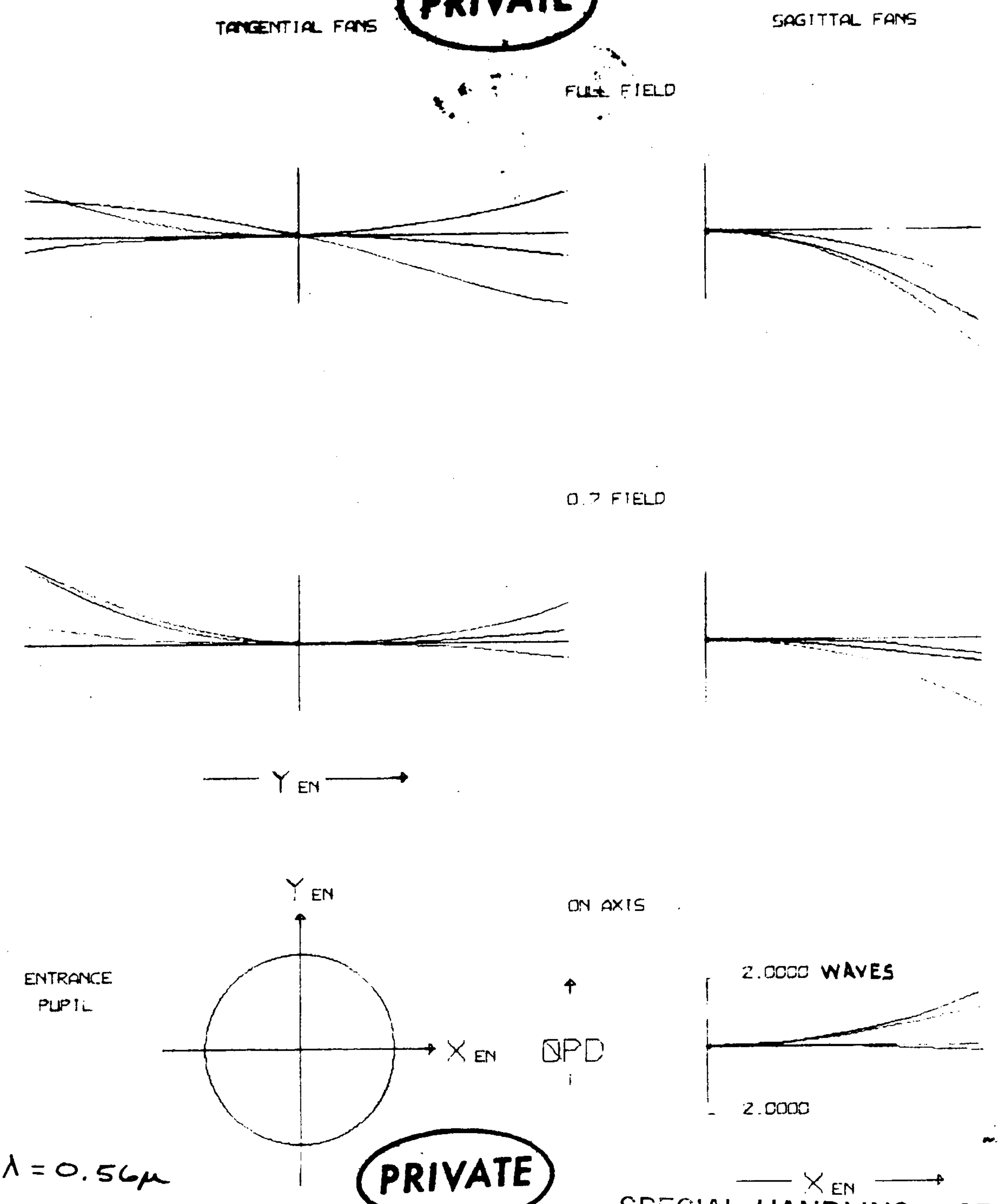
Fig. 36 1-16 - OPTICAL PATH DIFFERENCE AT 63.5 X$^{3.6\text{-}27}$

31.75X
COMPLETE
SYSTEM

SHAFER 9300.62 06/06/67

PRIVATE

9300.62 SHAF SFD 999 SFR 0232 06/06/67 LENS NO. 659 PLOT NO. 2



λ = 0.56μ

PRIVATE

RAY TRACE OPD (OPTICAL PATH DIFFERENCE)

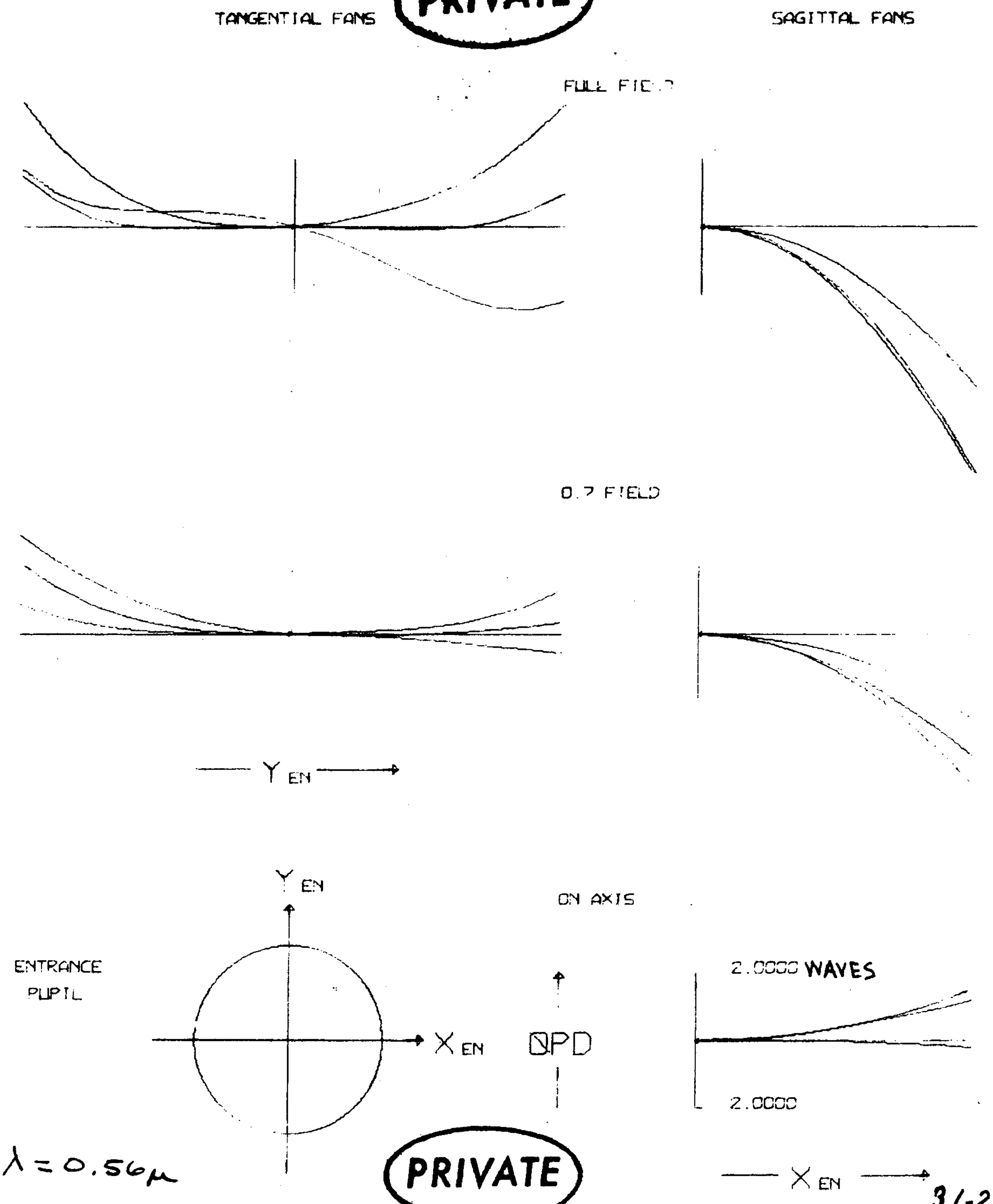
Fig. 36.1-17 - OPTICAL PATH DIFFERENCE AT 31.75X

21.17X
COMPLETE
SYSTEM

SHAFER 9300.62 06/06/67

PRIVATE

9300.62 SHAF SEQ 999 SER 0232 06/06/67 LENS NO 660 PLOT NO. 4



$\lambda = 0.56\mu$

PRIVATE

RAY TRACE (OPD - OPTICAL PATH DIFFERENCE)

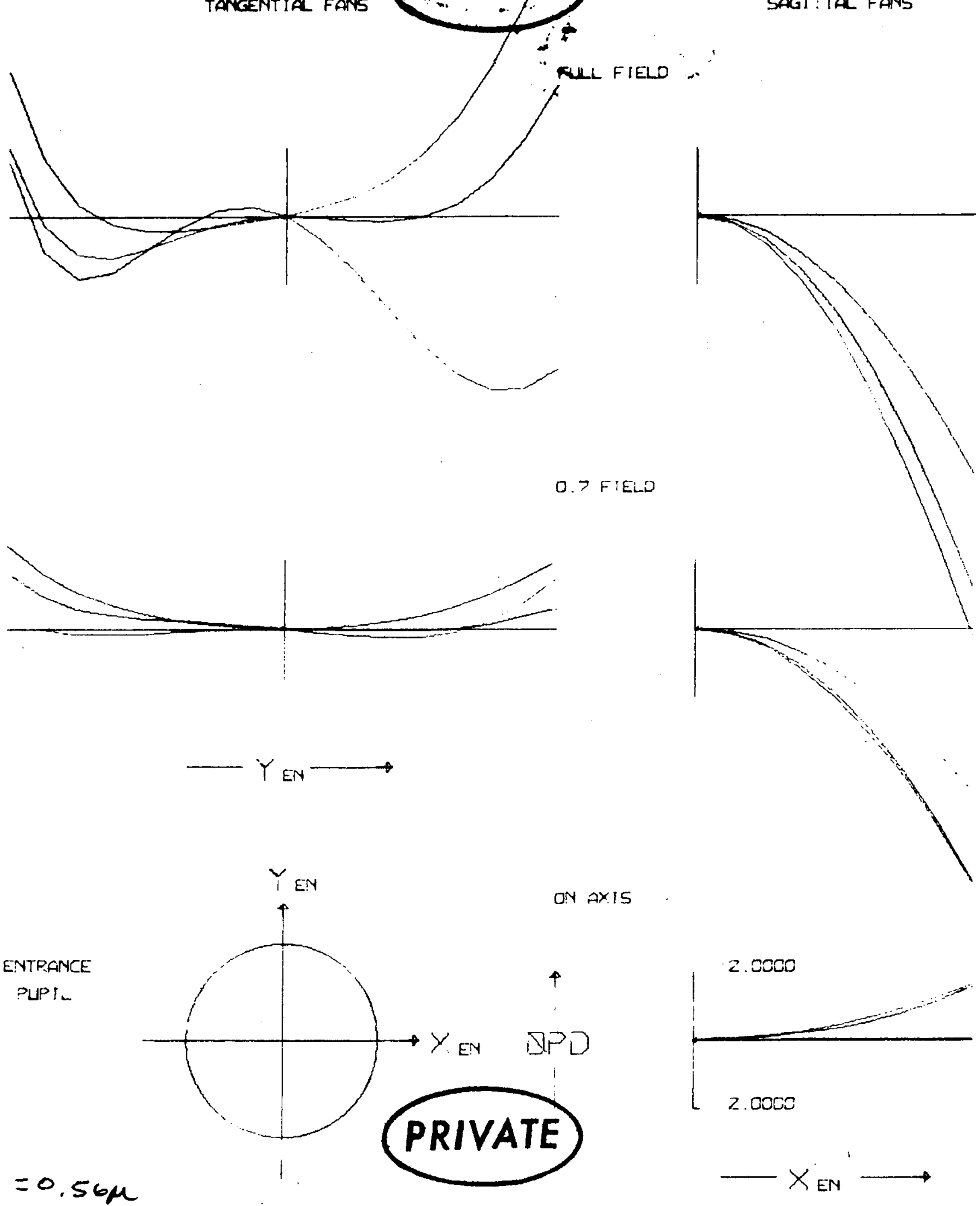
Fig. 36.1-18 - OPTICAL PATH DIFFERENCE AT 21.17 X

15.88X
COMPLETE
SYSTEM

SHAFER 9300.62 06/06/67

PRIVATE

300.62 SHAF SEQ 999 SFR 0232 06/06/67 LENS NO. 661 PLOT NO. 6



PRIVATE

λ = 0.56μ

3.6-30

RAY TRACE (OPD = OPTICAL PATH DIFFERENCE)

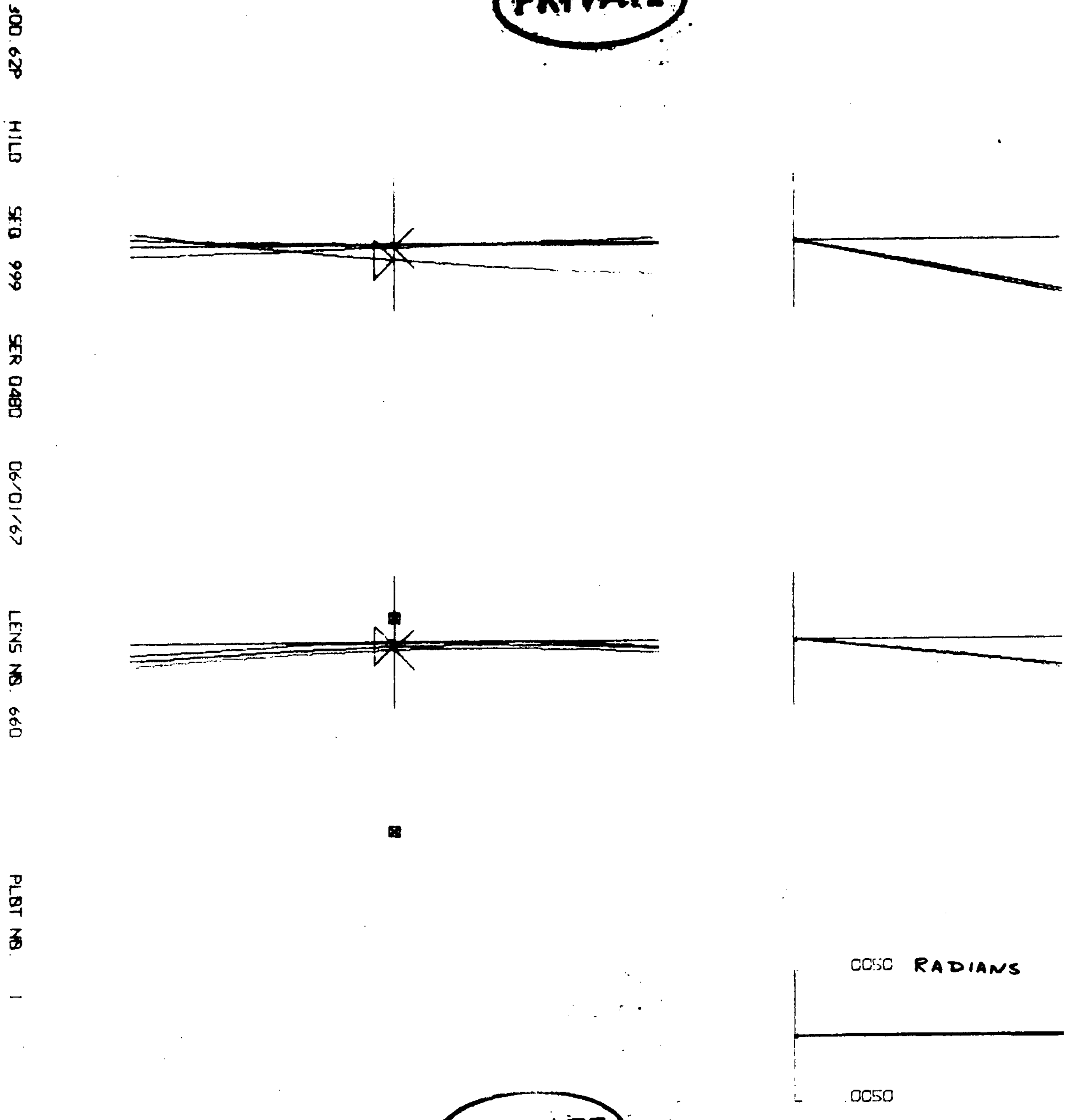
Fig. 36.1-19 . OPTICAL PATH DIFFERENCE AT 15.88X

127.0 X

HILB 9300.62P

06/01/67

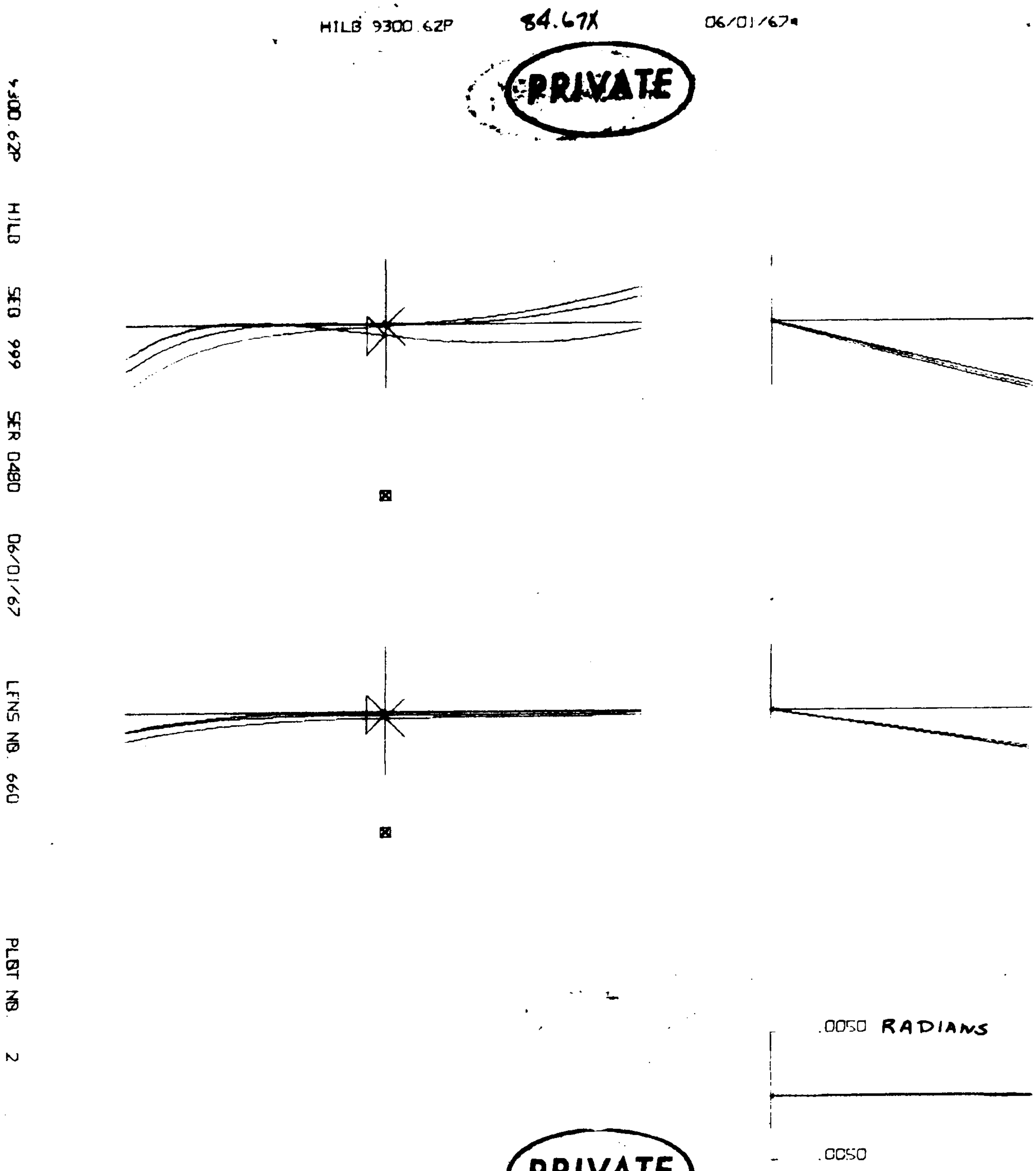
PRIVATE



PRIVATE

Fig. 36.1-20 ANGULAR ABERRATION OF ZOOM RELAY & EYEPIECE AT HIGH ZOOM

PRIVATE



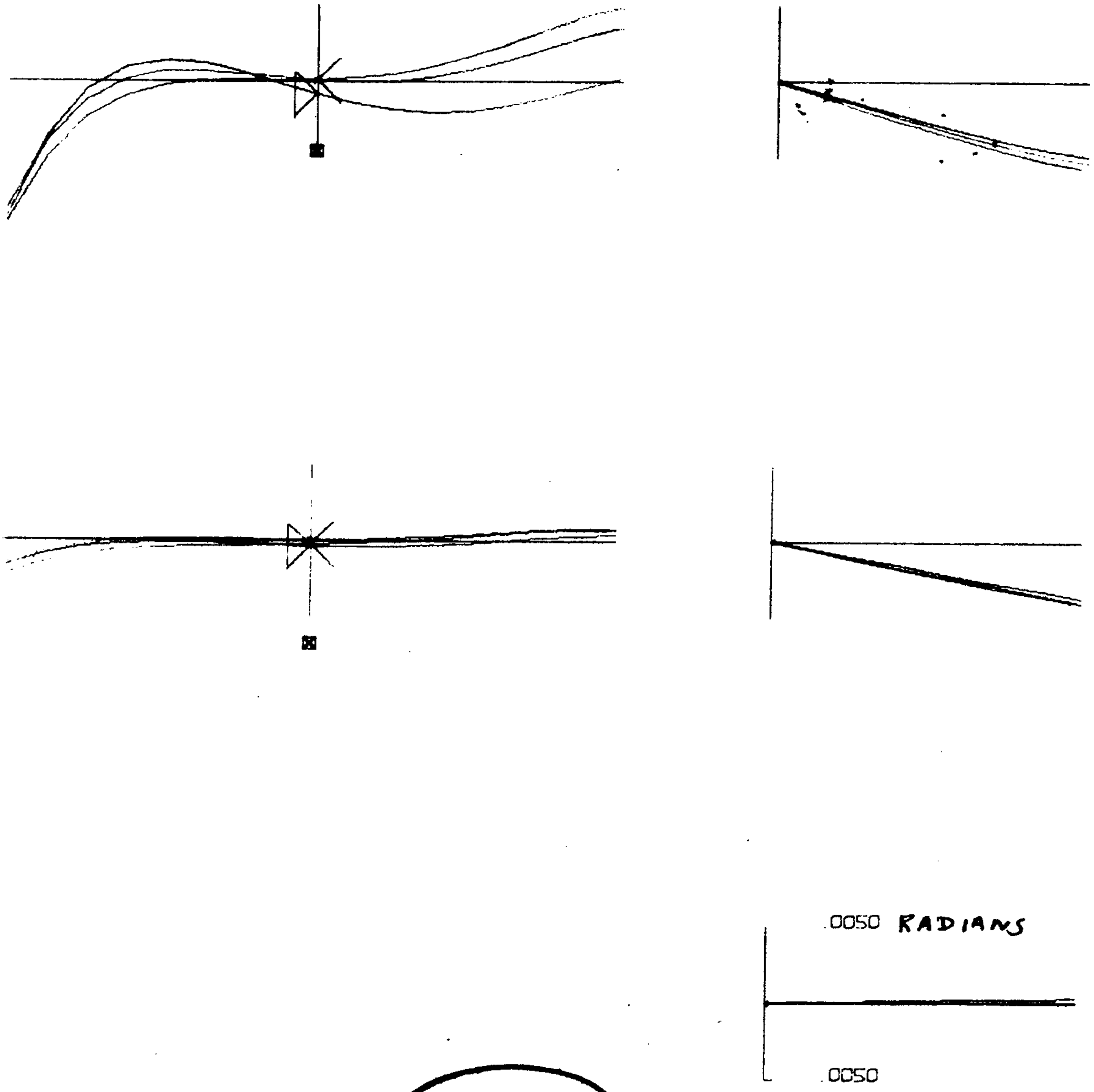
PRIVATE

Fig.3.6.1-21 ANGULAR ABERRATION OF ZOOM RELAY & EYEPIECE AT MID-ZOOM.

HILB 9300.62P 63.5K [illegible] 06/01/67

PRIVATE

9300.62P HILB SEQ 999 SER 0480 06/01/67 LENS NO 660 PLOT NO. 3

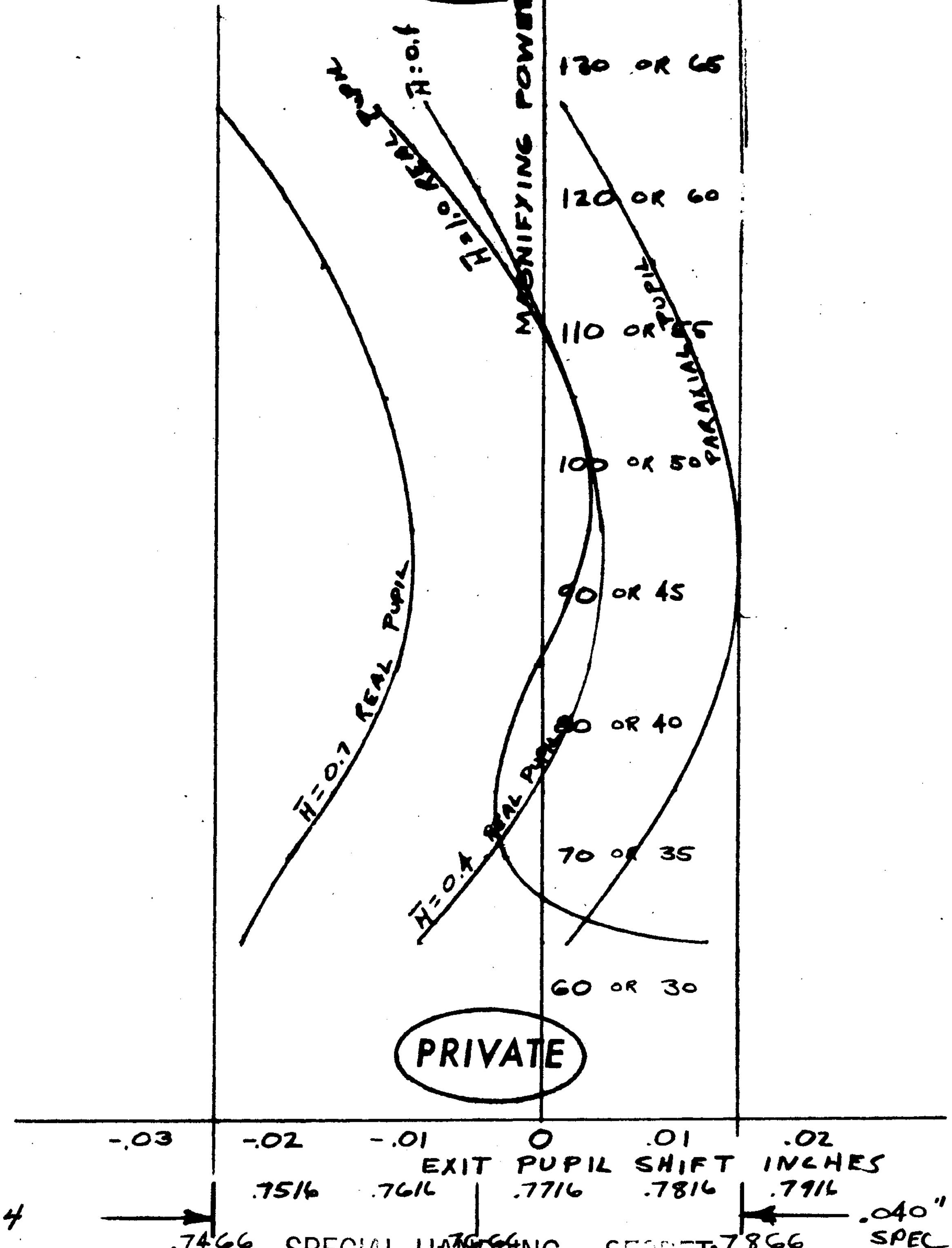


PRIVATE

Fig. 36.1-22 ANGULAR ABERRATION OF ZOOM RELAY & EYEPIECE AT LOW ZOOM

LENS C60
FINAL 9800 DESIGN

PRIVATE



PRIVATE

Fig. 3.6.1-23 EXIT PUPIL SHIFT VERSUS MAGNIFYING POWER

PRIVATE

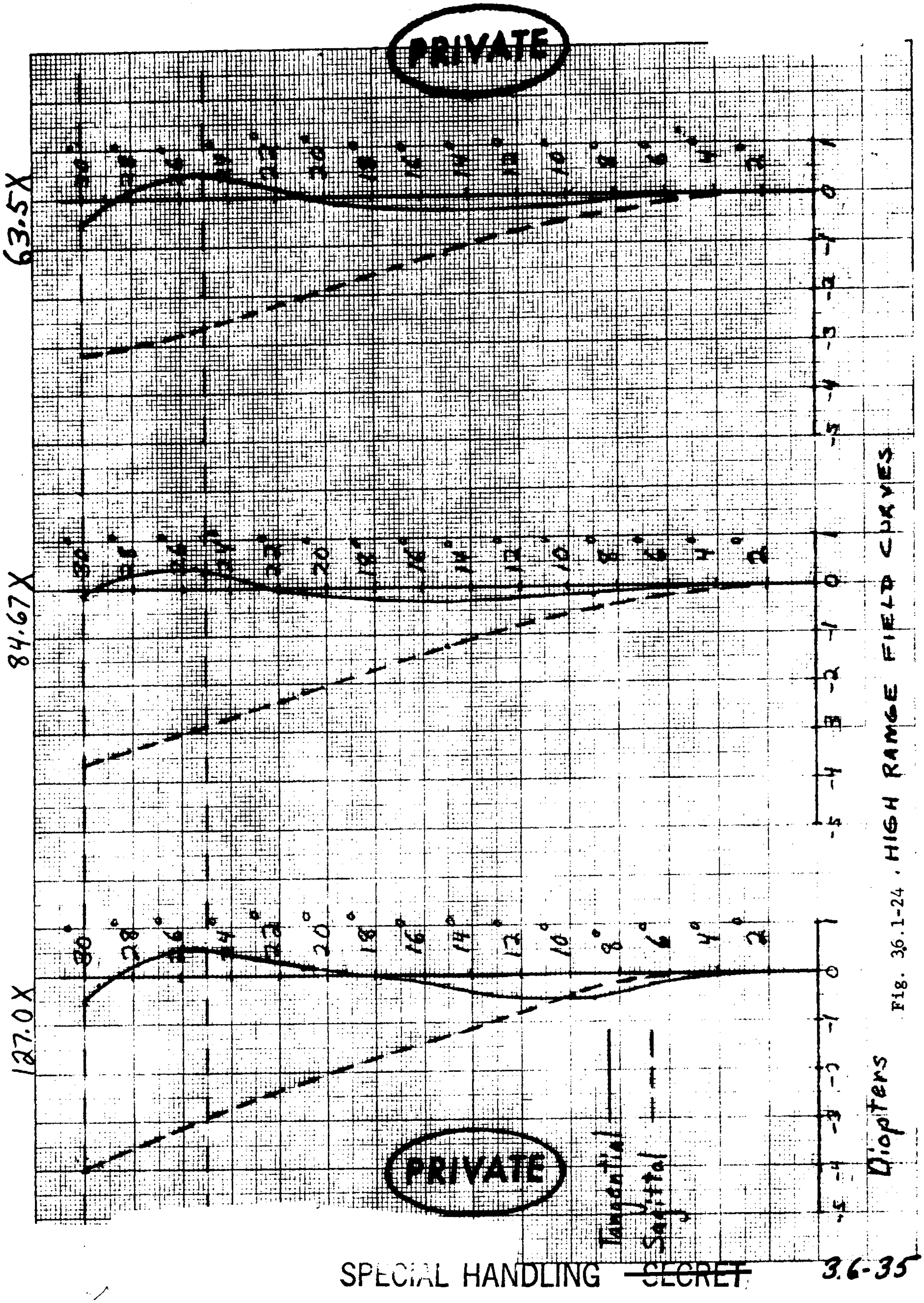
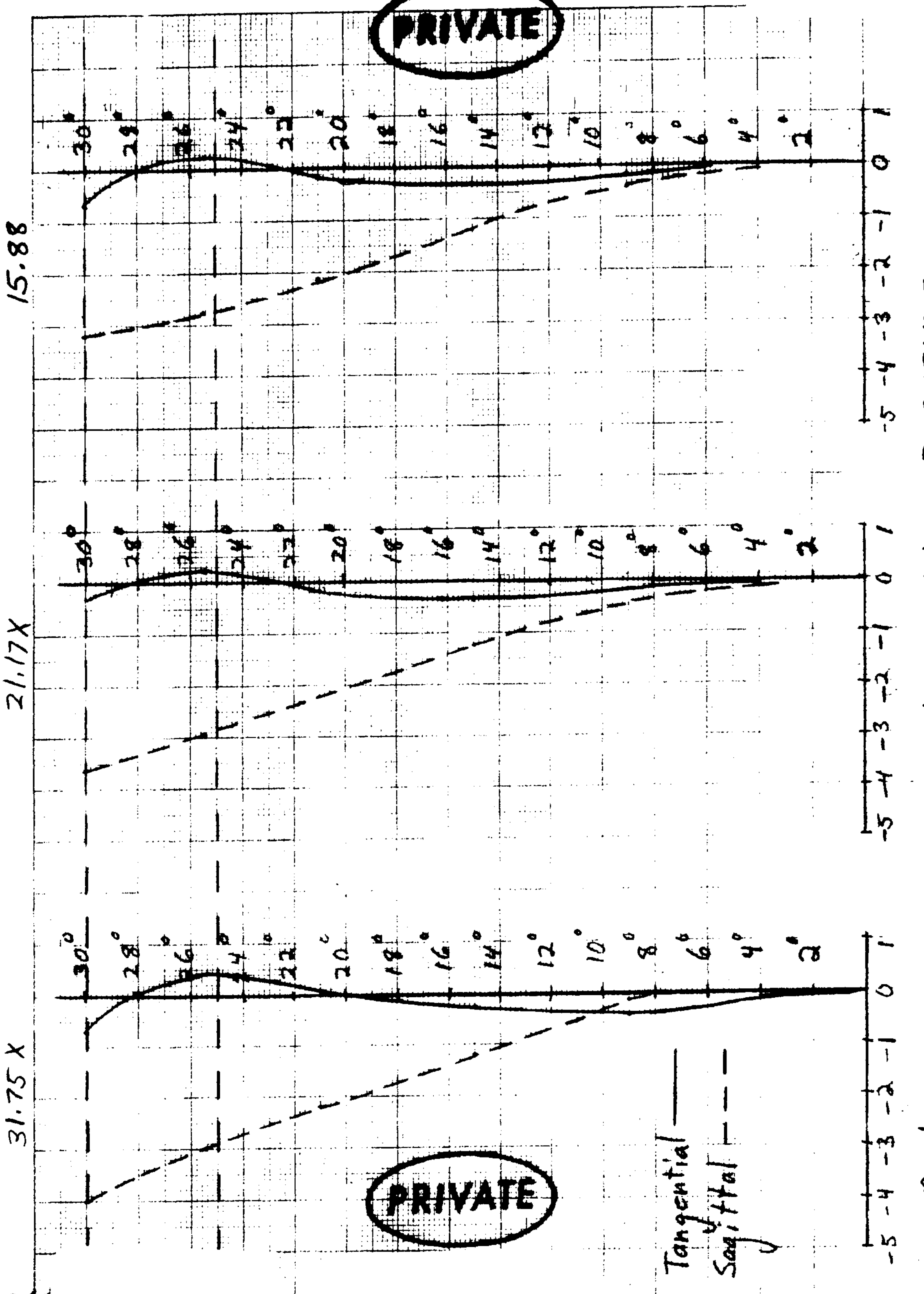


Fig. 36.1-24 . HIGH RANGE FIELD CURVES

PRIVATE

SPECIAL HANDLING ~~SECRET~~

PRIVATE



LOW RANGE FIELD CURVES

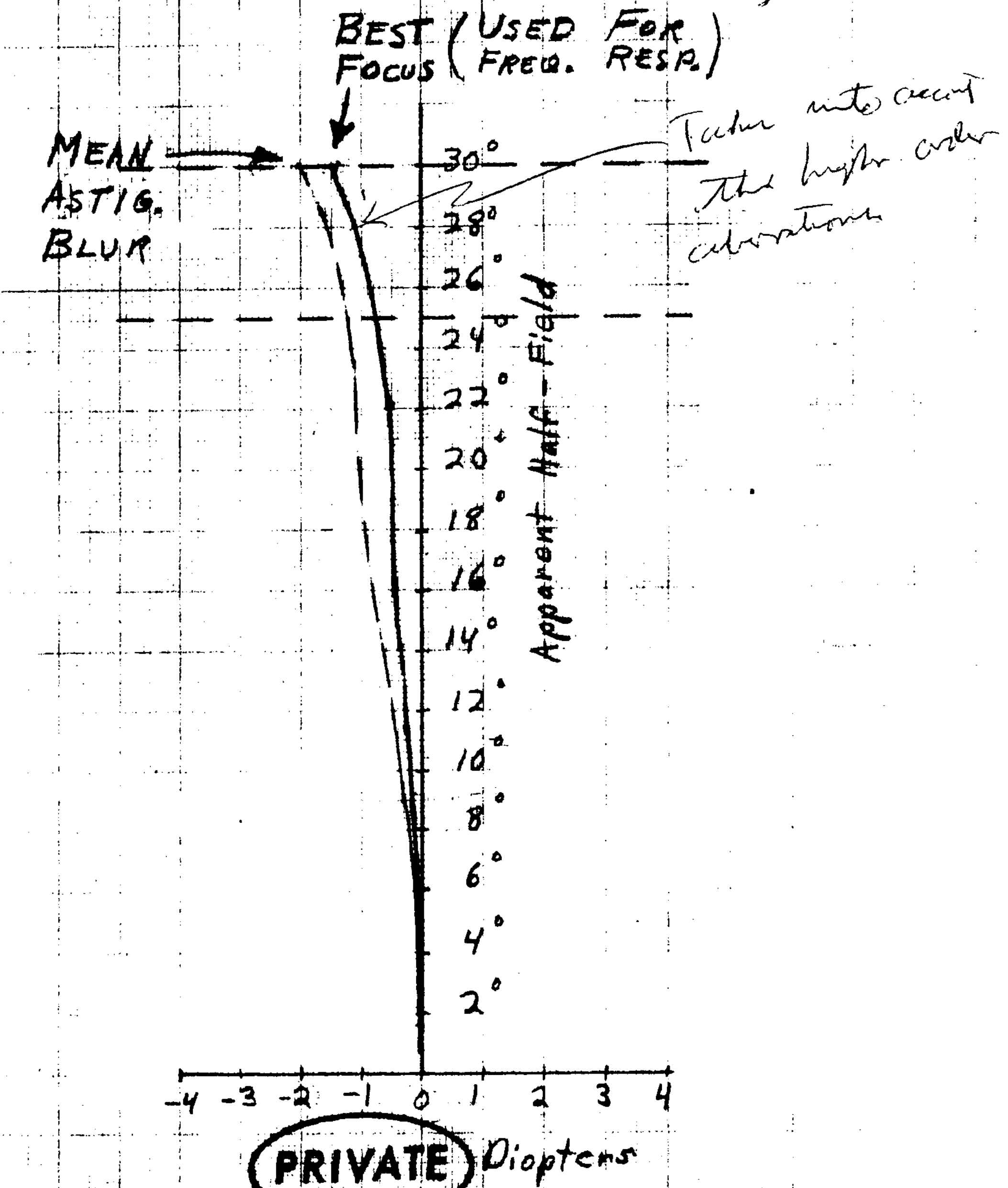
Fig. 36.1-25

PRIVATE

SPECIAL HANDLING ~~SECRET~~

PRIVATE

See page 3.6-201 ff.



Taken into account the higher order aberrations

PRIVATE

Fig. 36.1-26 MEAN AND BEST FOCUS FIELD CURVES

PRIVATE

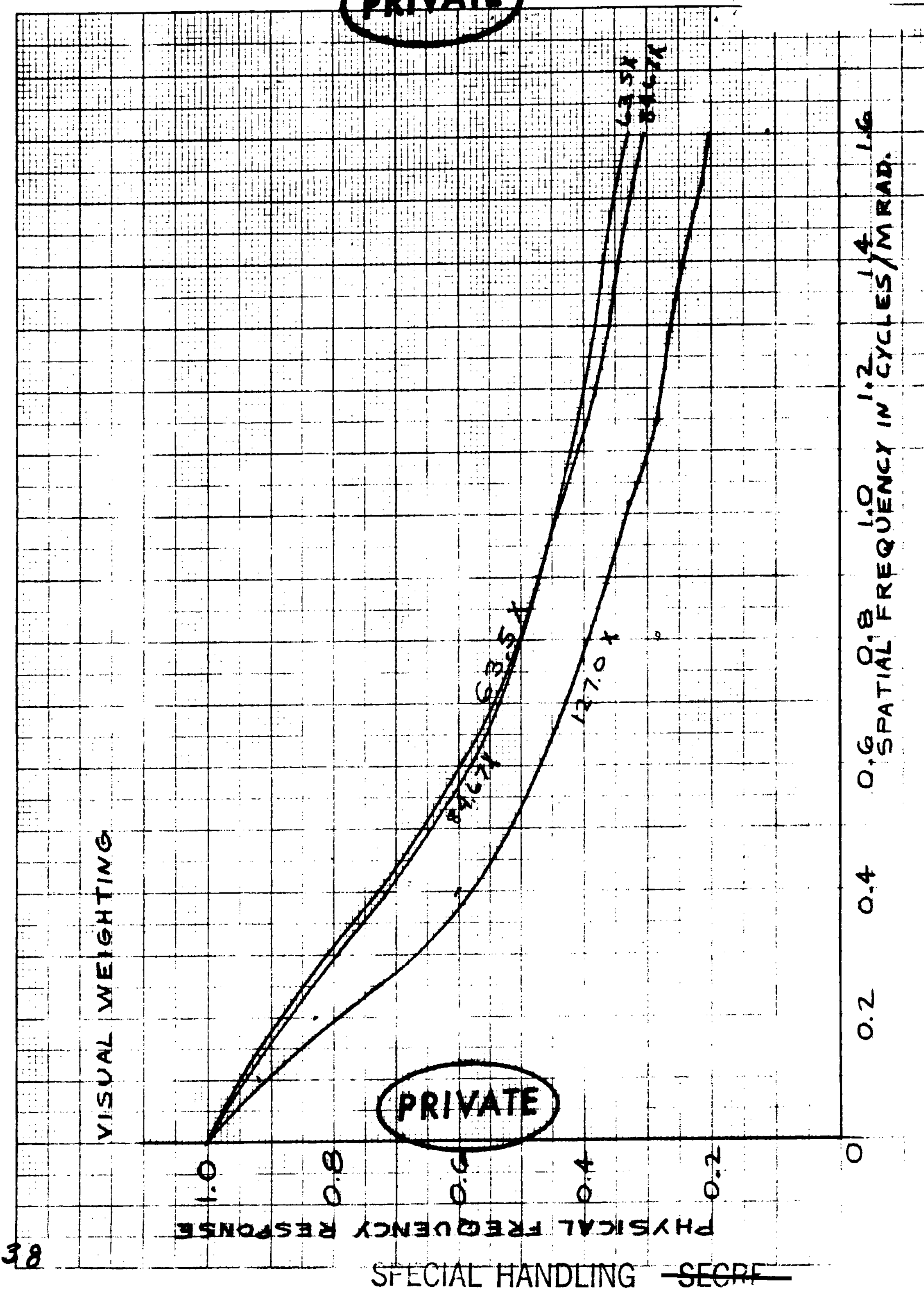


Fig. 36.1-27. ON-AXIS HIGH RANGE PHYSICAL FREQUENCY RESPONSE

PRIVATE

On-axis physical frequency response
for 9300 telescope low power mode

June 6, 1967

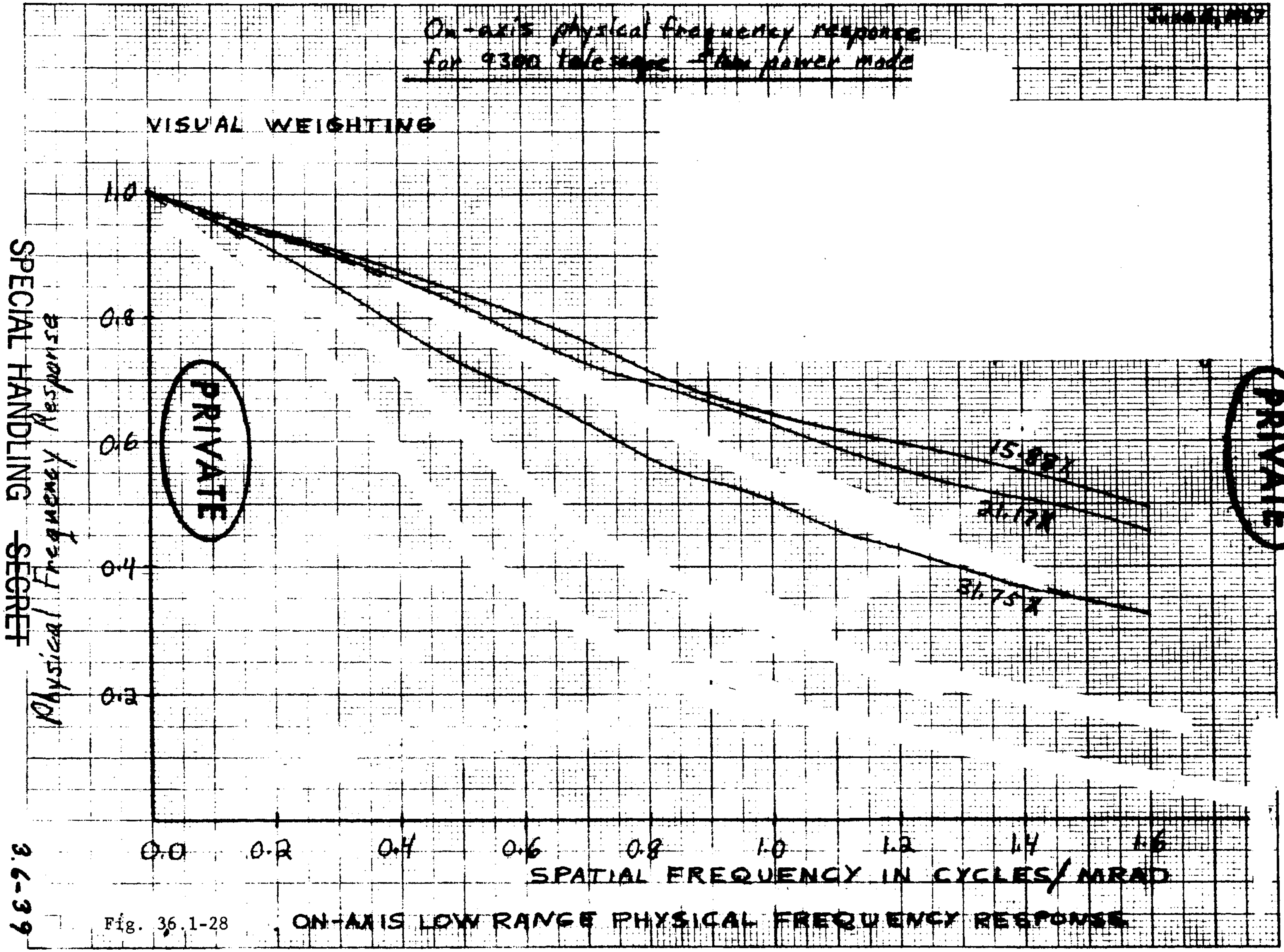


Fig. 36.1-28 ON-AXIS LOW RANGE PHYSICAL FREQUENCY RESPONSE

PRIVATE

PRIVATE

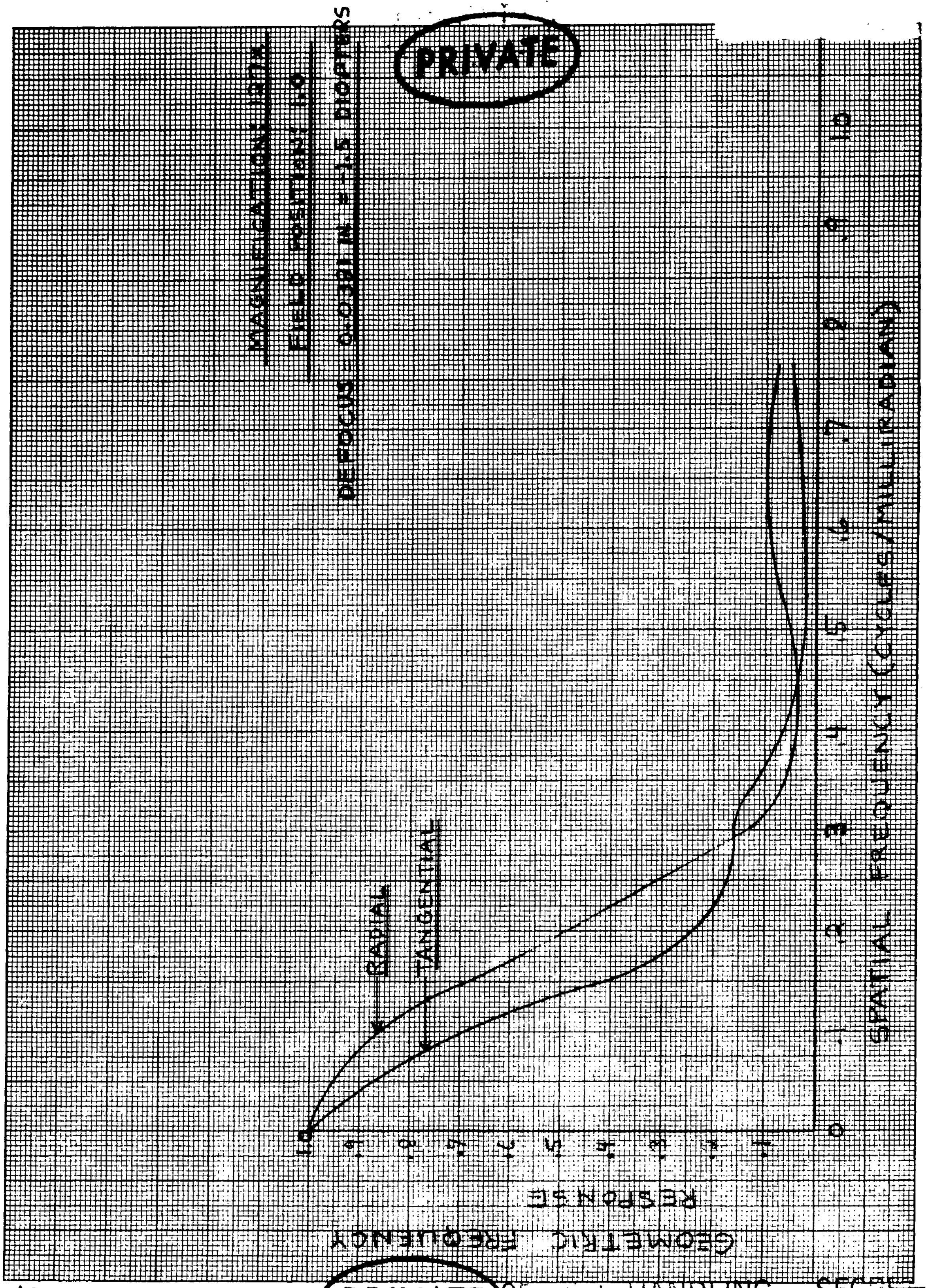


Fig. 36.1-29

PRIVATE

SPECIAL HANDLING ~~SECRET~~

PRIVATE

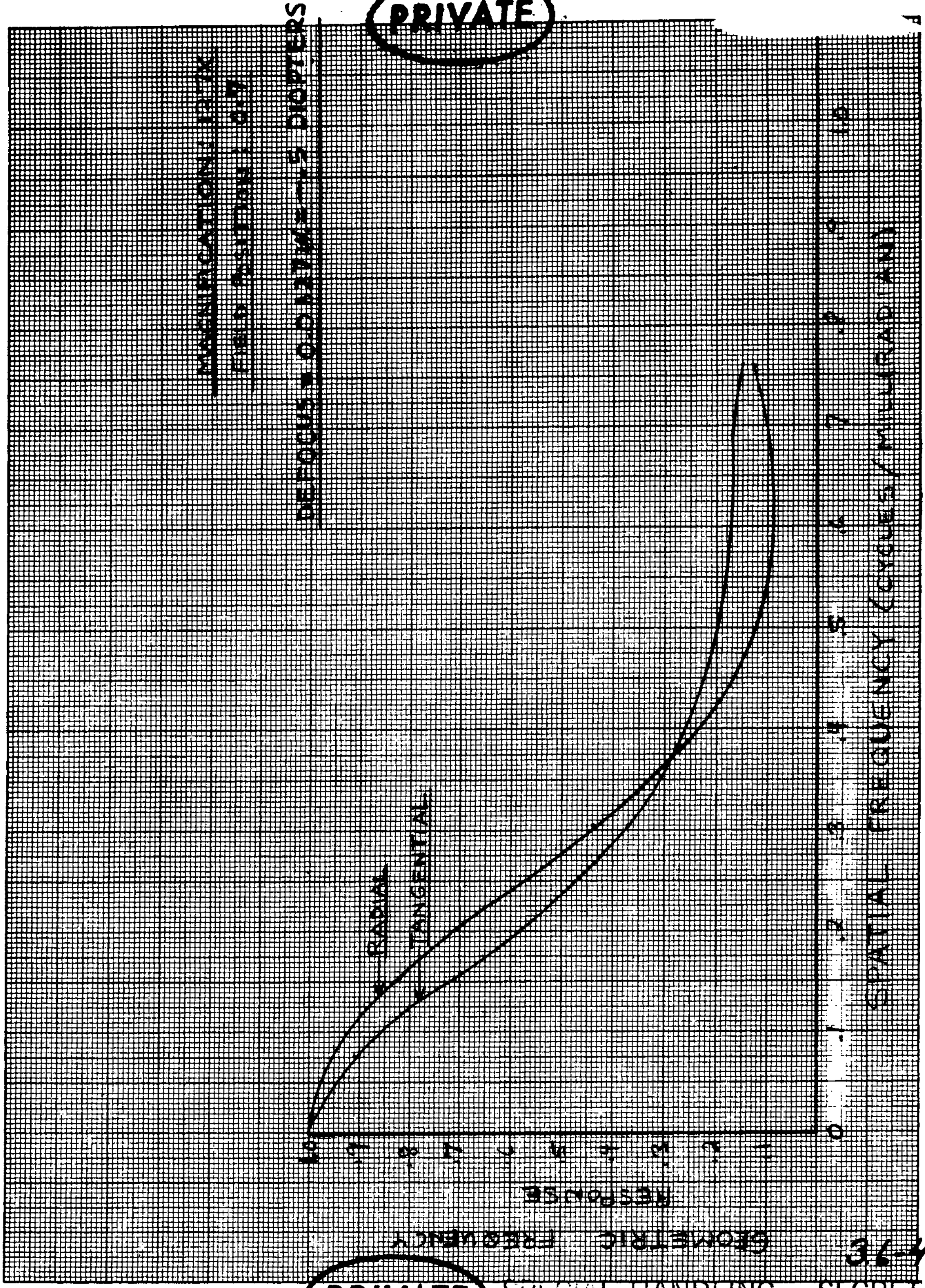


Fig. 36.1-30

36-41

PRIVATE SPECIAL HANDLING ~~SECRET~~

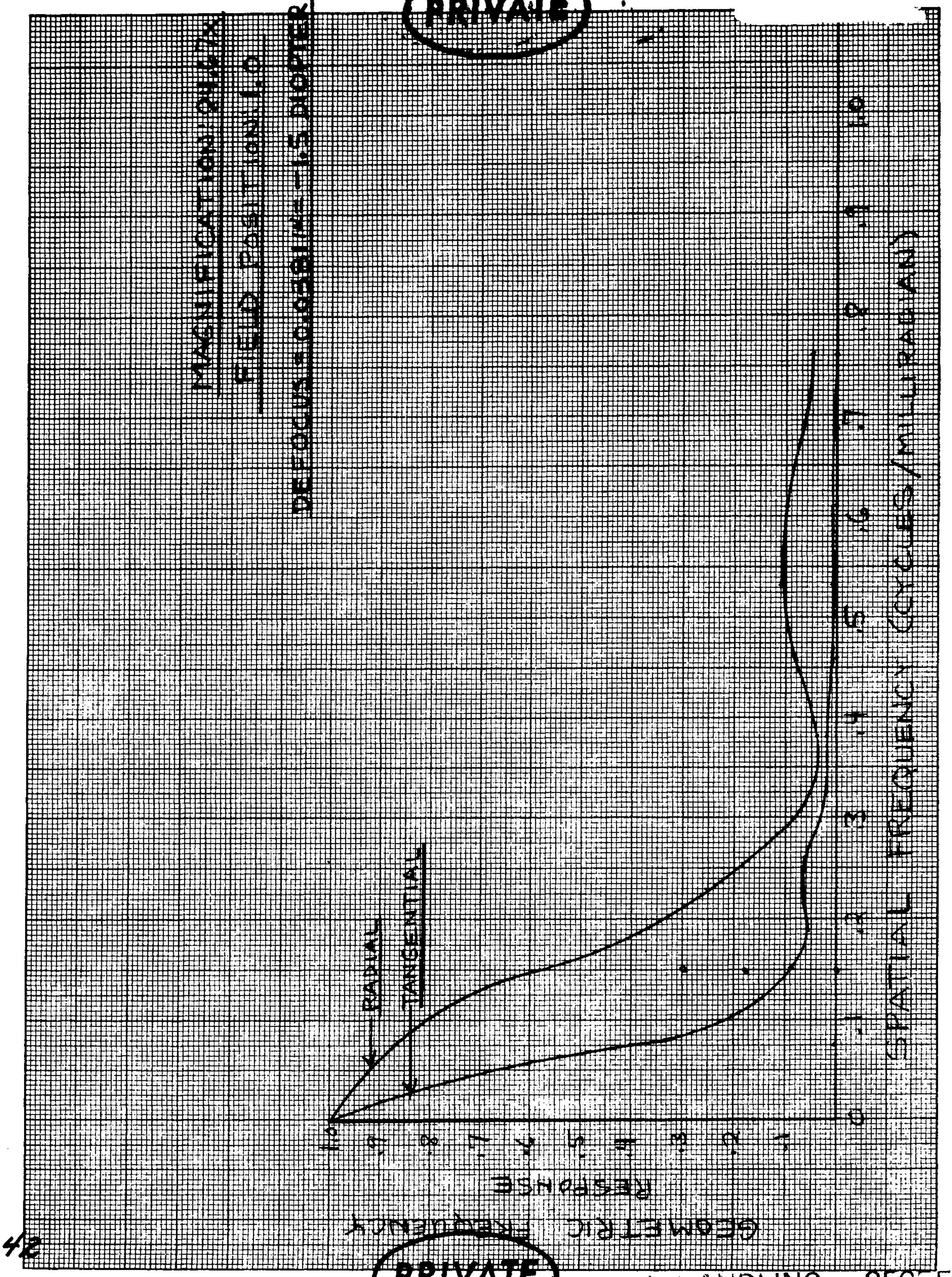


Fig. 36.1-31

3.6-42

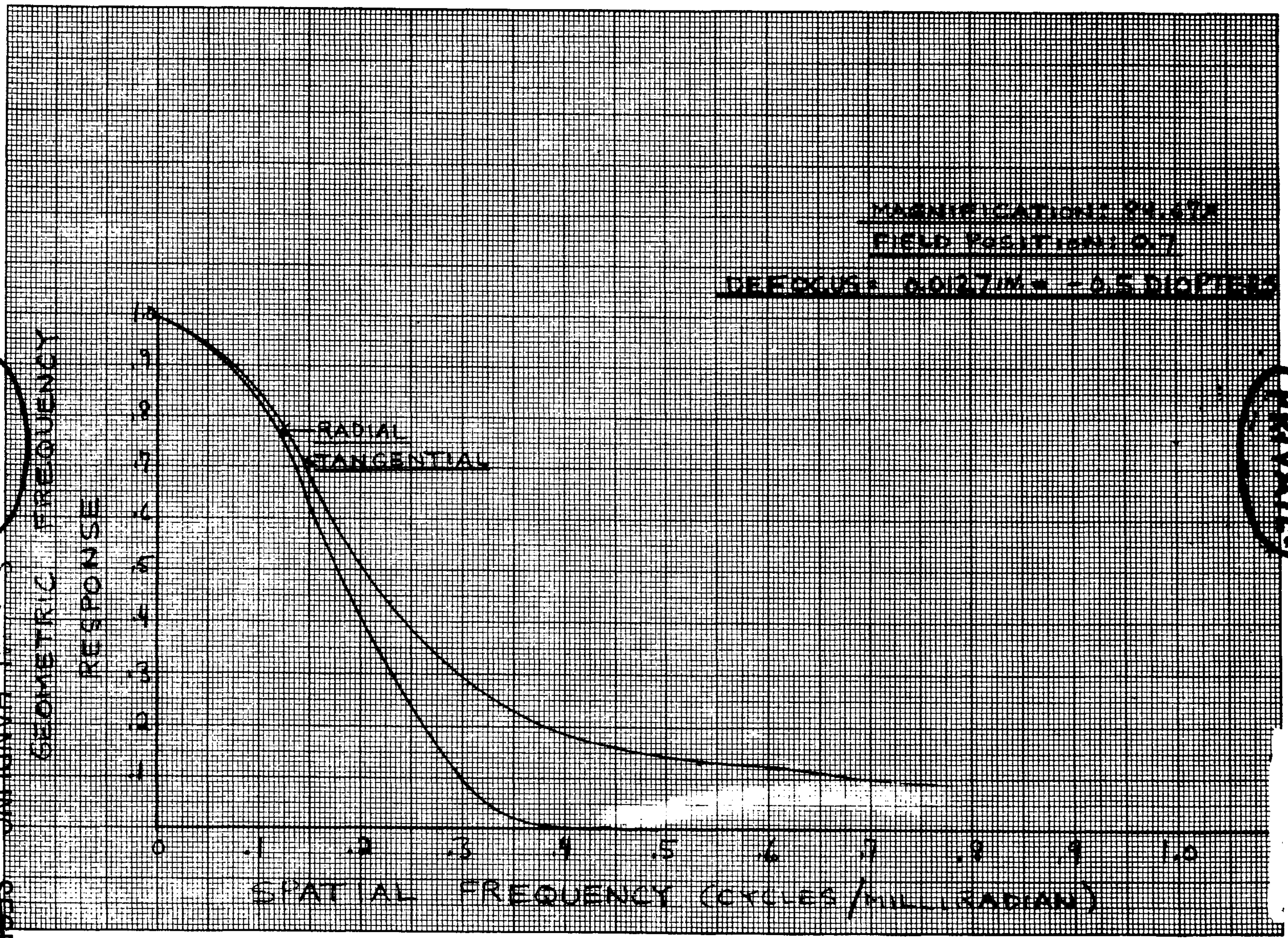


FIGURE 36.1-32

SPECIAL HANDLING ~~SECRET~~

PRIVATE

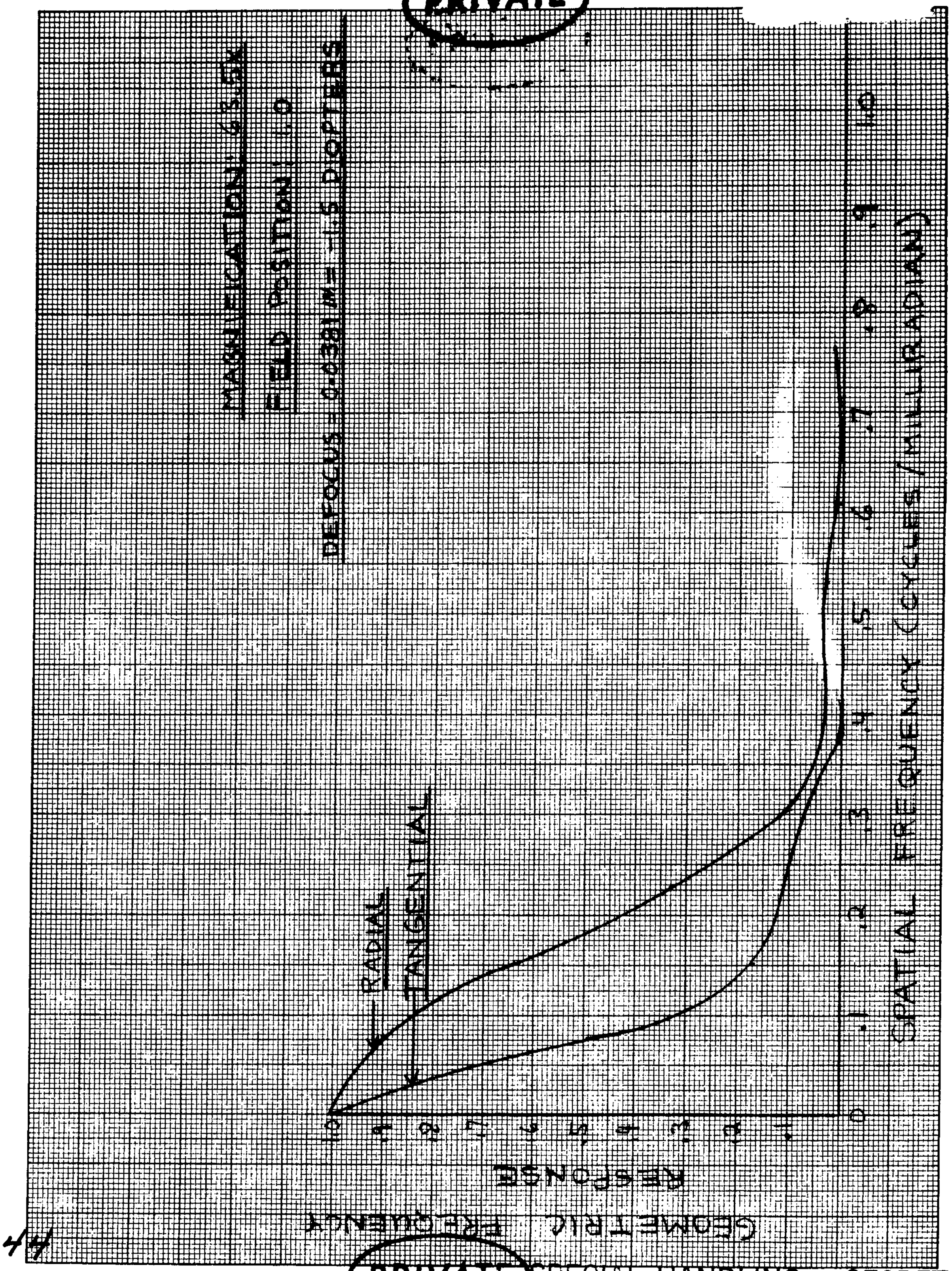


FIGURE 36.1-33

PRIVATE SPECIAL HANDLING ~~SECRET~~

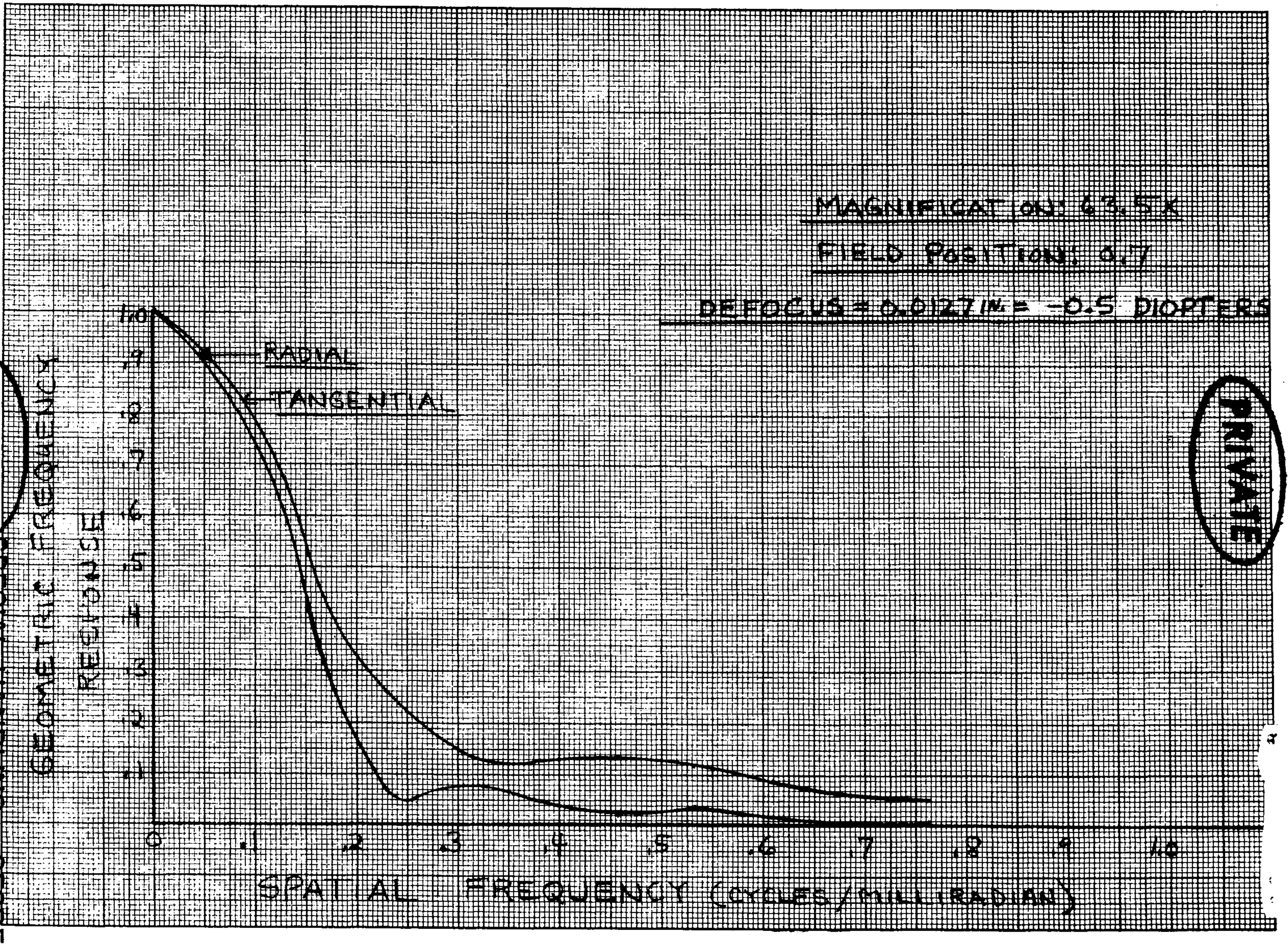


FIGURE 3.6.1-34

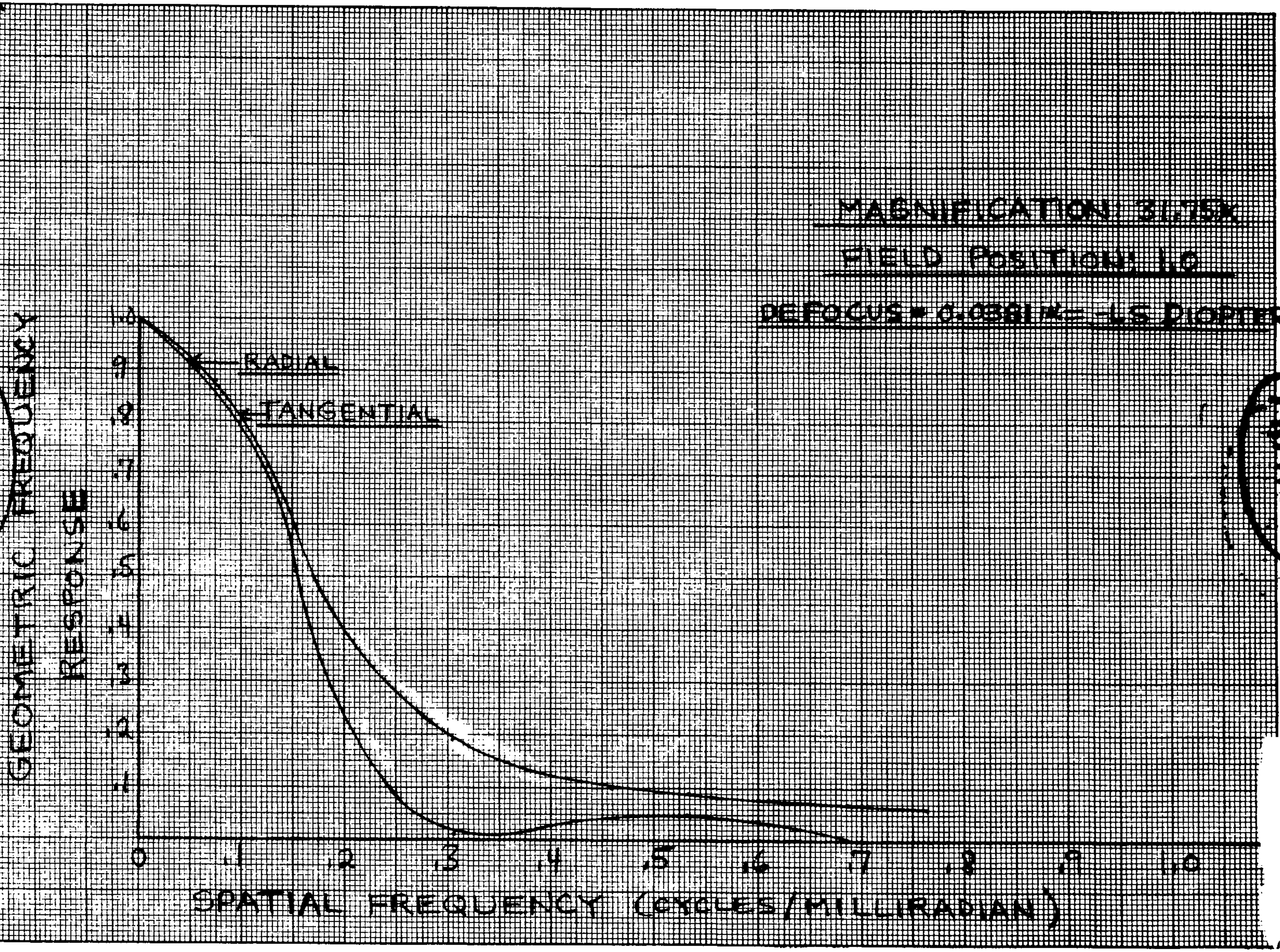


FIGURE 36.1-35

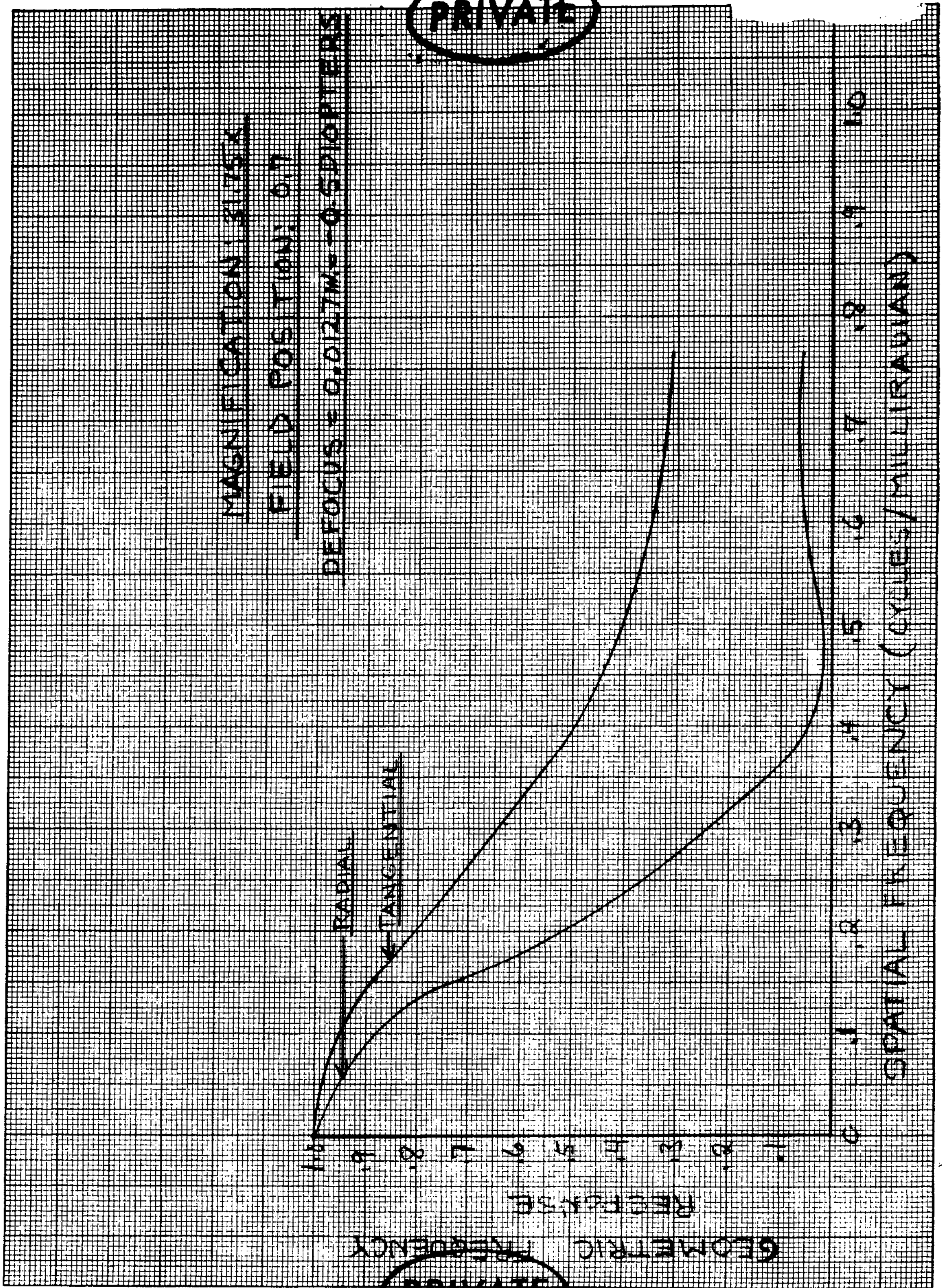


FIGURE 36.1-36

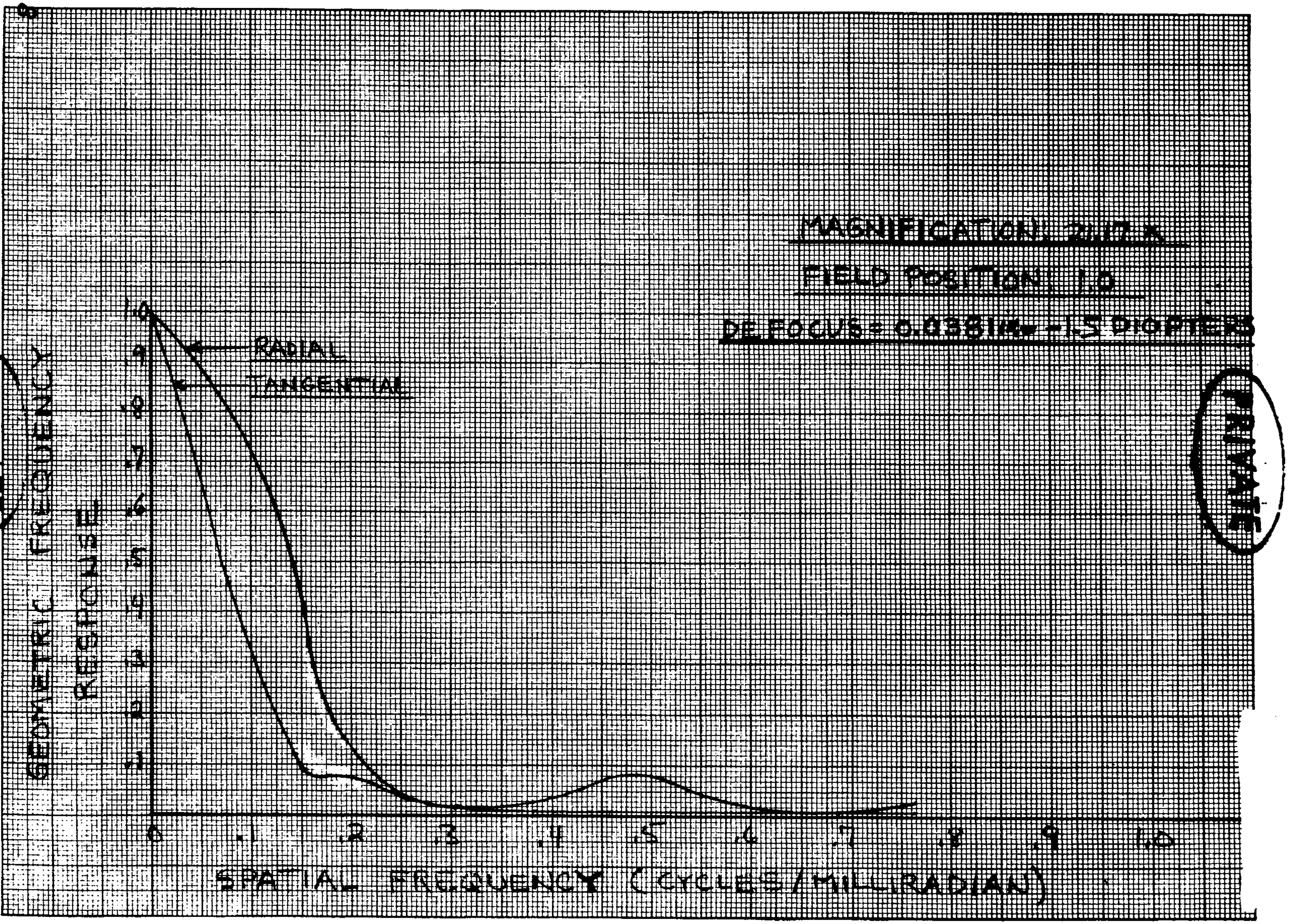


FIGURE 36.1-37

PRIVATE

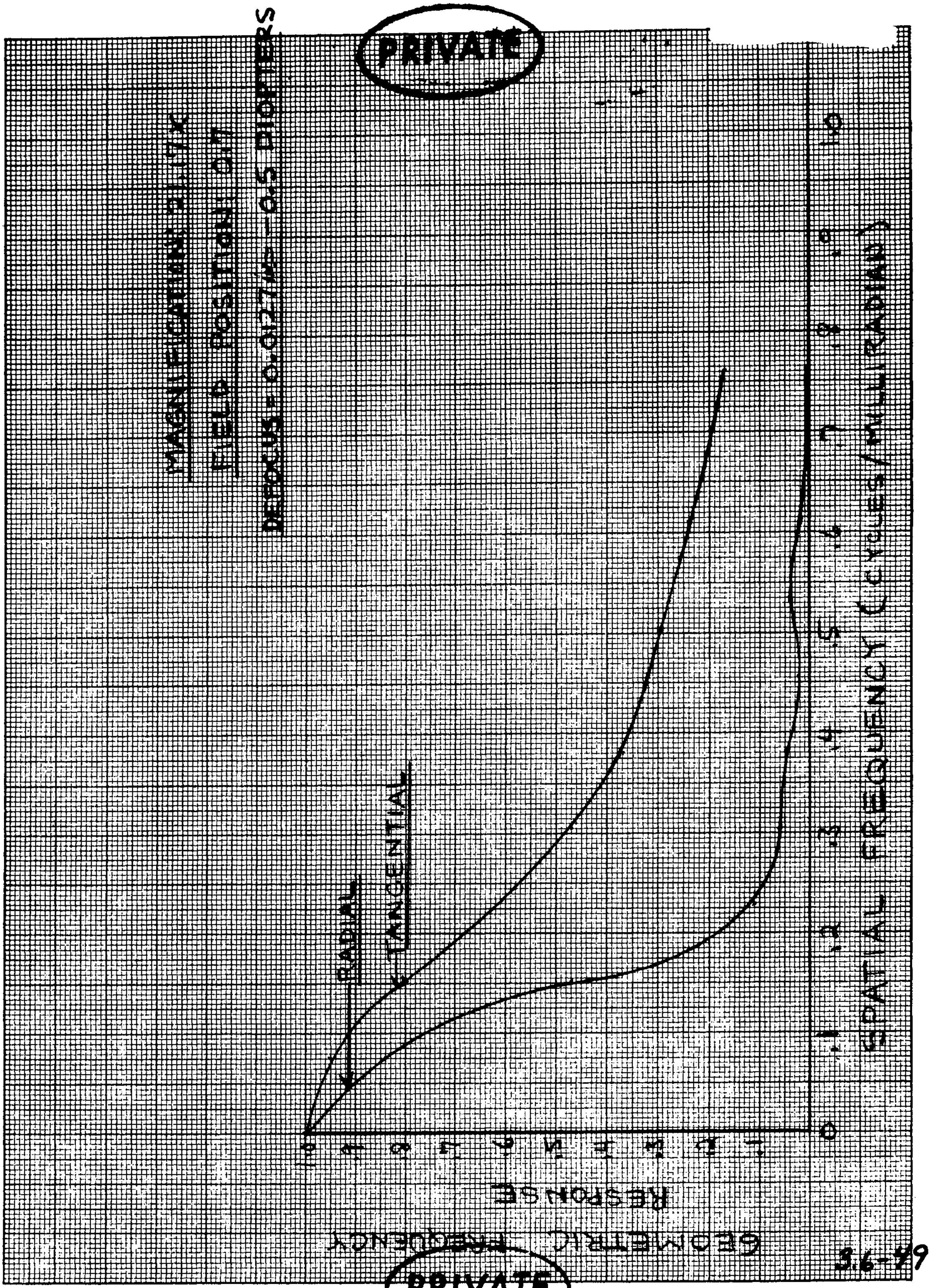


FIGURE 36.1-38

3.6-49

PRIVATE

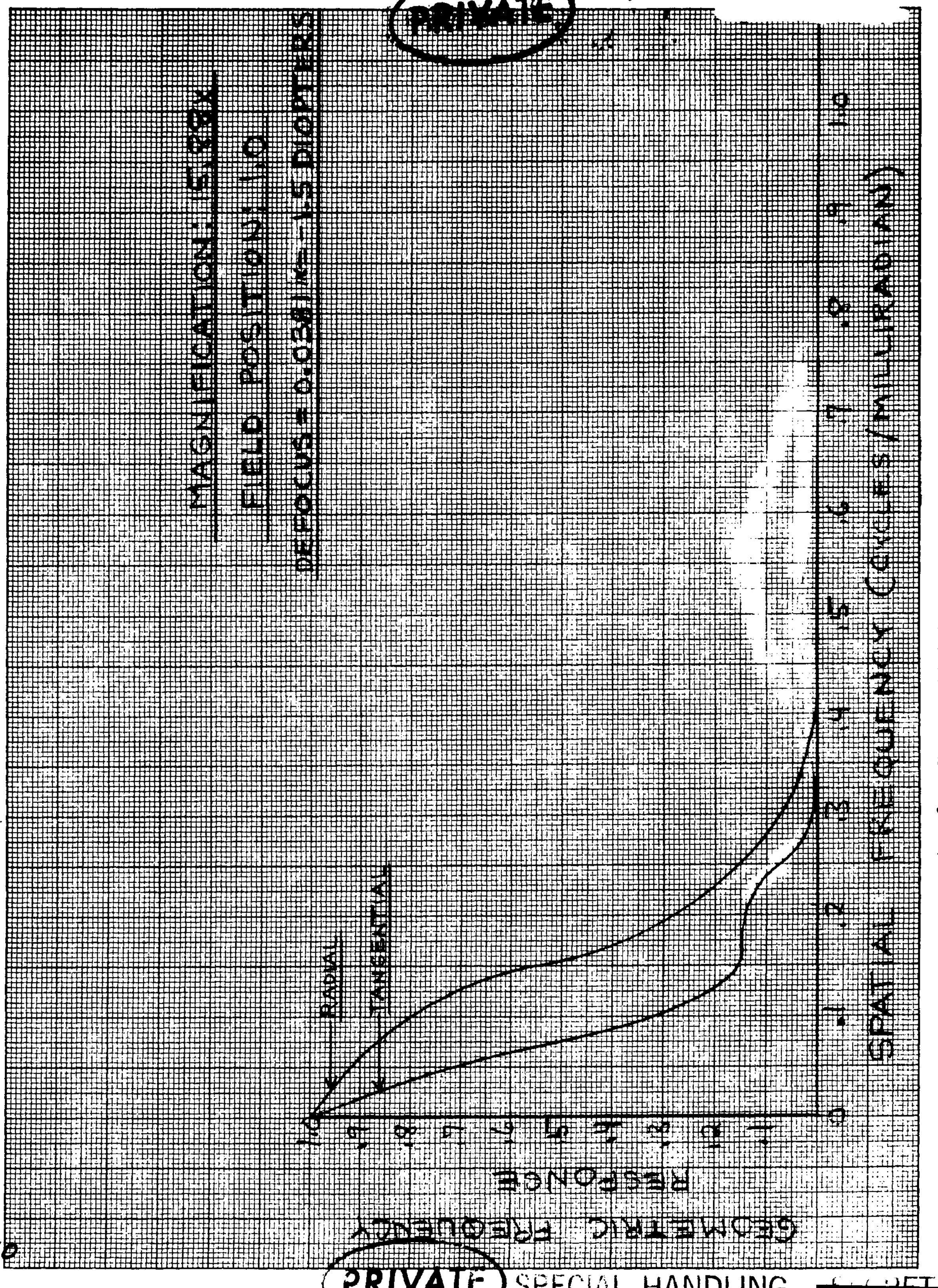


FIGURE 36.1-39

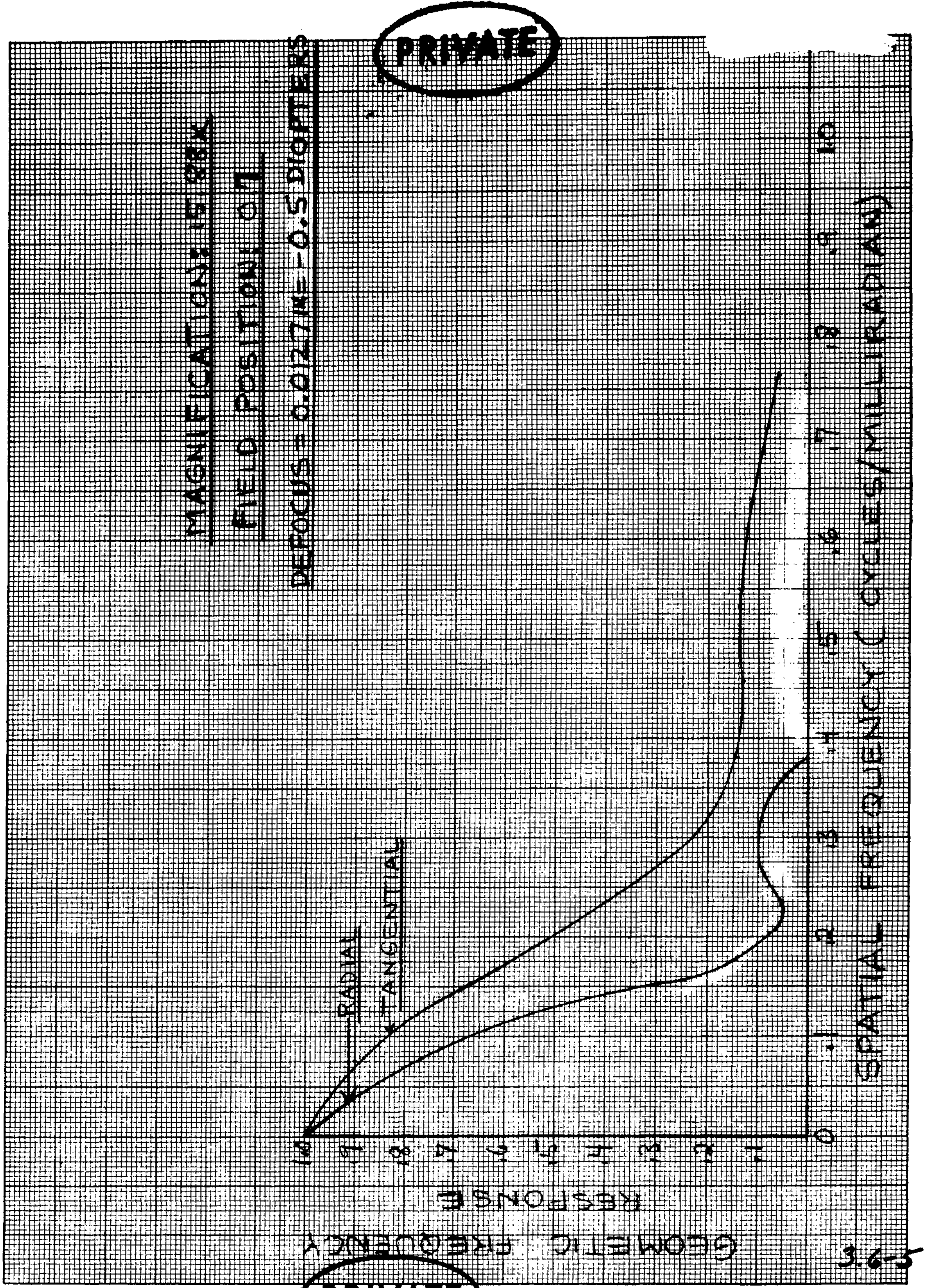


FIGURE 36.1-40

3.6-51

TITLE
Prescription for Optical System

NUMBER
MSM-S-201

DATE
22 Dec. 1966

USE
To evaluate ability of proposed design to meet requirements

OFFICE OF PRIMARY RESPONSIBILITY
Major Subcontrac
Project Mgmt.

REFERENCES (Authority, Regulation, etc.)

INTERRELATIONSHIP
The prescription will later become Part of the specification.

PREPARATION INFORMATION

The Subcontractor shall prepare a prescription which completely describes the parameters of the optical system from which the system can be simulated analytically for evaluation. It shall include the following information:

1. Curvature or radius of each surface.

2. Aspheric curvature coefficients per the aspheric sag expression

$$Z = \frac{\rho Y^2}{1 - K\rho^2 Y^2} + \alpha Y^4 + \beta Y^6 + \gamma Y^8 + \delta Y^{10} + \epsilon Y^{12}$$

where ρ is the vertex curvature per (1) above, K is the conic coefficient $K = 1 - e^2$ and e is the conic surface eccentricity.

3. Surface separations. This includes glass thickness, air spacings, pupil and stop locations, image or focal positions and other available cardinal points.

4. Glass types and/or indices of refraction with specified spectral wavelengths.

5. Clear apertures and obscurations for each optical surface.

6. All angular and linear dimensions on all prisms and mirrors.

AFLC AFSC FORM AUG 63 9 DATA ITEM PAGE 1 OF 2 PAGES

7. Optical dimensions, spectral data for all windows and filters - absorption or interference type.

8. Specification for coatings on each surface.

9. Tolerances on:

   a. Spacings
   b. Thickness
   c. Curvatures
   d. Aspheric coefficients
   e. Surface tilts and misalignments

10. System optical layout (drawings), with proper identification of surfaces by number, spacing, etc.

3.6.2 Deleted

Pages 3.6 - 55 through 3.6-63 deleted

3.6.3 Objective Lens Design Optimization

Introduction

The A/O doublet objective lens has been designed for maximum performance and minimum weight. A special glass (KzFSN-4) has been used to minimize the secondary color, which is the limiting on-axis aberration. This section will, therefore, show that the A/O objective design is optimized for these considerations as well as overall axial performance.

Discussion

In an achromatic doublet, the upper and lower wavelengths, designated here as C and F, are united at a common focus. The question then arises as to whether the other colors will also be united at this focus. To discover this, the value of $\ell'_D - \ell'_F$, which is defined to be longitudinal secondary spectrum, or secondary color, may be calculated where D is generally assumed to be the major or peak wavelength and ℓ' is the back focal length for a given wavelength. For an object at infinity, the longitudinal secondary spectrum is given by

$$\ell'_D - \ell'_F = f'\left(\frac{Pa - Pb}{Va - Vb}\right)$$

where

f' = focal length of the achromatic doublet

a = designates the first element

b = designates the second element

P = partial dispersion = $\frac{n_F - n_D}{n_F - n_C}$

and V = reciprocal dispersion = $\frac{n_D - 1}{n_F - n_C}$

3.6-64

The secondary spectrum of most thin achromatic doublets, made out of common glasses, is approximately the same and is given approximately by

$$l'_D - l'_F = -\frac{f'}{2500}$$

However, there are a few special glasses such as the "short flints" in which the partial dispersion is somewhat smaller than normal. Such a glass can be combined with a normal crown to make an achromatic doublet with reduced secondary spectrum. Many of these glasses, however, have undesirable chemical and physical properties and are available only in small diameters.

In addition to secondary spectrum, spherical aberration and the chromatic variation in spherical aberration must also be considered in optimizing axial performance.

Designs Considered

Several designs were considered in the analysis. All the designs presented here have a 10 inch diameter entrance pupil and are evaluated over a 1.042 degree field of view (63.5X case) and over the 0.47 to 0.65 micron spectral region. Some of these designs were evaluated at the reticle and include the Pechan prism and the field lens. Others consider only the objective lens. However, the case of the objective alone is directly comparable to that of the objective, Pechan prism and field lens combination, since only a lsight modification is required to compensate for these extra elements. This modification is approximately similar to adjusting the design to compensate for a plane parallel plate.

The first doublet considered was one consisting of common glasses, namely SK-16 and F-2. The lens specification data for this design is presented in Figure 3.6.3-1 and the corresponding optical path difference plots are presented in Figure 3.6.3-2.

It is seen that although this design has very good spherical correction at 0.56 microns, the chromatic variation of spherical aberration and the secondary spectrum are very large and could not be tolerated.

The second design considered was one in which a "short flint" KzFS-5 was used with a common crown SK-2. This design (see Figure 3.6.3-3 and 3.6.3-4), although not quite optimized, shows a considerable reduction in secondary spectrum and in chromatic variation of spherical aberration. It is also at a tolerable state of chromatic correction.

The glasses used in a design concept were SK-2 and KzFS-5. However, after many discussions with Schott and others about the "short flints", it was learned that KzFS-5 had undesirable physical properties and that KzFS-4 was the most desirable of these glasses for consideration.

The next design considered was an SK-2 and KzFSN-4 doublet. The lens specification data for this design and the corresponding optical path difference plots are presented in Figures 3.6.3-5 and 3.6.3-6, respectively. From Figure 3.6.3-6, it is seen that the performance of this design is comparable to that of the previous design. However, since the index of refraction of KzFSN-4 is lower than that of KzFS-5, steeper curvature is required for optical correction. This demanded an increase in central thickness and thus the weight increased approximately 3 pounds from the previous design.

The next design consideration was to try and match a common crown with an index slightly higher than SK-2 with KzFSN-4 to reduce the weight and also to achieve good optical correction. It was then found that SK-16 and KzFSN-4 combination rendered an optimum axial correction and also weighed approximately two pounds less than the

SK-2 and KzFSN-4 design. These glasses were then used in the final design and the performance of the final A/O objective system at the reticle is presented in Figure 3.6.3-7. It can be seen that the system is diffraction limited at 0.56 microns and has good chromatic corrections.

Conclusion

The A/O objective lens has been designed for maximum on-axis performance and minimum weight. To achieve satisfactory axial performance, it was necessary to use a short flint. However, the optical correction achieved did not vary significantly for the two short flints considered. Since KzFS-5 has undesirable physical properties, it was necessary to use KzFSN-4. The optical correction of several crown in conjunction with KzFSN-4 also stayed about the same. SK-16 was then chosen since it minimized the weight of the doublet and rendered good axial performance when combined with KzFSN-4.

A triplet design, which resulted in a 5% improvement in on-axis resolution is described in Section 3.6.2.

PRIVATE

LENS NO. 18

SYSTEM DATA

F-NUMBER = [redacted]
FOCAL LENGTH = [redacted]
BACK FOCUS = 1.5373
TOTAL LENGTH = 79,8950
EXIT PUPIL DISTANCE = 293,4845
GAUSSIAN IMAGE HEIGHT = .6710

ENTRANCE PUPIL DISTANCE =
OBJECT HEIGHT = -1,818E 0
CHIEF RAY ANGLE = ,009
CHIEF RAY POSITION =
AXIAL BEAM RADIUS = 5,000
DP/DV = ,000

WAVELENGTHS LOWER ,4700 MAJOR ,5600 UPPER ,6500

SURFACE DATA

SURFACE NUMBER	RADIUS OF CURVATURE	THICKNESS	APPROXIMATE N(D)		APPROXIMATE V(D)	APERTURE DIAMETER
OBJECT	INFINITE	2,000E 09	AIR			
1	48,8086	1,0075	1.620414	SK-16	60,30	10,0000
2	-31.3916	,2933	AIR			9,9809
3	-30,1219	,6000	1.620051	F-2	36,35	9,8907
4	-625,0714	32,7764	AIR			9,8281
5	-6,4535	,3613	AIR			6,2231
6	6,7753	,0091	AIR			6,0130
7	4,8786	,2934	AIR			5,9761
8	15,0681	13,2325	AIR			6,0239
9	INFINITE	6,4604	AIR			4.5673
10	-16.6987	,4468	AIR			3,8520
11	-3.9569	,1337	AIR			3,8452
12	-3,7132	,4516	AIR			3,8341
13	-14,0737	,0010	AIR			3,7372
14	9,2453	,4712	AIR			3,7019
15	-12.6200	12.4411	AIR			3,6852
16	INFINITE	9,1391	1.516799		64,24	2.2682

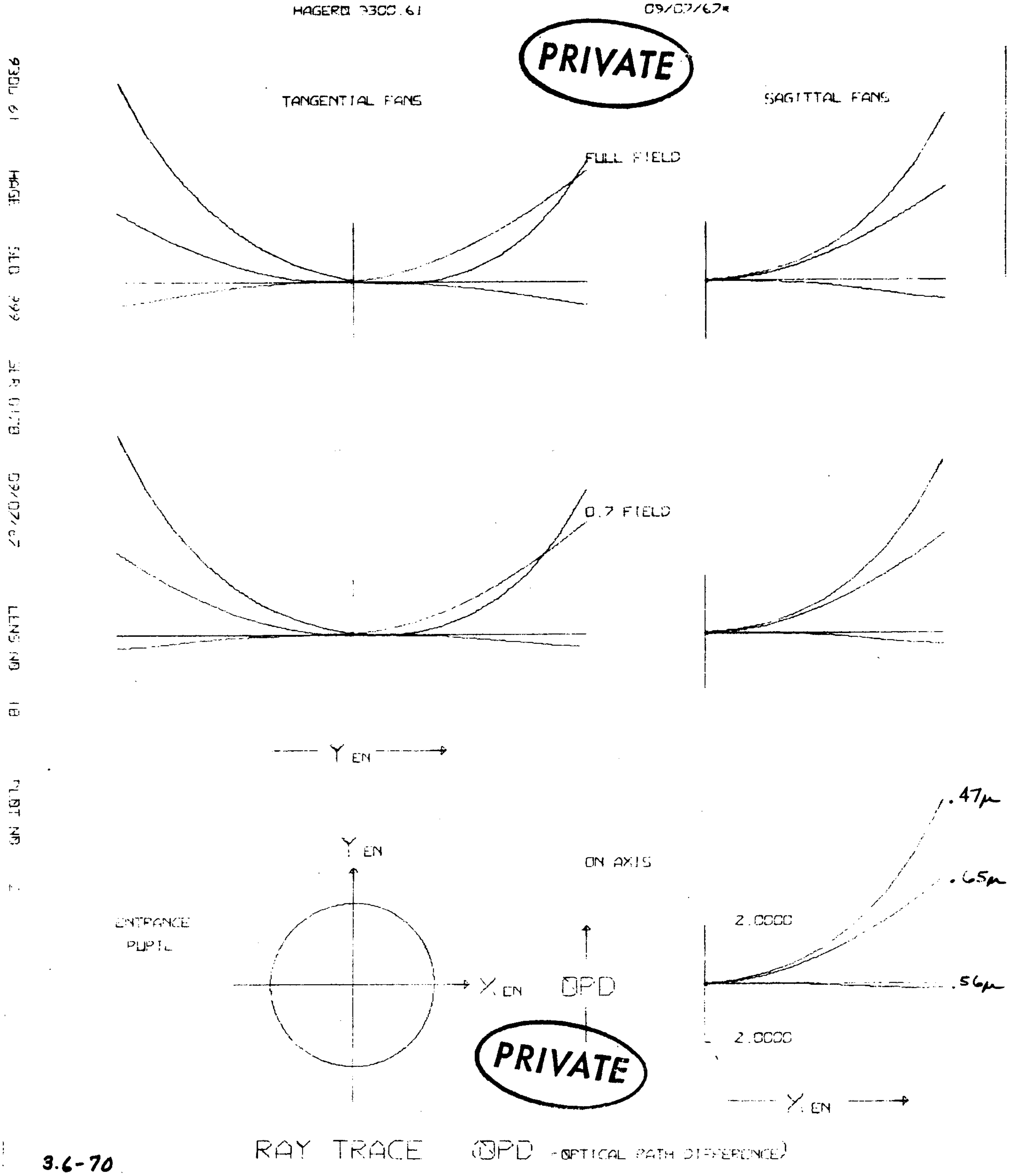
PRIVATE

Table 3.6.3-1Lens Specification Data for SK-16 and F-2 Doublet

17	INFINITE	0	AIR		1,5905
18	8,2419	,2391	1,516799	64,24	1,5862
19	11.1674	1,5373	AIR		1,5542
IMAGE	INFINITE				

Table 3.6.3-1Continued

PRIVATE



PRIVATE

Table 3.6.3-2 Optical Path Difference at Reticle for SK-16 and F-2 Doublet

PRIVATE

```
                                                                      4 3
UNITS - INCH                                               TTL -    76.2 96

F/NO. -      7.61        G.I.H. -      .6799         FOC. LENGTH -  [redacted]

WV MAJOR -      .5600        WV UPPER -      .6500        WV LOWER -      .4700

 N                                      N
S            R             TH            MAJ           V          C. A. DIA.

0        INFINITE      +9.999D+010      AIR                          .000 R
              8                             9
1         44.131          1.3000        1.6001  SK-Z  50.20        10.005 R
2        -19.9804          .1654        AIR                          9.976 R
3        -19.9149          .4800        1.65501 KZFS-535.07          9.897 R
4       -370.3987        74.4785        AIR                          9.834 R
```

Table 3.6.3-3 Lens Specification Data for SK-2 and KZFS-5

PRIV...

SK-2
KZFS-5

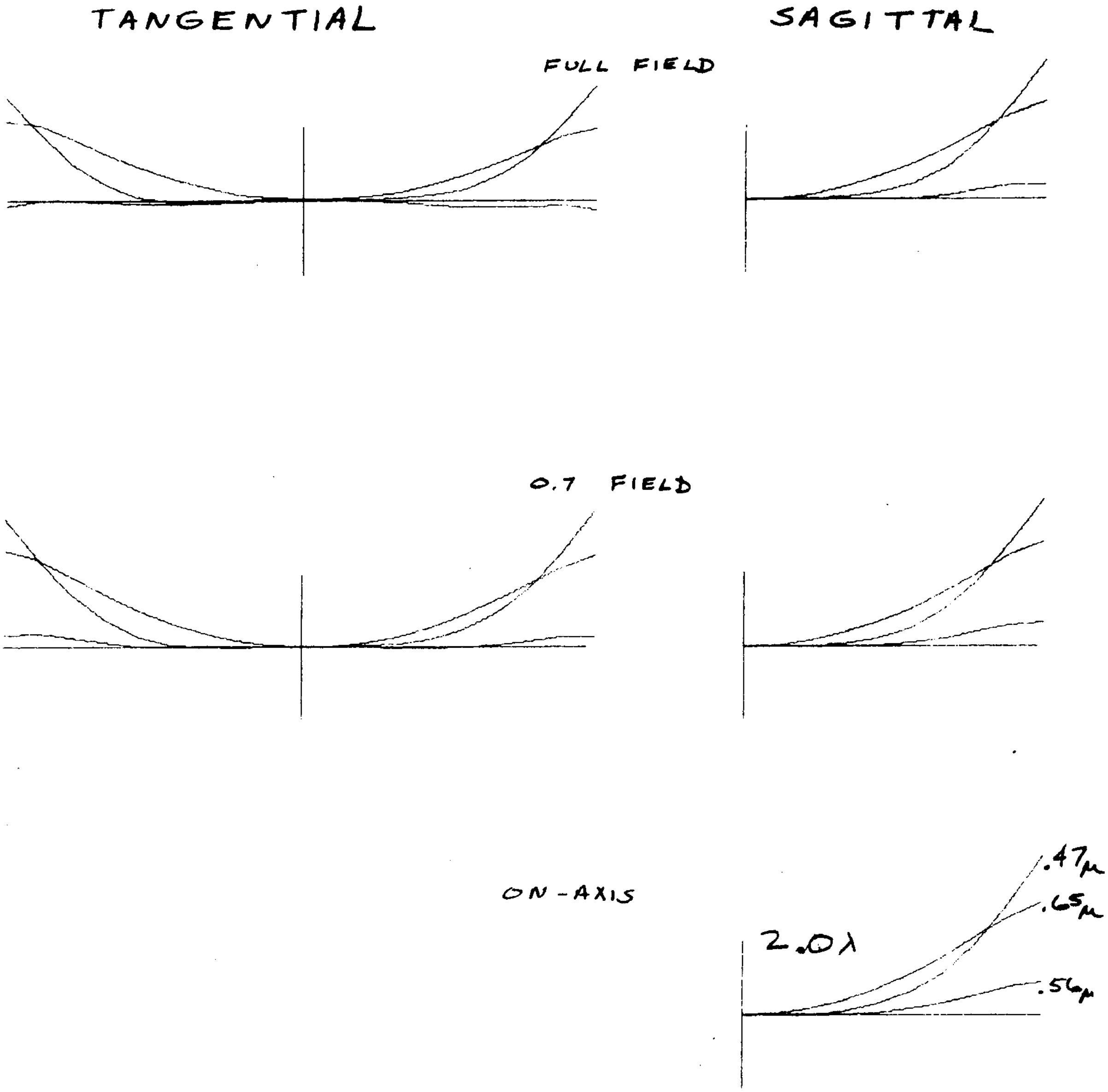


Table 3.6.3-4 Optical Path Difference for SK-2 and KZFS-5

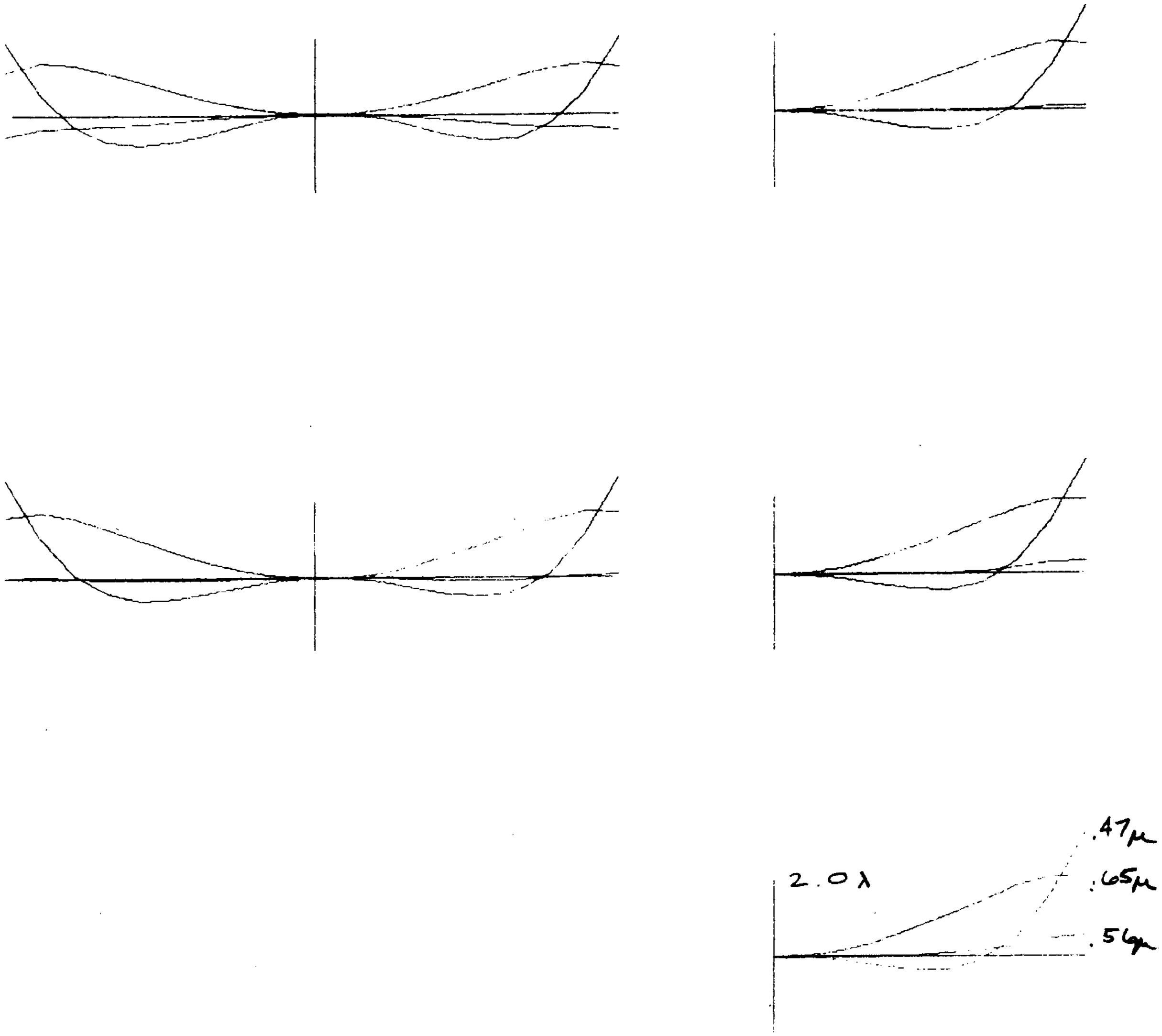
```
UNITS - INCH                                                TTL -    76.82152
F/NO. -    7.61          G.I.H. -      .6799           FOC. LENGTH - [redacted]
WV MAJOR -      .5600          WV UPPER -      .6500          WV LOWER -     .4700

 SN          R               TH              N MAJ             V          C. A. DIA.

 0       INFINITE       +9.999D+010       AIR                               .000 R
 1         45.9943          1.6410       1.60991  SK-2  50.20             10.004 R
 2        -13.3907           .0295       AIR                               9.975 R
 3        -13.3477           .4800       1.61550  KZFSN4 39.17             9.955 R
 4      -1368.6097      +0.000D+000      AIR                               9.858 R
 5       INFINITE         74.6708        AIR                               9.857 R
DRAG
```

Table 3.6.3-5 Lens Specification Data for SK-2 and KZFSN-4 Doublet

PRIVATE



PRIVATE

Table 3.6.3-6 Optical Path Difference for SK-2 and KZFSN-4

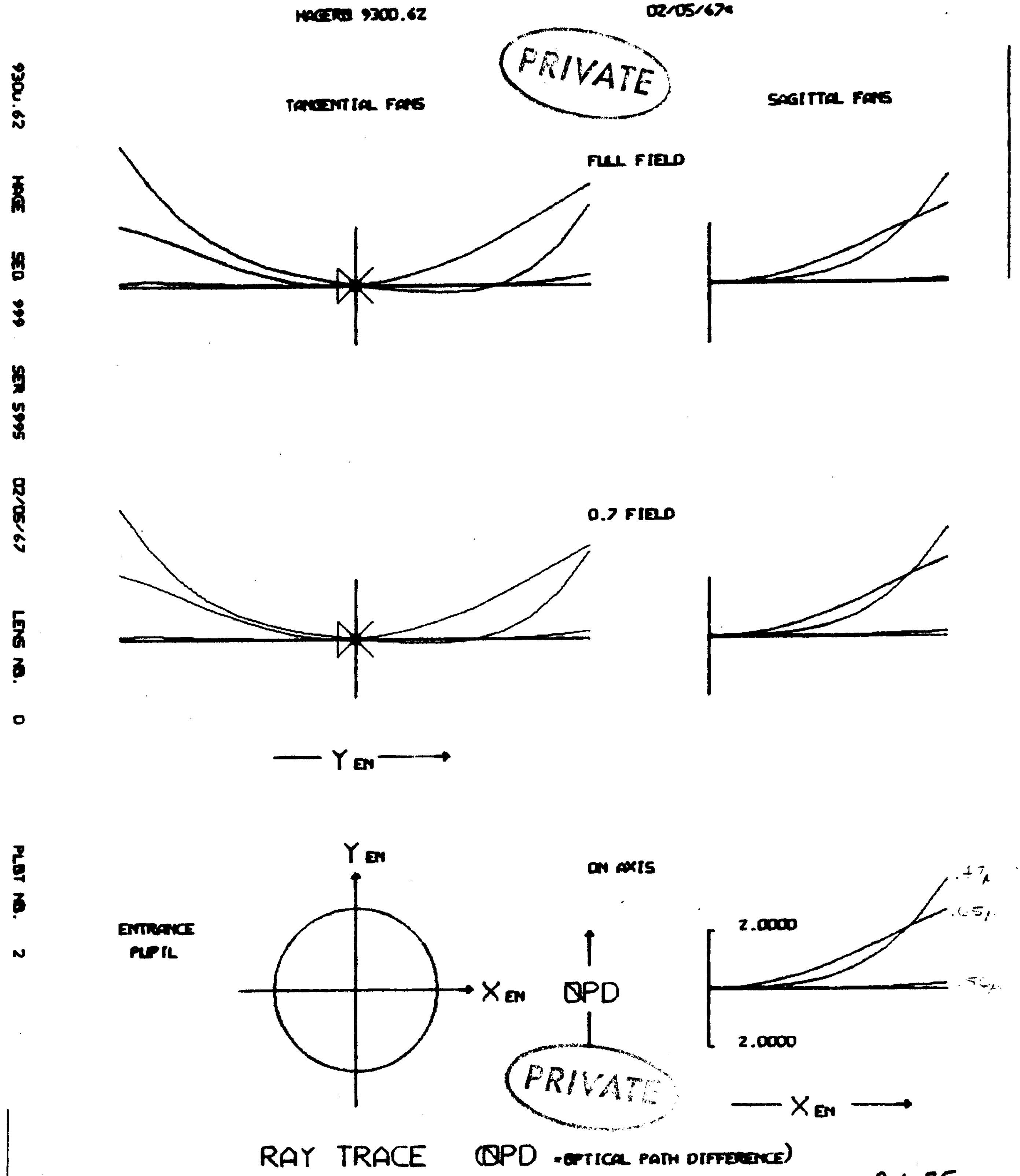


Table 3.6.3-7 Optical Path Difference for 9300 SK-16 and KZFSN-4 Doublet at Reticle

3.6.4 Illumination Studies

This section presents the results of two studies.

1. The vignetting of the interior optical train of the final A/O telescope. This study does not consider vignetting due to the external scan mirrors.
2. Spot diagrams are shown to illustrate the exit pupil shape versus field angle and color correction.

Internal Vignetting

The vignetting in the A/O zoom telescope was calculated at the peak wavelength (0.56 microns) and also throughout the visible (0.47 - 0.65 micron) spectral region. At the peak wavelength, 253 rays were traced at normalized field positions of 0.0, 0.5, and 1.0, since the transmission specifications are given at these field positions. To calculate the vignetting over the visible spectral region, 70 rays were traced at each of the following wavelengths 0.65, 0.605, 0.56, 0.515, and 0.47 microns. In both the monochromatic and polychromatic cases, the rays were traced at six magnifying powers, namely, 127X 84.67X, 63.5X, 31.75X, 21.17X, and 15.88X.

The percent vignetting for all these different cases is given in Figure 3.6.4-1 where

$$\text{Vignetting} = \frac{\text{Rays in} - \text{Rays out}}{\text{Rays in}}$$

Spot Diagrams - Spot diagrams of the exit pupil which are symmetrical about the Y-axis, for these different cases are presented in Figures 3.6.4-2 through 3.6.4-7. From these spot diagrams, it should be noted that the exit pupil grows with field angle. This is the result of pupil aberration which allows a slightly larger tolerance on eye position during observation without effecting system performance in any other way.

MAGNIFYING POWER	MONOCHROMATIC % VIGNETTING			POLYCHROMATIC % VIGNETTING		
	$\bar{H}$ = 0.0	$\bar{H}$ = 0.5	$\bar{H}$ = 1.0	$\bar{H}$ = 0.0	$\bar{H}$ = 0.5	$\bar{H}$ = 1.0
127X	0.0	0.0	0.0	0.0	0.0	0.0
84.67X	0.0	0.0	0.0	0.0	0.0	0.0
63.50X	0.0	0.0	20.2	0.0	0.0	19.2
31.75X	0.0	0.0	0.0	0.0	0.0	0.0
21.17X	0.0	0.0	0.0	0.0	0.0	0.0
15.88X	0.0	0.0	19.0	0.0	0.0	20.3

where $\bar{H}$ = normalized field position

$$\% \text{ vignetting} = \frac{\text{Rays in} - \text{Rays out}}{\text{Rays in}} \times 100\%$$

Figure 3.6.4-1 % Vignetting in Interior Train of 9300 Zoom Telescope.

PRIVATE

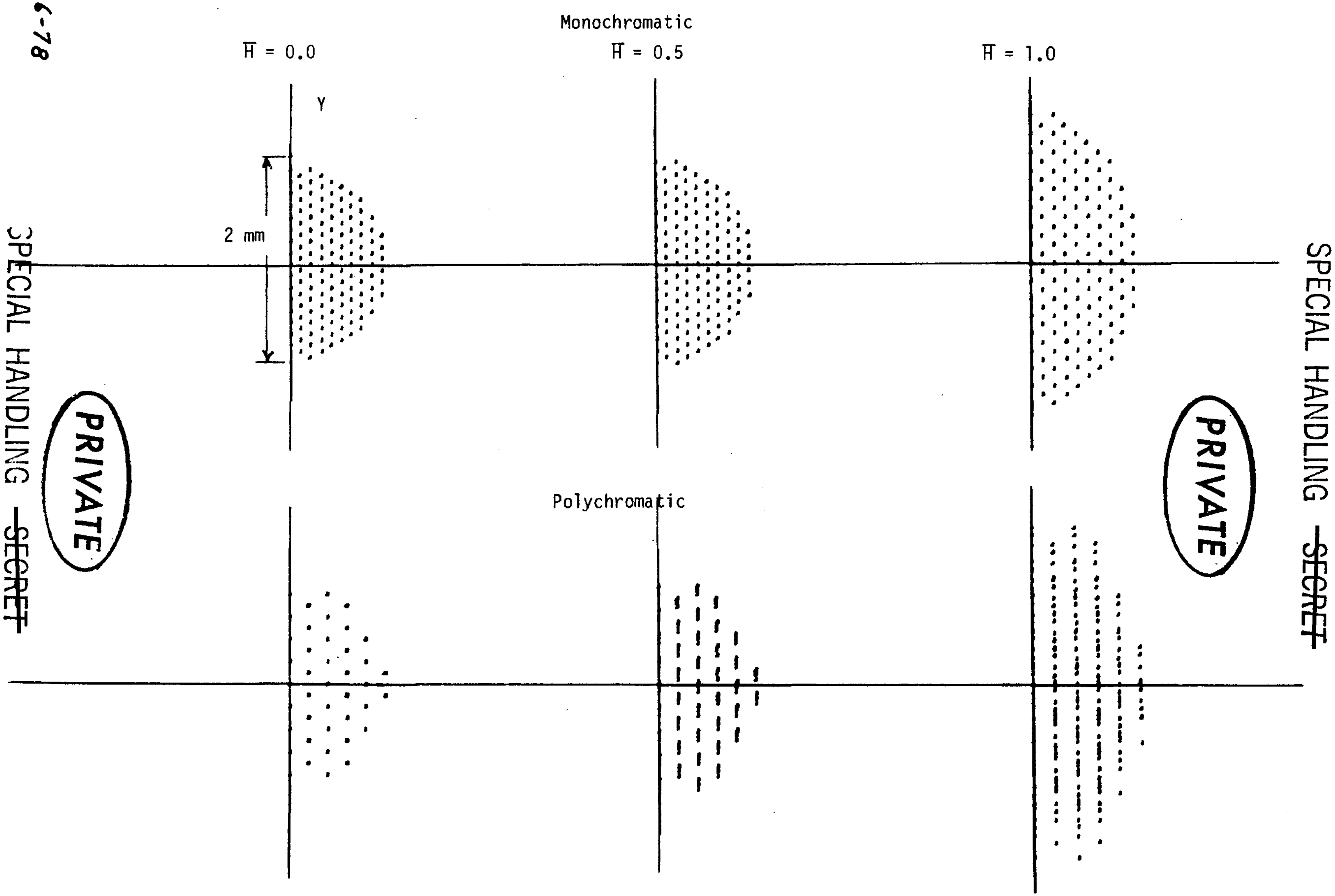


Figure 3.6.4-2 Spot Diagram of Exit Pupil at 127X

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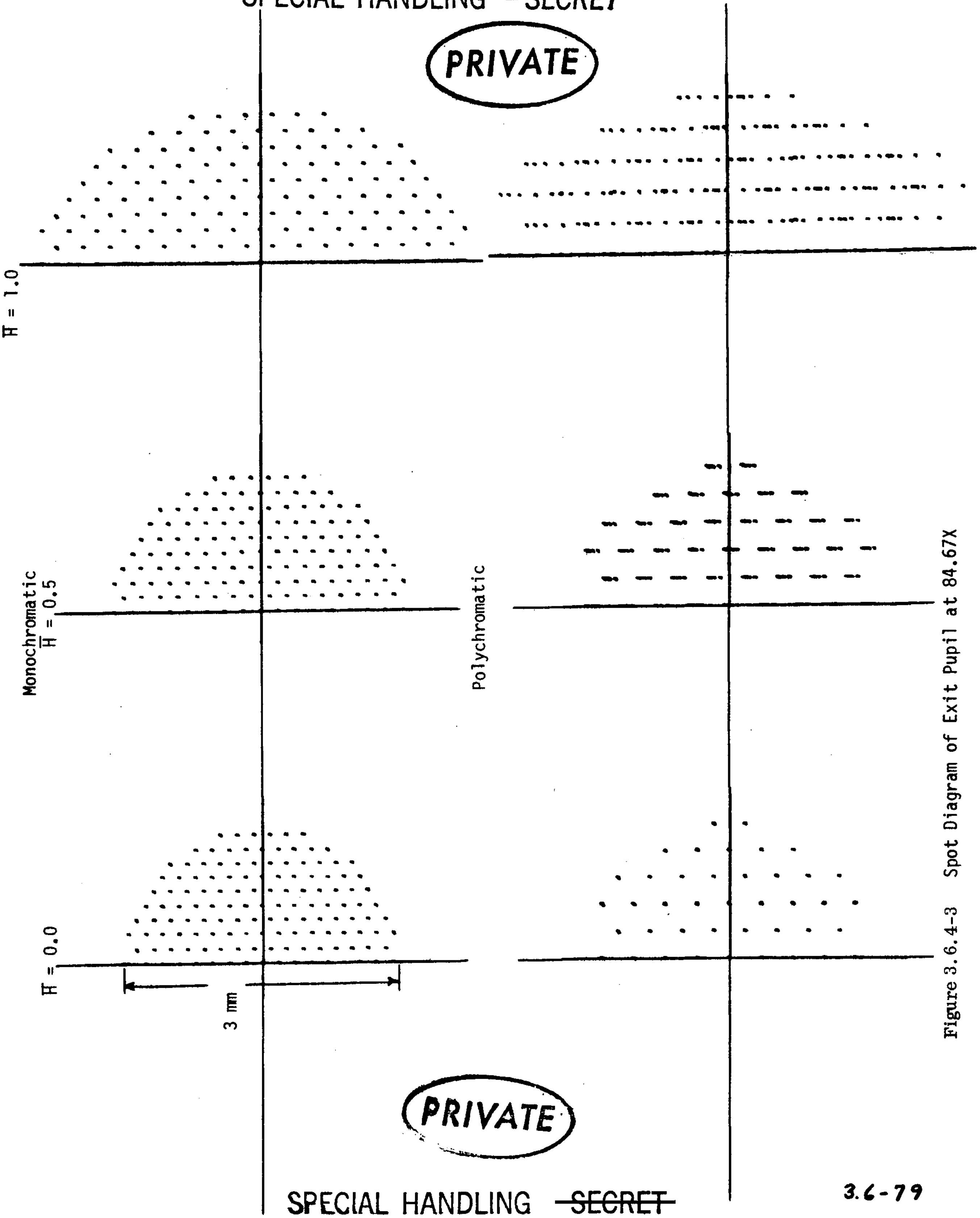

Figure 3.6.4-3 Spot Diagram of Exit Pupil at 84.67X

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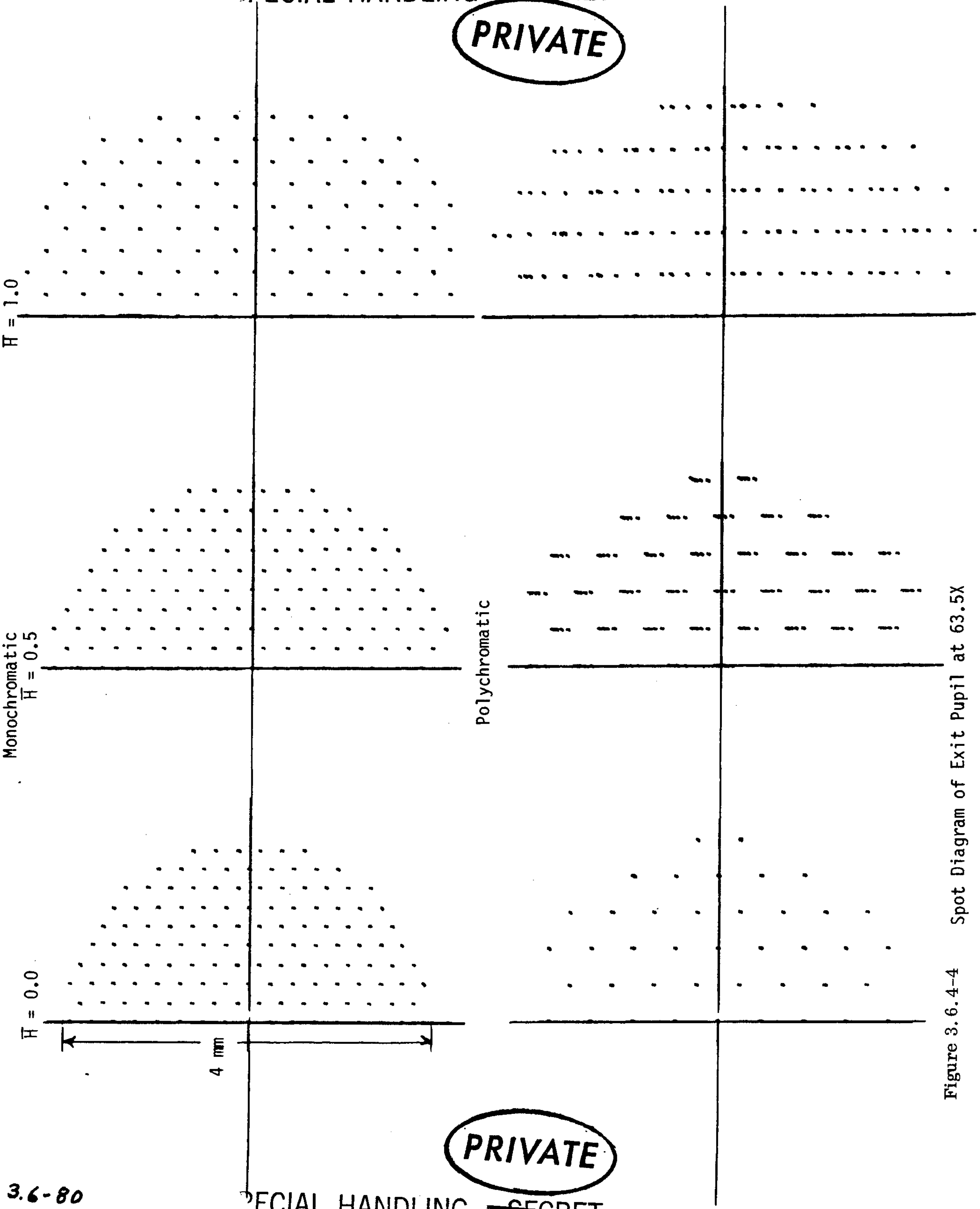

Figure 3.6.4-4 Spot Diagram of Exit Pupil at 63.5X

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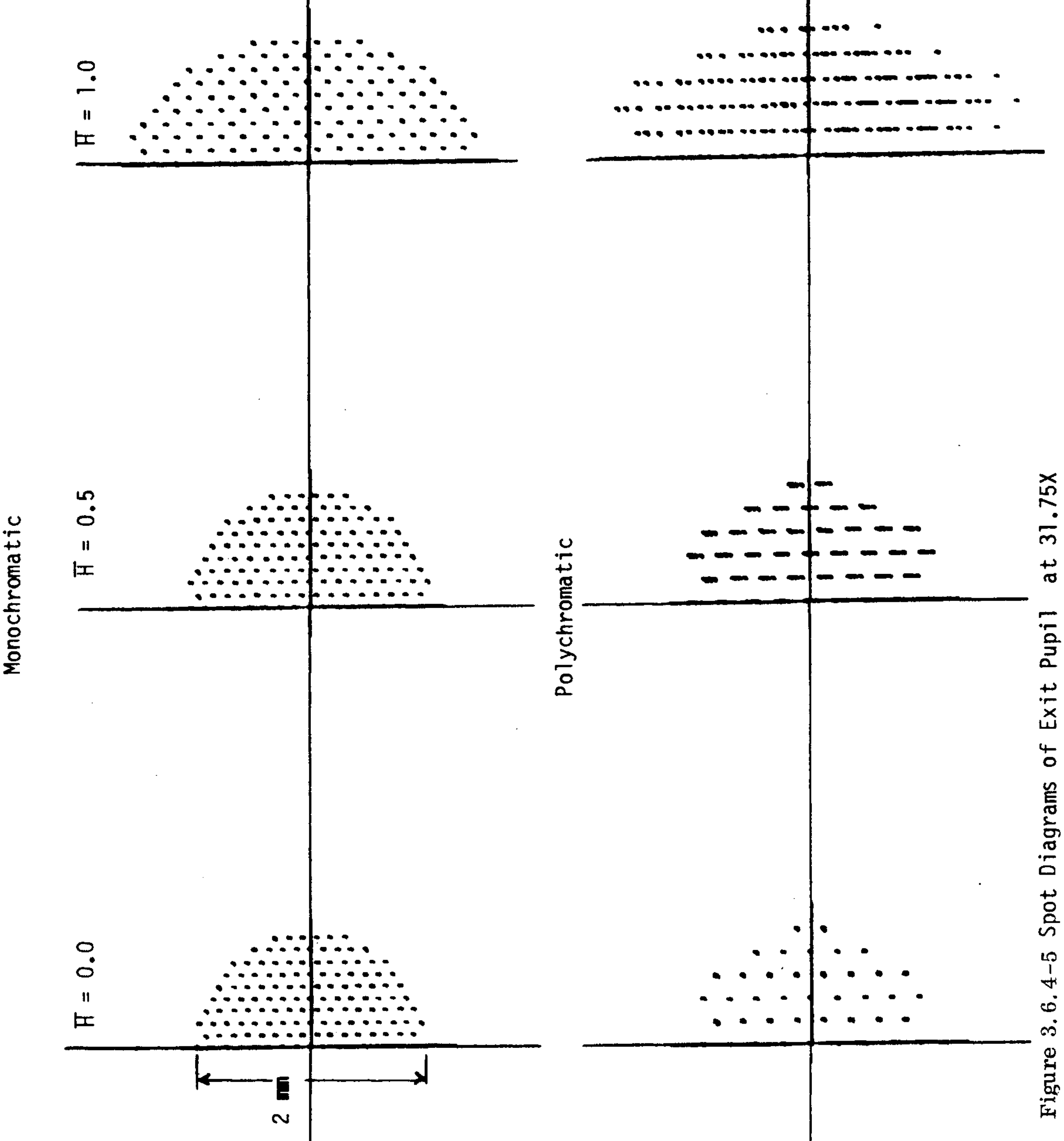

Figure 3.6.4-5 Spot Diagrams of Exit Pupil at 31.75X

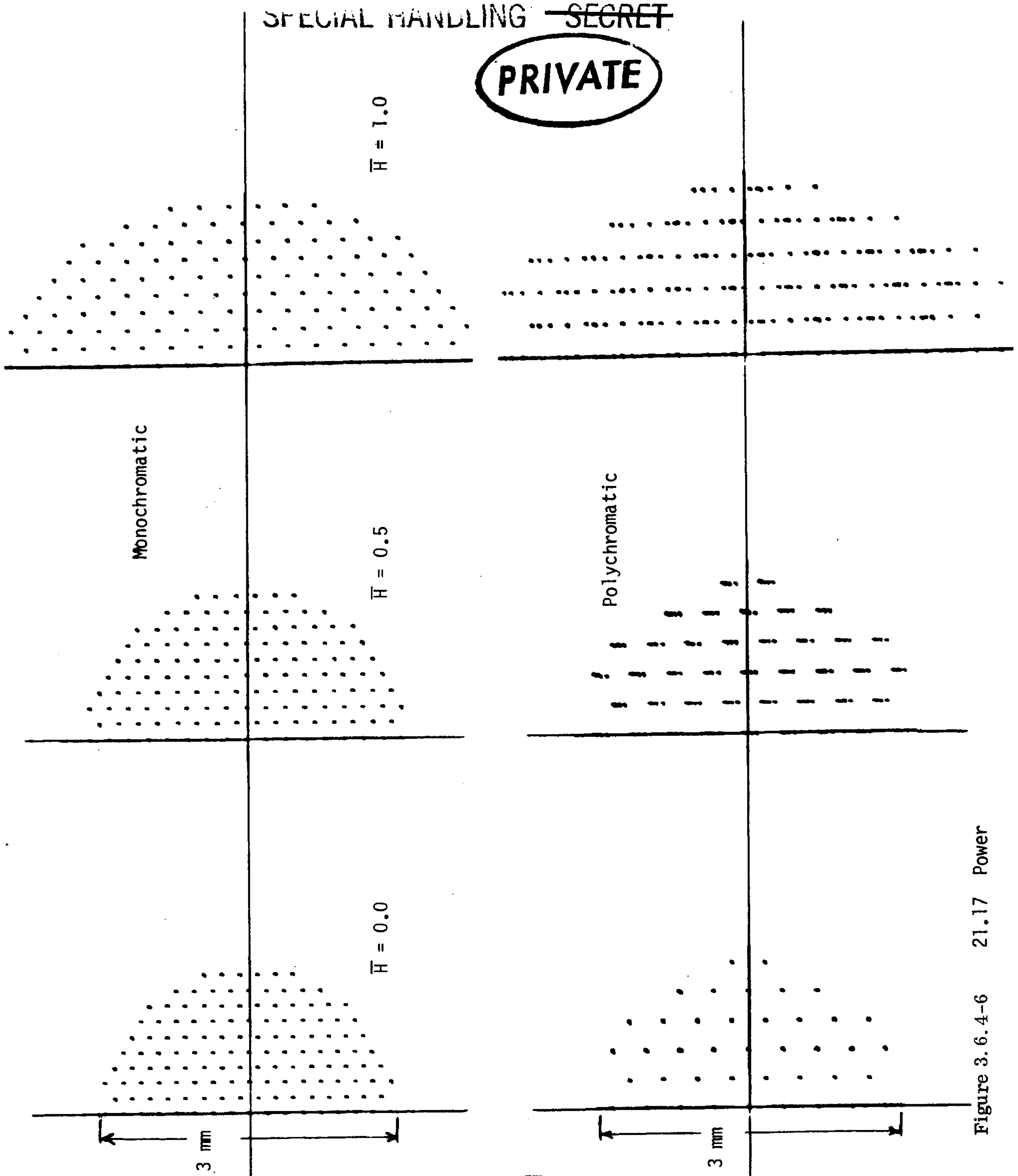

Figure 3.6.4-6 21.17 Power

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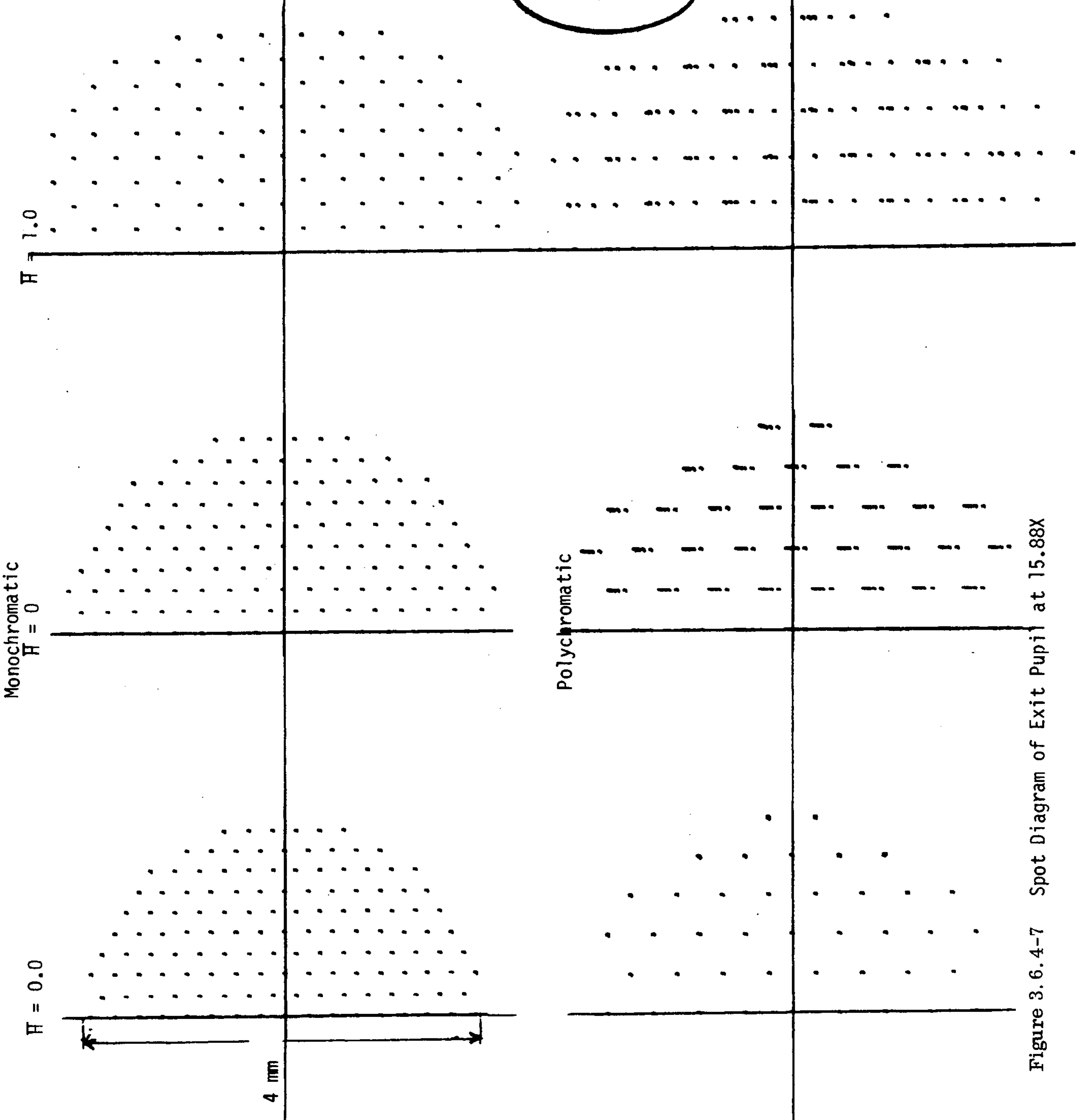

Figure 3.6.4-7 Spot Diagram of Exit Pupil at 15.88X

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3.6.5 Fabrication and Alignment Tolerances

Introduction

This section presents the optical fabrication and static alignment tolerances for the final A/O zoom telescope design A schematic diagram of the system at 31.75X is presented in Figure 3.6.5-1.

These tolerances are based upon the preliminary tolerance budget, copy of which is presented in Figure 3.6.5-2 It is to be noted that the power changer tolerances are not included in this budget since the resolution requirements are given only at 127X. However, tolerances have been assigned to the power changer on the basis of minimizing the apparent change in resolution observed at the eye.

It must be also be noted that the tolerance budget presented in Figure 3.6.5-2 assumes that actual measured radii and thicknesses will be used in the melt design and that the system will be "tweaked" up by adjusting certain airspaces to be determined. An additional assumption used here is that the system will be focused for the best on-axis focal position.

The mathematical assumptions employed in this tolerance analysis are the following. The tolerance on each optical parameter introduces some Δ O. P. D. (optical path difference) degradation into the final wavefront. The amount of this error has been calculated for each parameter. If the signs of the errors are assumed to have a random distribution and the errors add in a random fashion, then the probable degradation of the final wavefront due to the cumulative effects of n optical tolerances will be:

$$\Delta \text{ O.P.D.}_{\text{peak to peak}} = \left[\sum_{i=1}^{n} (\Delta \text{O.P.D.}_{\text{peak to peak}})_i^2 \right]^{1/2}$$

In other words, the expected cumulative error is the square root of the sum of the squares of the individual errors.

Radius, Thickness, and Airspace Tolerances

The radius, thickness, and airspace tolerances for the complete telescope are presented in Figure 3.6.5-3.

In section 3.6.1-4 it is shown that the objective airspace may be varied by as much as ± 0.050 in the melt design depending on how well objective elements (indices) can be matched. An additional tolerance that must be imposed is that in the high power mode the airspace between the objective and the Pechan prism must have the value of 67.1797 inches ± 0.1000 inch.

Element and Group Tilts and Decenters

An element tilt refers to the alignment of that element relative to the mechanical axis of the lens cell. A group tilt refers to the alignment of the mechanical axis of a lens cell (containing several elements) relative to the optical axis of the system. All elements are assumed to be tilted about their geometrical centers. Lens cells or groups, on the other hand, were rotated about points supplied by Engineering. The distances of these centers of rotation from the centers of the lens cells are given in Figure 3.6.5-4.

Similarly, an element decenter refers to the parallel translation of the axis of the element relative to the axis of the lens cell. A group decenter refers to a parallel translation of the axis of the cell relative to the optical axis of the system.

Element and group tilt and decenter tolerances are given in Figure 3.6.5-5.

Wedge Tolerances

The wedge tolerances for individual elements are given in Figure 3.6.5-5 in terms of total indicated runout (TIR) measured in inches at the edge of the element. In addition, all cementing layers must have a wedge of less than .0002 inch TIR.

Surface Irregularities

The maximum allowable surface irregularities are presented in Figure 3.6.5-6 where the surface irregularity is defined to be the peak-peak deviation of the surface being tested from the nearest sphere over any circle having a diameter equal to the axial beam diameter. For the elements other than the power changer, the 127X axial beam diameters are to be used. This data is presented in Figure3.6.5-7 For the power changer, the 15. 88 X axial beam diameters should be used. This data is presented in Figure 3.6.5-8.

Power Tolerance

Power (test plate match) is the deviation of the nearest sphere of the test plate over the clear aperture. All surfaces in the A/O telescope must be held to a power tolerance of λ/4 peak to peak except for the two external mirrors and the internal mirrors which must have power tolerances of λ/10 peak to peak and the Pechan prism surfaces which must have power tolerances of λ/8 peak to peak.

Glass Quality

The Pechan prism glass should be Schott Grade 4 and the rest of the elements Schott Grade 2.

Conclusion

The 9300 telescope has been toleranced on the basis of minimizing the cost of fabrication and alignment while keeping the expected wavefront deformation within the limits specified in the presented tolerance budget.

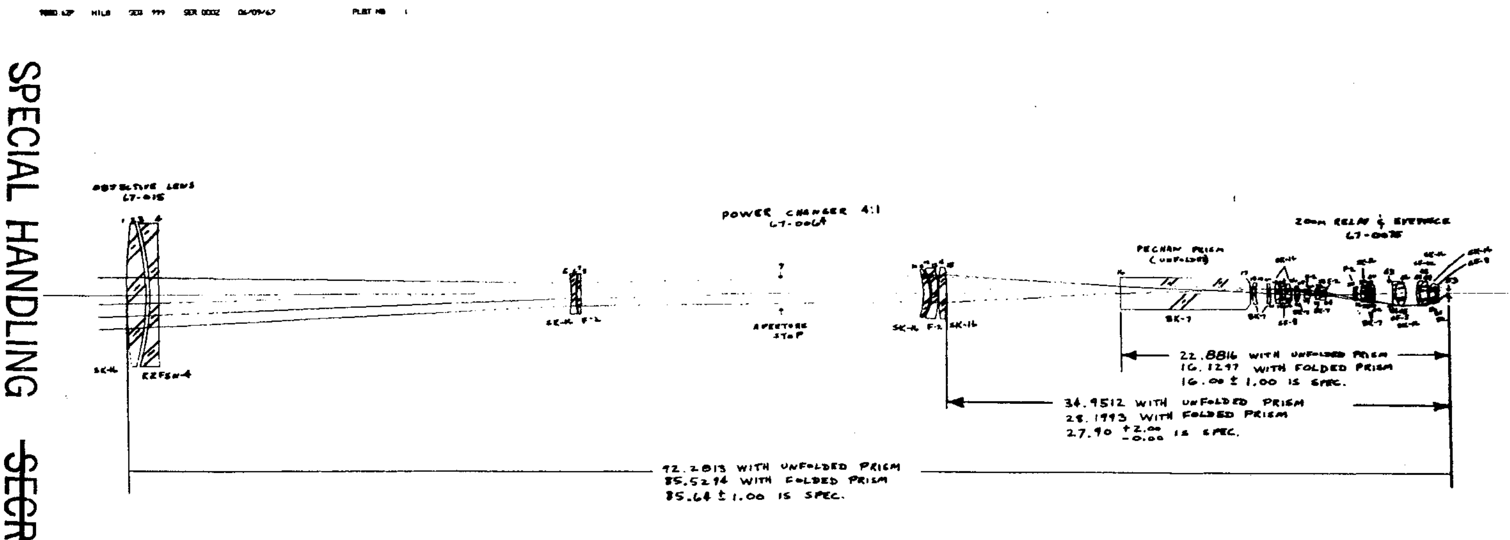
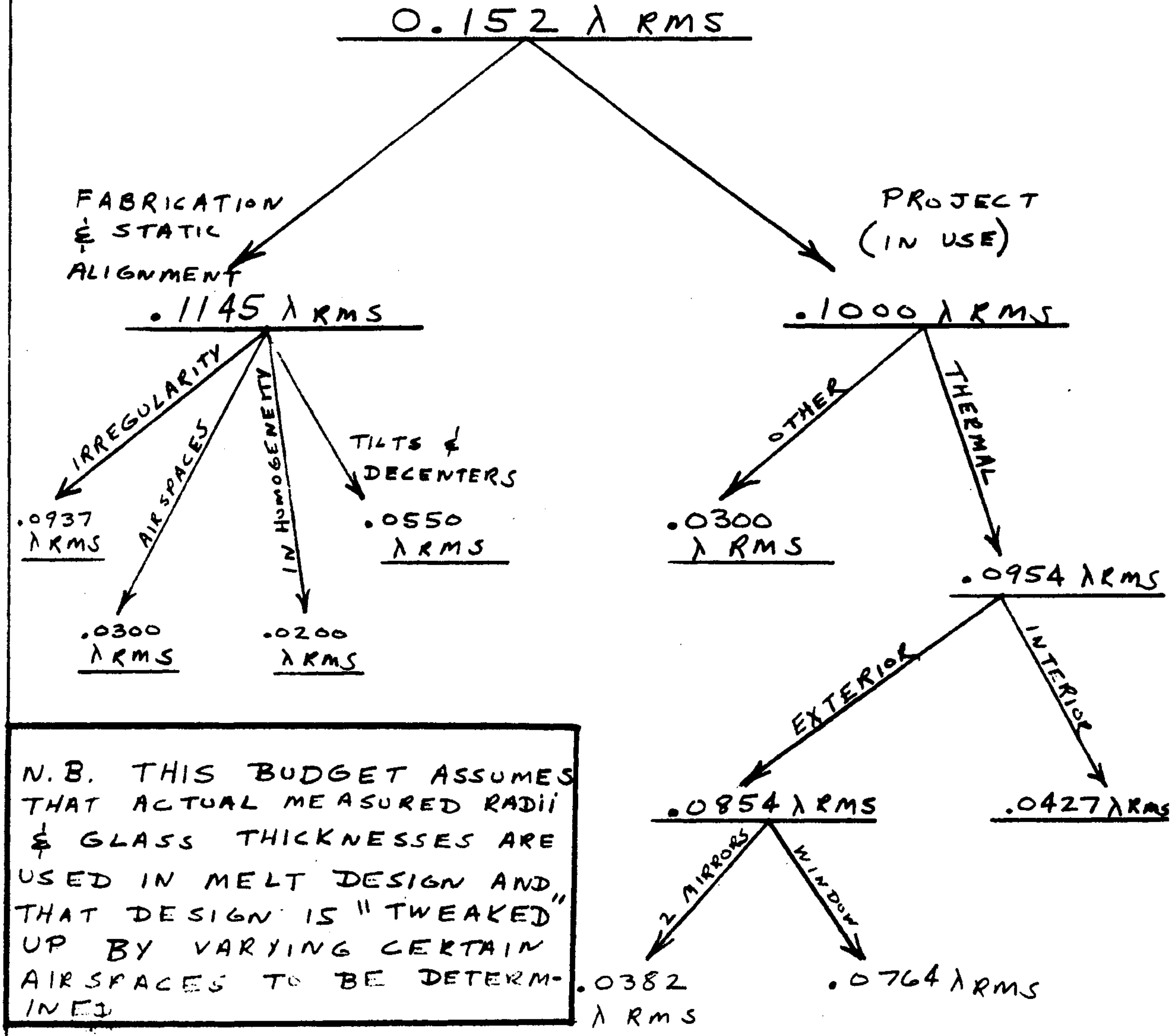


Figure 3.6.5-1 FINAL 9300 200 M TELESCOPE DESIGN AT 31.75 X



N.B. THIS BUDGET ASSUMES THAT ACTUAL MEASURED RADII & GLASS THICKNESSES ARE USED IN MELT DESIGN AND THAT DESIGN IS "TWEAKED" UP BY VARYING CERTAIN AIRSPACES TO BE DETERMINED

Figure 3.6.5-2 PRELIMINARY 127X TOLERANCE BUDGET

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DESIGN SPECIFICATION SHEET

Element Number	Surface Number	Radius	Radius Tolerance inches	Thickness	Thickness Tolerance inches	Airspace	Airspace Tolerance inches	Clear Aperture	n*	v**	Glass Type & Melt
DESIGN No. 67-015	1	40.1302	±.080	1.3544	+0.0 -.005			10.00	1.62041	60.33	SK-16
	2	-18.4179	±.005			0.2656	±.002	9.98			
	3	-17.8183	±.005	0.6000	+0.0 -.005			9.84	1.61340	44.30	KzFSN-4
	4	273.6105	±3.000			28.8180	±.030	9.73			
DESIGN NO. 67-0064	5	-8.9940	±.036	0.3613	±.005			2.79	1.62041	60.33	SK-16
	6	10.7028	±.050			0.0200	±.005	2.79			
	7	7.6130	±.026	0.2934	±.005			2.80	1.62004	36.37	F-2
	8	486.4318	±105.000			13.9069	±.010	2.79			
	9	∞				10.0873	±.010	2.06			
	10	-5.4627	±.010	0.4468	±.005			3.28	1.62041	60.33	SK-16
	11	-3.1057	±.003			0.1337	±.005	3.35			
	12	-3.0157	±.003	0.4516	±.005			3.32	1.62004	36.37	F-2
	13	-6.7970	±.013			0.0200	±.005	3.55			
	14	11.9795	±.038	0.5711	±.005			3.63	1.62041	60.33	SK-16
	15	-18.5349	±.090			12.0696	±.010	3.63			
DESIGN No. 67-016	16	∞		9.1391 Unfolded				2.22	1.51680	64.17	BK-7
	17	∞				0.1017	±.005	1.55			
	18	2.2310	±.008	0.2391	±.005			1.53	1.51680	64.17	BK-7
	19	2.2002	±.008			0.7916	±.005	1.46			

SYSTEM: 67-0075 **UNIT:** Inch

APPROVED: E. Hagerott **LENS DESIGNER** **DATE:** 6/22/67
R. Hilbert 6/22/67
R. Wientzen 6/22/67

* n = refractive index at 5876 Angstrom units

** v = reciprocal dispersive power at 5876 Å

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Figure 3.6.5-3 Lens Specification Data

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DESIGN SPECIFICATION SHEET

Element Number	Surface Number	Radius	Radius Tolerance inches	Thickness	Thickness Tolerance inches	Airspace	Airspace Tolerance inches	Clear Aperture	n*	v**	Glass Type & Melt
	20	∞		0.2000	±.005			1.36	1.51680	64.17	BK-7
	21	∞				0.3229	±.005	1.37			Reticle
DES 16 NO.	22	2.5493	±.011	0.3959	±.005			1.39	1.62041	60.33	SK-16
67-0075	23	-1.8689	±.006			0.0837	±.005	1.36			
	24	-1.3669	±.004	0.2310	±.005			1.33	1.68893	31.18	SF-8
	25	1.3808	±.004	0.4500	±.005	0.2274	±.005 High	1.35	1.62041	60.33	SK-16
	26	-2.2523	±.009			0.5215	Mid	1.37			
	27	2.9031	±.022	0.3200	±.005	0.9993	Low	1.09	1.51680	64.17	BK-7
	28	-1.4431	±.006			0.3750		1.05			
	29	-0.6161	±.002	0.3996	±.005	0.3342	±.005 High	0.66	1.62004	36.37	F-2
	30	-0.8979	±.005			1.1384	Mid	0.67			
	31	1.7353	±.015	0.3246	±.005	1.3933	Low	0.75	1.51680	64.17	BK-7
	32	-0.8258	±.003			0.0500		0.79			
	33	-0.7985	±.003	0.3933	±.005	1.8578	±.005 High	0.78	1.62004	36.37	F-2
	34	-3.4038	±.041			0.7597	Mid	0.91			
	35	1.7311	±.009	0.2072	±.005	0.0266	Low	0.98	1.62004	36.37	F-2
	36	1.0715	±.004			0.3178	±.005	0.98			
	37	1.2965	±.004	0.3000	±.005			1.18	1.62041	60.33	SK-16
	38	5.4668	±.069			0.1500	±.005	1.18			

SYSTEM: 67-0075 **UNIT:** Inch

APPROVED: E. Hagerott **LENS DESIGNER** **DATE:** 6/22/67
R. Hilbert 6/22/67
R. Wientzen 6/22/67

* n = refractive index at 5876 Angstrom units

** v = reciprocal dispersive power at 5876 Å

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Figure 3,6,5-3 Continued

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DESIGN SPECIFICATION SHEET

Element Number	Surface Number	Radius	Radius Tolerance inches	Thickness	Thickness Tolerance inches	Airspace	Airspace Tolerance inches	Clear Aperture	n*	v**	Glass Type & Melt
DES NO 67-0075	39	∞ Filter		0.1700	±.005			1.18	1.51680	64.17	BK-7
	40	∞				0.1500	±.005	1.18			
	41	-1.9993	±.009	0.2001	±.005			1.18	1.51680	64.17	BK-7
	42	-4.1623	±.035			1.0426	±.005	1.24			
	43	∞				0.2000	±.005	1.50			Image Plane
	44	-7.4978	±.084	0.1670	±.005			1.54	1.68893	31.18	SF-8
	45	1.1851	±.002	0.7560	±.005			1.67	1.62041	60.33	SK-16
	46	-1.7750	± 004			0.7504	±.005	1.74			
	47	2.1978	±.006	0.2100	±.005			1.78	1.64831	33.84	SF-12
	48	1.1552	±.002	0.5880	±.005			1.67	1.62041	60.33	SK-16
	49	-30.2177	±1.253			0.0150	±.005	1.61			
	50	0.9348	±.002	0.5000	±.005			1.44	1.62041	60.33	SK-16
	51	-11.9989	±.300	0.1490	±.005			1.29	1.68893	31.18	SF-8
	52	1.3461	±.006			0.7716	±.005	1.02			
	53										Eye Point

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SYSTEM: 67-0075 UNIT: Inch

APPROVED: E. Hagerott LENS DESIGNER DATE: 6/22/67
R. Hilbert 6/22/67
R. Wientzen 6/22/67

* n = refractive index at 5876 Angstrom units

** v = reciprocal dispersive power at 5876 Å

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Figure 3.6.5-3 Continued

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Group	Surfaces	Distance of rotation point from first surface of group
1	1,2,3,4	+ 1.10 inches
2	5,6,7,8	+ .34 inches
3	10,11,12,13,14,15	+ .80 inches
4	20,21,22,23,24,25,26	+ 1.68 inches
5	27,28,29,30	+ 1.59 inches
6	31,32,33,34	- .50 inches
7	35, 36,37,38	+ .94 inches
8	44,45,46,47,48,49,50,51,52	- .50 inches

* Note that surfaces 39 and 40 (the filter) and surfaces 41 and 42 (last relay element) are both elements and groups. The element tilt data is given in Figure 5.

Figure 3.6.5-4 Assumed Centers of Rotation for Lens Cells

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Figure 3.6.5-5 Element & Group Tilts & Decenters & Wedge (TIR)

Element	Surfaces	Decenter (inches)	Tilt Angle (radians)	TIR inch	Group	Surfaces	Decenter (inches)	Tilt Angle (radians)
1	1 & 2	±.001	±.0001	.00005	1	1,2	±.001	±.0001
2	3 & 4	±.001	±.0001	.00005		3,4		
3	5 & 6	±.001	±.0004	.00005	2	5,6	±.003	±.0006
4	7 & 8	±.001	±.0004	.00005		7,8		
5	9	Aperture Stop						
6	10 & 11	±.001	±.0003	.00015	3	10,11	±.002	±.0006
7	12 & 13	±.001	±.0003	.00015		12,13		
8	14 & 15	±.001	±.0003	.00005		14,15		
9	16 & 17	±.001	±.0004					
10	18 & 19	±.001	±.0030	.00015				
11	20 & 21	±.001	±.0034	.00020	4	20,21	±.002	±.0034
12	22 & 23	±.001	±.0013	.00015		22,23		
13	24 & 25	±.001	±.0013	.00020		24,25		
14	25 & 26	±.001	±.0013	.00020		26		
15	27 & 28	±.001	±.0017	.00015	5	27,28	±.001	±.0010
16	29 & 30	±.001	±.0010	.00020		29,30		
17	31 & 32	±.001	±.0010	.00015	6	31,32	±.001	±.0010
18	33 & 34	±.001	±.0010	.00015		33,34		
19	35 & 36	±.001	±.0020	.00015	7	35,36	±.001	±.0010
20	37 & 38	±.001	±.0015	.00015		37,38		
21	39 & 40	±.001	±.0040					
22	41 & 42	±.001	±.0015	.00010				
23	43	Eyepiece Focal Plane						
24	44 & 45	±.001	±.0005	.00015	8	44,45	±.003	±.0006
25	45 & 46	±.001	±.0005	.00015		46		
26	47 & 48	±.001	±.0011	.00015		47,48		
27	48 & 49	±.001	±.0011	.00015		49		
28	50 & 51	±.001	±.0012	.00015		50,51		
29	51 & 52	±.001	±.0014	.00015		52		

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Refracting Elements	Surfaces	Surface * Irregularity Peak - Peak	Individual Surface Contribution to Wavefront Peak - Peak
Window	2	λ/10	λ/20
Objective	4	λ/10	λ/20
Power Changer	10	λ/8	λ/16
Field Lens	2	λ/20	λ/40
Pechan prism	4	λ/20	λ/40
Reticle	2	λ/20	λ/40
Zoom relay-eyepiece	26 **	λ/20	λ/40

Reflecting Elements	Surfaces	Surface Irregularity Peak - Peak	Individual Surface Contribution to Wavefront Peak - Peak
External Mirrors	2	λ/12	λ/6
Internal Mirror	1	λ/16	λ/8
Pechan prism	5	λ/20	0.15 λ cos i where i = angle of incidence

* Surface irregularity is the peak - peak deviation of the surface being tested from the nearest sphere over any circle having a diameter equal to the axial beam diameter at 127X.

** Cemented surfaces were neglected.

Figure 3.6.5-6

SN	Axial Beam Dia.	SN	Axial Beam Dia	SN	Axial Beam Dia.
1	10.00 in.	19	0.13 in.	37	0.12 in.
2	9.87	20	0.02	38	0.11
3	9.74	21	0.00 (assume .02 in.)	39	0.09
4	9.68	22	0.05	40	0.09
5	---	23	0.08	41	0.07
6	---	24	0.08	42	0.06
7	---	25	0.11	43	0.0
8	---	26	0.15	44	0.01
9	---	27	0.17	45	0.02
10	---	28	0.20	46	0.05
11	---	29	0.20	47	0.05
12	---	30	0.24	48	0.05
13	---	31	0.25	49	0.10
14	---	32	0.24	50	0.10
15	---	33	0.24	51	0.10
16	0.95	34	0.24	52	0.08
17	0.16	35	0.14	53	0.08
18	0.15	36	0.14		

Figure 3.6.5-7 127X Axial Beam Diameters

SN	Axial Beam Dia.
5	1.50 in.
6	1.50
7	1.60
8	1.60
9	2.00
10	2.40
11	2.50
12	2.44
13	2.52
14	2.52
15	2.52

Figure 3.6.5-8 15.88X Axial Beam Diameter for Power Changer

3.6.6 Optical Transmittance

This is a study of the transmittance of the complete A/O telescope system, including one internal mirror, two external mirrors, and the window. The transmittance calculation takes into account the absorption and reflection losses of each individual element, and examines the variation of reflection and absorption with the glass type and the angle of incidence of the light at each surface.

The total transmittance of the complete A/O telescope system has been calculated and found to be 35.4% for the 127 X (high power) mode and 31.2% for the 31.75 X (low power) mode. The following assumptions were made: single layer magnesium fluoride anti-reflection coatings on all refracting surfaces, both external mirrors are aluminized and have a SiO protective coating (87% reflection each), the internal folding mirror aluminized with a 2-layer enhancement coating (93% reflection), and multilayer coatings (98.5% reflection) on two surfaces of the Pechan prism. The transmittance calculation takes into account the expected reflection and absorption losses of each element, rather than the theoretically predicted values. The performance assumed for the single layer magnesium fluoride coatings, for example, is based on actual measurements made on coatings on different index glasses. Although the variation of reflection with glass index and angle of incidence of the light are considered, the effects of vignetting and filters (aside from surface reflections) has been ignored.

Before proceeding with the actual transmittance calculation, it is important to establish the effect of the angle of incidence of light on the performance of the anti-reflection coatings.

The change of the reflectance of a $\lambda/4$ one layer anti-reflection coating as a function of the incident angle of the light was computed using a multilayer film analysis program on the computer. The results show that the transmission of the film changes by about 0.1% (for example, from 99.5% transmission to 99.4%) as the angle of incidence of the light goes from normal to 30°.

Anti-Reflecting Surfaces - Magnesium Fluoride

Angle of Incidence	Transmittance of one surface Substrate Index of Refraction			
	1.52	1.62	1.65	1.69
0°	98.74%	99.35%	99.49%	99.64%
5°	98.74%	99.35%	99.49%	99.64%
15°	98.73%	99.34%	99.48%	99.64%
25°	98.68%	99.29%	99.43%	99.58%
35°	98.50%	99.10%	99.23%	99.38%
45°	97.93%	98.53%	98.66%	98.81%
practical value	98.4%	98.8%	99.0%	99.3%

Now the angles of incidence of the on-axis rays have been tablulated for each refracting surface of the A/O telescope for both the 127X (high power) mode, and the 31.75X (low power) mode. The average angle of incidence of the marginal ray is 4.0° for the high power mode and 5.1° for the low power mode, and none of the angles are above 30° in either mode.

For these reasons, we can say that the reflection losses for the whole axial beam will be indistinguishable from the losses of an axial pencil at normal incidence to all the surfaces. A similar type of analysis has been done for the off-axis beams, where the angles of incidence at the surfaces are higher, and the conclusion is that the off-axis reflection losses for refracting surfaces will be less than 2.0% greater than the axial reflection losses. When the transmission of the whole system is considered, this variation of transmission with field angle becomes less than 1%, i.e. the transmission at full field in the high power mode will be between 34.4% and 35.4%, where the latter figure is the axial transmission.

For these reasons, the variation of the transmission of the complete A/O telescope with field angle is considered negligible. The results obtained by the following analysis are, therefore, valid across the field.

A summary of assumed reflection losses for every surface in the system, as well as the results of the cumulative reflection loss calculation are shown in Figure 3.6.6-1. Most of this information was taken from G. R. Wirtenson's memo, "Coating Thruput Values (Project 9300)", July 27, 1967, which is enclosed as Addendum 3.6.6-A.

Absorption losses are not as great as reflection losses, but are significant enough to be analyzed. There are approximately 20.0 inches of glass which light must pass through, in the low power mode, before reaching the eye (counting the unfolded length of the Pechan prism and the window). Of this 20.0 inches of glass, roughly 11.8 inches consists of low index glasses like BK-7, the other 8.2 inches are high index glasses, such as SK-16. The transmission of these glasses and the resulting absorption calculation are shown in Figure, 3.6.6-2

the source of the data used.

Figure 3.6.6-3 shows a summary of the results, and the calculation of the transmittance of the whole system, combining the effect of reflection and absorption losses. The value of 35.4% transmittance for the whole system in the high power mode for the major color represents the product of 39.2% transmission due to reflection losses alone and 90.2% transmission due to absorption losses alone.

If the internal folding mirror were coated with the same multilayer dielectric stack (98.5% reflectance) as the Pechan prism faces, instead of aluminum and a two-layer enhancement coating, the transmission would rise from 35.4% and 31.2% (for the high power and low power modes respectively) to 37.5% and 33.0%.

Because of the hostile environment, little can be gained by trying to use better coatings on the external mirrors.

In the real case, we must trade off the ideal transmission versus that required to meet the specification, schedule and cost. Durability and reliability of the coatings are of prime importance.

The study has been carried further based upon the trade-off considerations, and the following critical items were considered.

1. The Pechan prism reflecting surfaces coated with aluminum plus a protective coating for 87% transmission.
2. The internal fold mirror coating to be enhanced for 98.5% reflection.
3. The external scanning mirror to be coated with aluminum and SiO for 87% reflection.
4. The external fold mirror coating to be enhanced for 93% reflection.
5. All other element surfaces to be coated with magnesium fluoride for $\lambda/4$ where λ equals 0.56μ.

The transmission of the entire system then becomes 29.2% at 127X and 25.7% at 15X. Therefore, the decision has been made to apply the coating characteristics specified above. These coatings are part of the optical design given in Section 3.6.1.

Effect of Reflection Losses Alone on System Transmission

Figure 3.6.6-1

Glass	Surfaces*		Coating	Transmission of single surface	Total Light Passed	
	High Power	Low Power	Single layer $\lambda/4$ mag. fluoride	$.56\mu$	High Power	Low Powe
SK-16	10	16	$\lambda_0 = .56\mu$	98.8%	88.6%	82.4%
F-2	6	10	same	98.8%	93.0%	88.6%
SF-8	3	3	same	99.3%	97.9%	97.9%
KZFS-N4	2	2	same	99.75%	97.5%	97.5%
SF-12	1	1	same	99.0%	99.0%	99.0%
Window BK-7	2	2	same	98.4%	96.8%	96.8%
BK-7	13	13	same	98.4%	81.1%	81.1%
	3	3	uncoated (Pechan)	95.8%	87.8%	87.8%
Total of all Surfaces	40	50		Total Transmission of Refracting Surfaces -	53.7%	47.6%

Effect of Reflection Losses Alone on System Transmission

Figure 3.6.6-1 (continued)

Glass	Surfaces	Coating	Transmission of single surface	Total Light Passed
Internal Mirror	1	Aluminized with 2-layer enhancement coating	93%	93%
External Scan Mirror	1	Aluminized with SiO coating	87%	87%
External Fold Mirror	1	Aluminized with 2-layer enhancement coating	93%	93%
Pechan Prism	2	Multi-layer dielectric stack	98.5%	97%
Pechan Prism	3	None - total internal reflection	100%	100%
Total -	8	Total transmission of Reflecting Surfaces		73.0%

Total of all surfaces -

High Power	Low Power
48	58

Total transmission due to reflection losses-

High Power	Low Power
39.2%	34.8%

*Cemented surfaces are not counted or considered.

**The total light passed is 100% minus reflection losses. Absorption is considered separately.

Effect of Aborption Losses Alone on System Transmission

Figure 3.6.6-2

Glass	Thickness		Transmission/inch*	Total Light Passed**	
	High Power	Low Power		High Power	Low Power
High Index Glass Approximation= SK-16	~ 6.1 inches	~ 8.2 inches	.564 99.7%	98.1%	97.5%
Low Index Glass Approximation= BK-7	~ 11.3 inches	~11.3 inches	99.3%	92.3%	92.3%
BK-7 Window	.5 inches	.5 inches	99.3%	99.6%	99.6%
Total -	17.9 inches	20.0 inches	Total transmission due to absorbtion losses alone-	90.2%	89.6%

Note: Because of the shapes of the optical elements and the small absorption losses, the variation of absorption with field angle is negligible.

---

*Excluding reflection losses.

**The total light passed is 100% minus absorption losses. Reflection is considered separately.

Transmission of Complete System

Figure 3.6.6-3

	High Power Mode	Low Power Mode
Transmission due to reflection losses alone	.56μ 39.2%	.56μ 34.8%
Transmission due to absorption losses alone	90.2%	89.6%
Transmission due to combined effects	35.4%	31.2%

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INTEROFFICE MEMORANDUM

Date: 27 July 1967

Page 1 of 2 Pages

To: D. Shafer Facility: Lexington

From: G. R. Wirtenson Facility: Lexington

Subject: Coating Thruput Values (Project 9300)

This report contains both theoretical and practical thruput values for the coatings specified. All values are given for 5600 Å light. The theoretical data is obtained from our CDC 3300 computer using the MULTIFILM program. The practical data are measured values for the anti-reflecting films and estimates for the reflectors. The estimated values are based upon prior knowledge of typical performances.

A brief description of the coating type is given.

1) Scanning Mirror - Overcoated Aluminum

∠ of incidence	Reflectance Theoretical (P/S)	Practical
normal	.9143	.87
20°	.9156 (.9104/.9207)	.87
40°	.9137 (.8921/.9352)	.87
60°	.8973 (.8437/.9508)	.85
80°	.9086 (.8406/.9766)	.86

2-3) Folding Mirrors Internal-External
Enhanced Aluminum (2 layer dielectric overcoat)

∠ of incidence	Reflectance Theoretical	Practical
45°	.9559	.93
38°	.9586	.93

4-5) Pechan Prism Multi-layer dielectric Stack

∠ of incidence	Reflectance Theoretical	Practical
22.5°	.9971	.985

6) Anti-Reflecting Surfaces - Magnesium Fluoride

∠ of incidence	Transmittance Substrate index 1.52	1.62	1.65	1.69
Theoretical (5°	.9874	.9935	.9949	.9964
Theoretical (15°	.9873	.9934	.9948	.9964
Theoretical (25°	.9868	.9929	.9943	.9958
Deviation in transmittance	.0006	.0006	.0006	.0006
Practical	.984	.988	.990	.993

ADDENDUM 3.6.6-A

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INTEROFFICE MEMORANDUM

Date: 27 July 1967

Page 2 of 2 Pages

To: D. Shafer Facility: Lexington

From: G. R. Wirtenson Facility: Lexington

Subject: Coating Thruput Values (Project 9300)

As shown above, the expected change in transmittance per anti reflecting surface is of the order of 0.1% as the angle of incident light changes from normal thru to 30°. A change of this order is not detectable by ordinary techniques and will not measurably affect system thruput.

G R Wirtenson
G. R. Wirtenson

GRW/hb

CC: R. Gebelein
E. Hagerott
F. Nitchie
E. Prevost
J. Rancourt
S. Robinson

3.6.7 Optical Element Weights

Introduction

The weights of the optical components of the complete A/O telescope are presented here, element by element, and the results are summed to give the total glass weight of 50.756 pounds.

The window was assumed to be BK-7, 0.5 inches thick and 10.4 inches in diameter. The Pechan prism is 2.40 inches wide, to prevent vignetting at that element. One should note that the actual dimensions of the Pechan prism (rather than its unfolded length) must be used when calculating its weight. The element diameters have been increased to allow for mounting so the weights given represent the weights of the actual elements.

Table 3.6.7-1 is the lens specification data from which inputs to the weight analysis computer program were taken.

Table 3.6.7-2 is a computer print out of the glass weights, except the window. In order to allow for mounting the elements, the actaul clear apertures have been increased. The resultant element diameters are larger than the clear apertures by 0.4 inches for the window and objective lens, 0.26 inches for the power changer and field corrector, 0.16 inches for the zoom relay, and 0.10 inches for the eyepiece.

The BK-7 window estimated weight is 3.856 lbs. The two (2) external CER-VIT mirrors will weigh 22.111 lbs., and the internal CER-VIT folding mirror is 0.52 lbs.

Summation:

Total weight of glass elements, excluding the window	24. 269 lbs.
BK-7 window	3. 856 lbs.
Two (2) external mirrors	22. 111 lbs.
Internal folding mirror	0. 520 lbs.
Total weight of optical elements	50. 756 lbs.

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DESIGN SPECIFICATION SHEET

Element Number	Surface Number	Radius	Radius Tolerance	Thickness	Thickness Tolerance	Airspace	Airspace Tolerance	Clear Aperture	n*	v**	Glass Type & Melt
DESIGN NO. 67-015	1	40.1302		1.3544				10.00	1.62041	60.33	SK-16
	2	-18.4179				0.2030		9.98			
	3	-17.8183		0.6000				9.84	1.61340	44.30	KzFSN-4
	4	273.6105				28.8180		9.73			
DES GN NO. 67-0064	5	-8.9940		0.3613				2.79	1.62041	60.33	SK-16
	6	10.7028				0.0200		2.79			
	7	7.6130		0.2934				2.80	1.62004	36.37	F-2
	8	486.4318				13.9069		2.79			
	9	∞				10.0873		2.06			
	10	-5.4627		0.4468				3.28	1.62041	60.33	SK-16
	11	-3.1057				0.1337		3.35			
	12	-3.0157		0.4516				3.32	1.62004	36.37	F-2
	13	-6.7970				0.0200		3.55			
	14	11.9795		0.5711				3.63	1.62041	60.33	SK-16
	15	-18.5349				12.0696		3.63			
DESIGN NO. 67-015	16	∞		9.1391 Unfolded				2.22	1.51680	64.17	BK-7
	17	∞				0.1017		1.55			
	18	2.2310		0.2391				1.53	1.51680	64.17	BK-7
	19	2.2002				0.7916		1.46			

SYSTEM: 67-0075 **UNIT:** Inch

APPROVED: E. Hagerott **LENS DESIGNER** **DATE:** 6/22/67
R. Hilbert 6/22/67
R. Wientzen 6/22/67

* n = refractive index at 5876 Angstrom units

** v = reciprocal dispersive power at 5876 Å

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Table 3.6.7-1 Lens Specification Data

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DESIGN NO. 67-0075

Element Number	Surface Number	Radius	Radius Tolerance	Thickness	Thickness Tolerance	Airspace	Airspace Tolerance	Clear Aperture	n*	v**	Glass Type & Melt
	20	∞		0.2000				1.36	1.51680	64.17	BK-7
	21	∞				0.3229		1.37			Reticle
	22	2.5493		0.3959				1.39	1.62041	60.33	SK-16
	23	-1.8689				0.0837		1.36			
	24	-1.3669		0.2310				1.33	1.68893	31.18	SF-8
	25	1.3808		0.4500		0.2274	High	1.35	1.62041	60.33	SK-16
	26	-2.2523				0.5215	Mid	1.37			
	27	2.9031		0.3200		0.9993	Low	1.09	1.51680	64.17	BK-7
	28	-1.4431				0.3750		1.05			
	29	-0.6161		0.3996		0.3342	High	0.66	1.62004	36.37	F-2
	30	-0.8979				1.1384	Mid	0.67			
	31	1.7353		0.3246		1.3933	Low	0.75	1.51680	64.17	BK-7
	32	-0.8258				0.0500		0.79			
	33	-0.7985		0.3933		1.8578	High	0.78	1.62004	36.37	F-2
	34	-3.4038				0.7597	Mid	0.91			
	35	1.7311		0.2072		0.0266	Low	0.98	1.62004	36.37	F-2
	36	1.0715				0.3178		0.98			
	37	1.2965		0.3000				1.18	1.62041	60.33	SK-16
	38	5.4668				0.1500		1.18			

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SYSTEM: 67-0075 **UNIT:** Inch

APPROVED: E. Hagerott **LENS DESIGNER** **DATE:** 6/22/67

R. Hilbert 6/22/67

R. Wientzen 6/22/67

* n = refractive index at 5876 Angstrom units

** v = reciprocal dispersive power at 5876 Å

Table 3.6.7-1 Continued

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Element Number	Surface Number	Radius	Radius Tolerance	Thickness	Thickness Tolerance	Airspace	Airspace Tolerance	Clear Aperture	n*	v**	Glass Type & Melt
	39	∞ Filter		0.1700				1.18	1.51680	64.17	BK-7
DESIGN NO 67-0075	40	∞				0.1500		1.18			
	41	-1.9993		0.2001				1.18	1.51680	64.17	BK-7
	42	-4.1623				1.0426		1.24			
	43	∞				0.2000		1.50			Image Plane
	44	-7.4978		0.1670				1.54	1.68893	31.18	SF-8
	45	1.1851		0.7560				1.67	1.62041	60.33	SK-16
	46	-1.7750				0.7504		1.74			
	47	2.1978		0.2100				1.78	1.64831	33.84	SF-12
	48	1.1552		0.5880				1.67	1.62041	60.33	SK-16
	49	-30.2177				0.0150		1.61			
	50	0.9348		0.5000				1.44	1.62041	60.33	SK-16
	51	-11.9989		0.1490				1.29	1.68893	31.18	SF-8
	52	1.3461				0.7716		1.02			
	53										Eye Point

SYSTEM: 67-0075 **UNIT:** Inch

APPROVED: E. Hagerott **LENS DESIGNER** **DATE:** 6/22/67

R. Hilbert 6/22/67

R. Wientzen 6/22/67

* n = refractive index at 5876 Angstrom units

** v = reciprocal dispersive power at 5876 Å

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Table 3.6.7-1 Continued

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WEIGHT ANALYSIS

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.6 FYE PFL

ID HIPOW PJN 9300.62 DAT

	ELEMENT	SPECIFIC GRAVITY	BOUNDING SURFACES	WEIGHT	SUBWEIGHT
Objective	1	3.610	1 2	8.942 LBS.	
	2	3.200	3 4	9.965 LBS.	
Power Changer	3	3.610	5 6	.458 LBS.	
	4	3.600	7 8	.207 LBS.	
	5	3.610	10 11	.399 LBS.	
	6	3.600	12 13	.900 LBS.	
	7	3.610	14 15	.682 LBS.	
Pechan	8	2.510	16 17	1.525 LBS. (Adjusted from unfolded weight to actual weight.)	
Field Corrector	9	2.510	18 19	.052 LBS.	
ZOOM Relay	10	2.510	20 21	.034 LBS.	
	11	3.610	22 23	.069 LBS.	
	12	4.210	24 25	.139 LBS.	
	13	3.610	25 26	.047 LBS.	
			WEIGHT OF CEMENTED ELEMENTS		.186 LBS.
	14	2.510	27 28	.023 LBS.	
	15	3.600	29 30	.027 LBS.	
	16	2.510	31 32	.013 LBS.	
	17	3.600	33 34	.044 LBS.	

Table 3.6.7-2

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	18	3.600	35	36	.036 LBS.	
	19	3.610	37	38	.041 LBS.	
	20 (Filter)	2.510	39	40	.022 LBS.	
	21	2.510	41	42	.032 LBS.	
Eyepiece	22	4.210	44	45	.135 LBS.	
	23	3.610	45	46	.136 LBS.	
			WEIGHT OF CEMENTED ELEMENTS			.271 LBS.
	24	3.720	47	48	.118 LBS.	
	25	3.610	48	49	.115 LBS.	
			WEIGHT OF CEMENTED ELEMENTS			.233 LBS.
	26	3.610	50	51	.065 LBS.	
	27	4.210	51	52	.042 LBS.	
			WEIGHT OF CEMENTED ELEMENTS			.107 LBS.

<u>TOTAL WEIGHT</u> 24.269 POUNDS

Table 3.6.7-2 (Continued)

3.6.8 Redesign of Power Changer

The preliminary power changer design consisted of BK-7 and F-2 elements. The lens specification data for this preliminary design up to the reticle is presented in Figure 3.6.8-1. Schematic diagrams of the power changer elements are presented in Figures 3.6.8-2, 3.6.8-3, 3.6.8-4. The transverse aberrations at the reticle of the low power objective system with this power changer design are presented in Figure 3.6.8-5 and the corresponding OPD (optical path difference) plots are presented in Figure 3.6.8-6. From Figures 3.6.8-5 and 3.6.8-6, it is seen that this design has approximately 1/2 λ of zonal spherical aberration.

It was then decided to see if this zonal spherical aberration could be reduced by replacing the BK-7 elements with a higher index glass, namely SK-16. The lens specification data for this new and final design is presented in Figure 3.6.8-7. Schematic diagrams of the power changer elements are presented in Figures 3.6.8-8, 3.6.8-9, and 3.6.8-10. The transverse aberration plots and the corresponding OPD plots are presented in Figures 3.6.8-11 and 3.6.8-12 respectively. From these figures, it is seen that the zonal spherical aberration has been considerably reduced. This power changer design was thus selected as the final design since a significant improvement in optical performance was achieved.

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DESIGN SPECIFICATION SHEET

Element Number	Surface Number	Radius	Radius Tolerance	Thickness	Thickness Tolerance	Airspace	Airspace Tolerance	Clear Aperture	n*	v**	Glass Type & Melt
1	1	40.1302		1.3544				10.00	1.62041	60.29	SK-16
	2	-18.4179				0.2656		9.98			
2	3	-17.8183		0.6000				9.84	1.61340	44.30	KZFSN-4
	4	273.6105				31.6880		9.73			
3	5	-8.0563		0.3613				2.54	1.51680	64.20	BK-7
	6	6.7968				0.0200		2.53			
4	7	5.8369		0.2934				2.54	1.62004	36.34	F-2
	8	28.5434				11.6526		2.53			
Stop	9	∞				9.5665		1.96			
5	10	-8.0824		0.4468				3.25	1.51680	64.20	BK-7
	11	-4.0433				0.1337		3.31			
6	12	-3.5512		0.4516				3.30	1.62004	36.34	F-2
	13	-8.7150				0.0200		3.52			
7	14	16.4098		0.5711				3.60	1.51680	64.20	BK-7
	15	-7.1704				11.9748		3.63			
8	16	∞		9.1391				2.21	1.51680	64.20	BK-7
	17	∞				0.1017		1.54			
9	18	2.2310		0.2391				1.51	1.51680	64.20	BK-7
	19	2.2002				0.9208		1.44			

SYSTEM: 67-024-T04-A1
9300 Power Changer **UNIT:** Inches

APPROVED: E. Hagerott **LENS DESIGNER DATE:**

APPROVED: **PROJ ENGINEER DATE:**

*** n = refractive index at** 5876 **Angstrom units**

**** v = reciprocal dispersive power at** 5876 **Å**

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Figure 3.6.8-1 DESIGN DATA OF 9300 LOW POWER OBJECTIVE LENS SYSTEM

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DESIGN [illegible]CATION SHEET

Element Number	Surface Number	Radius	Radius Tolerance	Thickness	Thickness Tolerance	Airspace	Airspace Tolerance	Clear Aperture	n*	v**	Glass Type & Melt
10	20	∞		0.2000				1.34	1.51680	64.20	BK-7

SYSTEM: 67-024-T04-A1
9300 Power Changer

UNIT: Inches

APPROVED: E. Hagerott **LENS DESIGNER DATE:** ________

APPROVED: ________ **PROJ ENGINEER DATE:** ________

*** n = refractive index at ______ Angstrom units**

**** v = reciprocal dispersive power at ______ Å**

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Figure 3.6.8-1 CONTINUED

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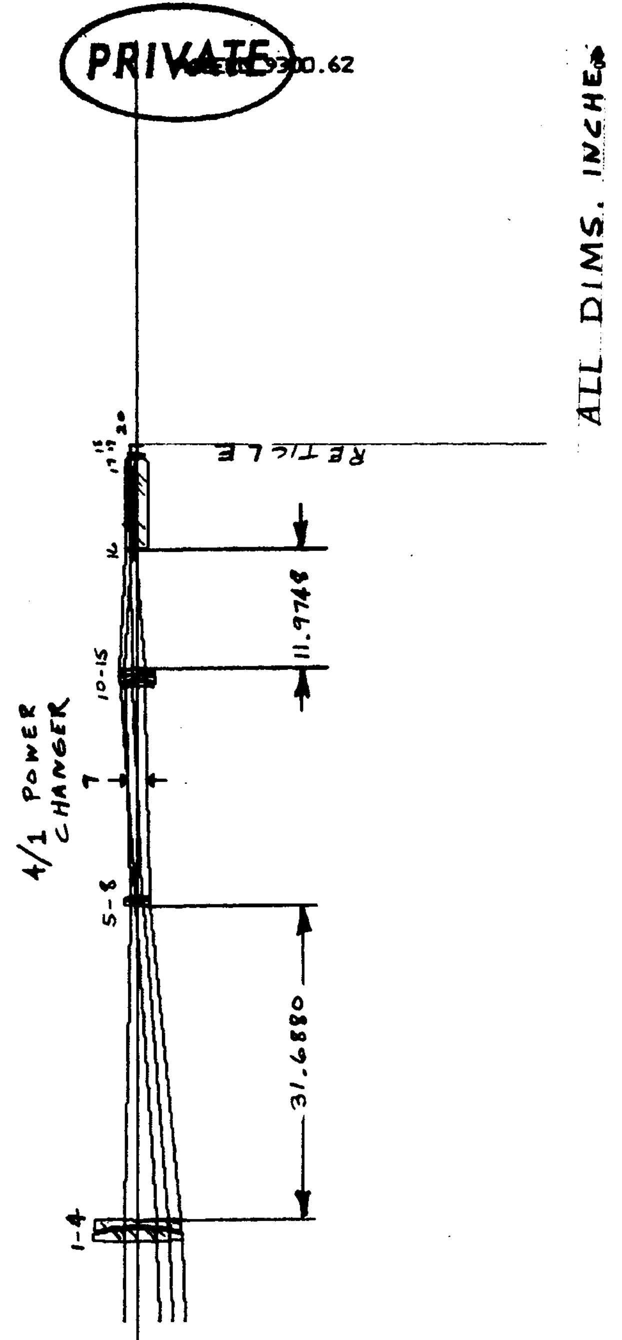

Figure 3.6.8-2 . 9300 LOW POWER OBJECTIVE LENS SYSTEM

SCALE FACTOR = .062500

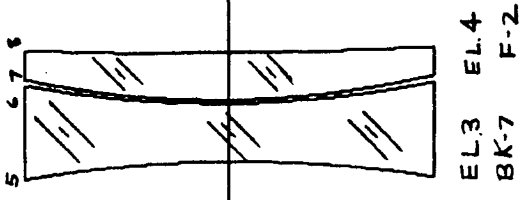

Figure 3.6.8-3 FIRST LENS GROUP OF POWER CHANGER

SCALE FACTOR = 1.000000

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02/26/67

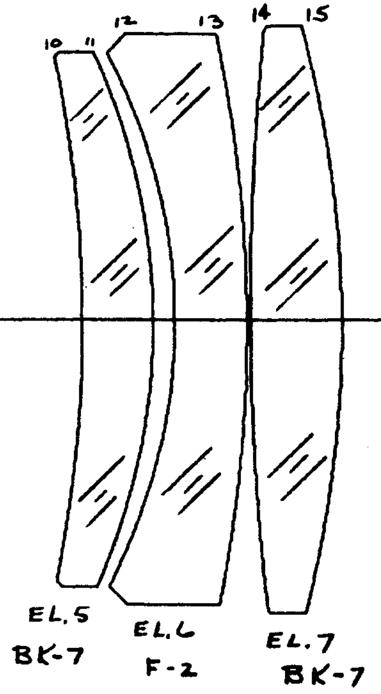

Figure 3.6.8-4 SECOND LENS GROUP OF POWER CHANGER

SCALE FACTOR = 1.000000

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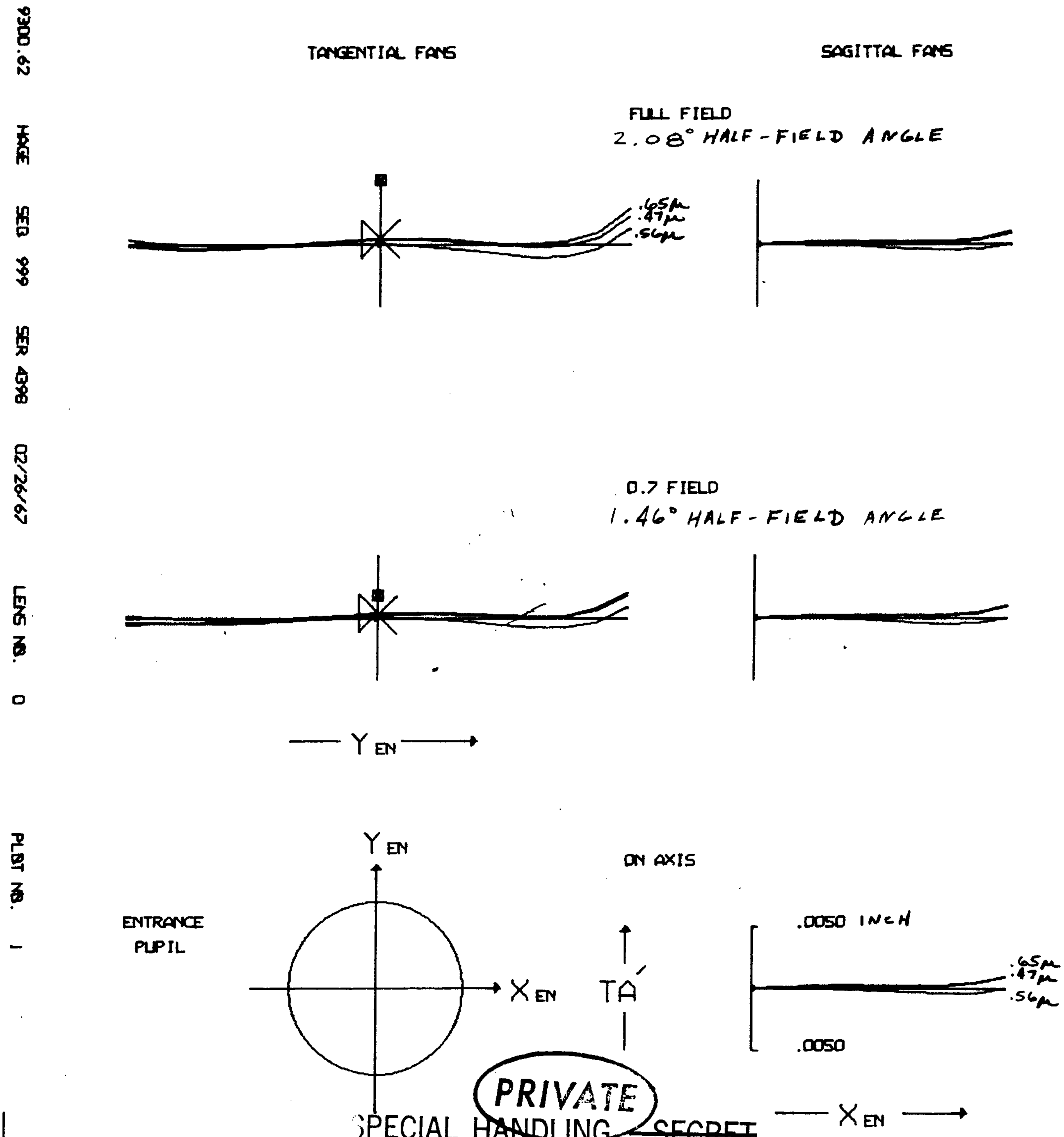

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RAY TRACE (TA = TRANSVERSE ABERRATION)

Figure 3.6.8-5 TRANSVERSE ABERRATION PLOTS AT RETICLE FOR 15.88 X CASE

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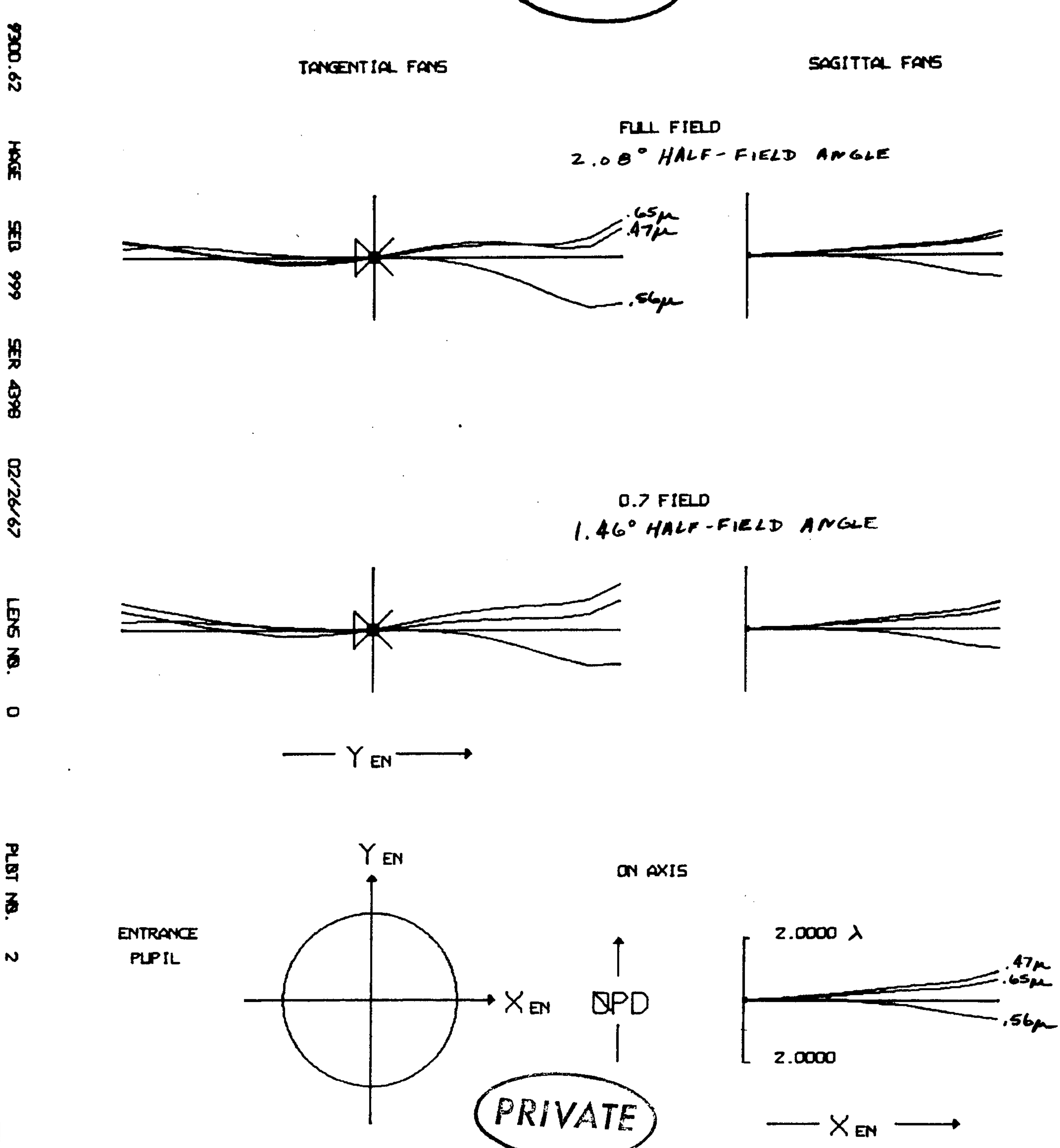

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RAY TRACE (OPD - OPTICAL PATH DIFFERENCE)

Figure 3.6.8-6 OPD PLOTS AT RETICLE FOR 15.88 X CASE

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DESIGN SPECIFICATION SHEET

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Element Number	Surface Number	Radius	Radius Tolerance	Thickness	Thickness Tolerance	Airspace	Airspace Tolerance	Clear Aperture	n*	v**	Glass Type & Melt
1	1	40.1302		1.3544				10.00	1.62041	60.29	SK-16
	2	-18.4179				.2656		9.98			
2	3	-17.8183		.6000				9.84	1.61340	44.30	KzFSN-4
	4	273.6105				28.8180		9.73			
3	5	- 8.9940		.3613				2.78	1.62041	60.29	SK-16
	6	10.7028				.0200		2.78			
4	7	7.6130		.2934				2.79	1.62004	36.34	F-2
	8	48 6.4318				13.9070		2.78			
STOP	9	∞				10.0873		2.05			
[illegible]	10	- 5.4627		.4468				3.27	1.62041	60.29	SK-16
	11	- 3.1057				.1337		3.34			
6	12	- 3.0157		.4516				3.31	1.62004	36.34	F-2
	13	- 6.7970				.0200		3.54			
7	14	11.9795		.5711				3.62	1.62041	60.29	SK-16
	15	-18.5349				12.0696		3.62			
8	16	∞		9.1391				2.22	1.51680	64.20	BK-7
	17	∞				.1017		1.54			
9	18	2.2310		.2391				1.51	1.51680	64.20	BK-7
	19	2.2002				.7906		1.44			

← Redesigned Power Changer

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SYSTEM: 9300 Power Changer **UNIT:** Inches

APPROVED: R. Cuntz **LENS DESIGNER DATE:** 5/19/67

APPROVED: ______ **PROJ ENGINEER DATE:** ______

*** n = refractive index at** 5876 **Angstrom units**

**** v = reciprocal dispersive power at** 5876 **Å**

Figure 3.6.8-7 Redesign of the Power Changer

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DESIGN SPECIFICATION SHEET

Element Number	Surface Number	Radius	Radius Tolerance	Thickness	Thickness Tolerance	Airspace	Airspace Tolerance	Clear Aperture	n*	v**	Glass Type & Melt
10	20			.200				1.35	1.51680	64.20	BK-7

SYSTEM: 9300 Power Changer **UNIT:** Inches

APPROVED: R. Wientzen **LENS DESIGNER DATE:** 5/14/67

APPROVED: ________ **PROJ ENGINEER DATE:** ________

*** n = refractive index at** 5876 **Angstrom units**

**** v = reciprocal dispersive power at** 5876 **Å**

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Figure 3.6.8-7 (continued)

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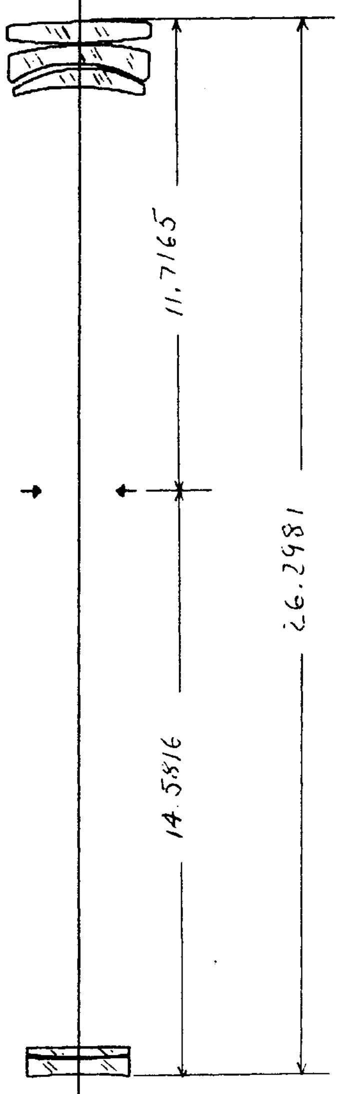

Figure 3.6.8-8 — POWER CHANGER

SCALE FACTOR = .250000

ALL DIMENSIONS IN INCHES

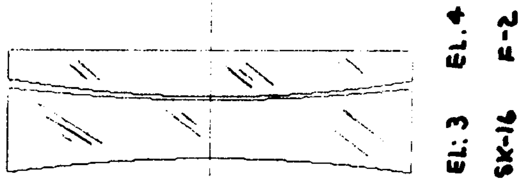

Figure 3.6.8-9 **FIRST LENS GROUP OF POWER CHANGER**

SCALE FACTOR = 1 000000

3.6-126

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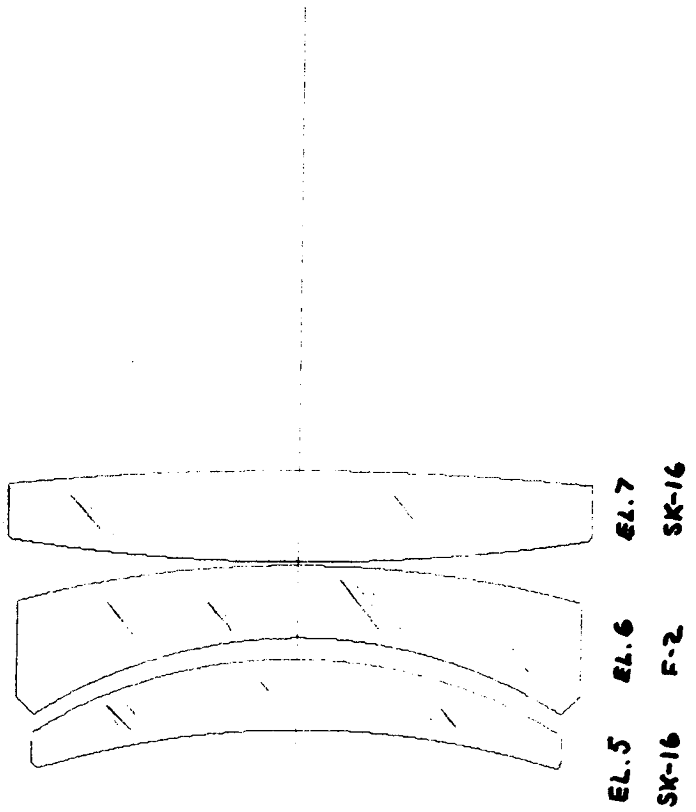

Figure 3.6.8-10 SECOND LENS GROUP OF POWER CHANGER

SCALE FACTOR - 1.000000

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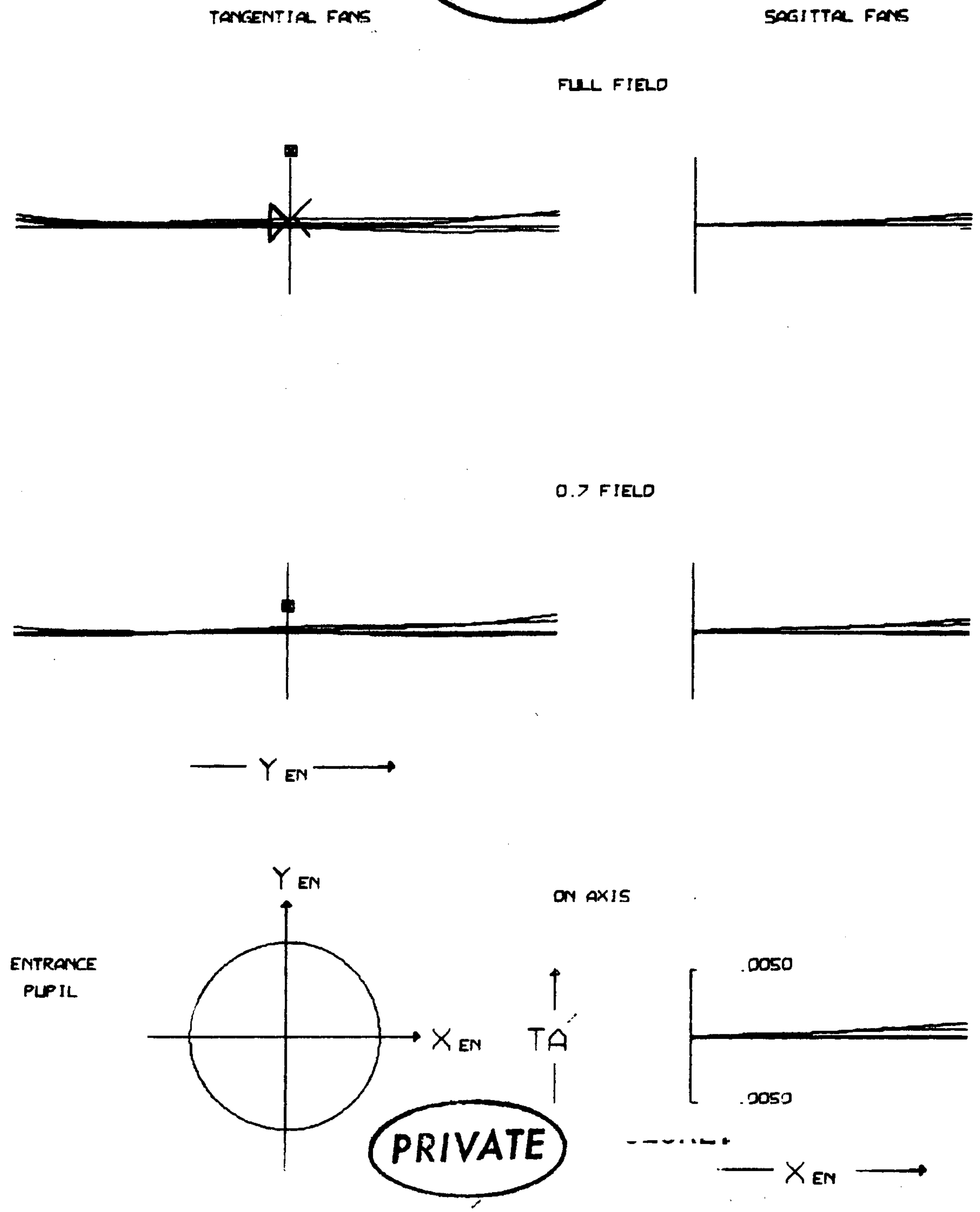
15.88 X

PRIVATE



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RAY TRACE (TA' - TRANSVERSE ABERRATION)

Figure 3.6.8-11 - Power Changer at Reticle

15.88 X

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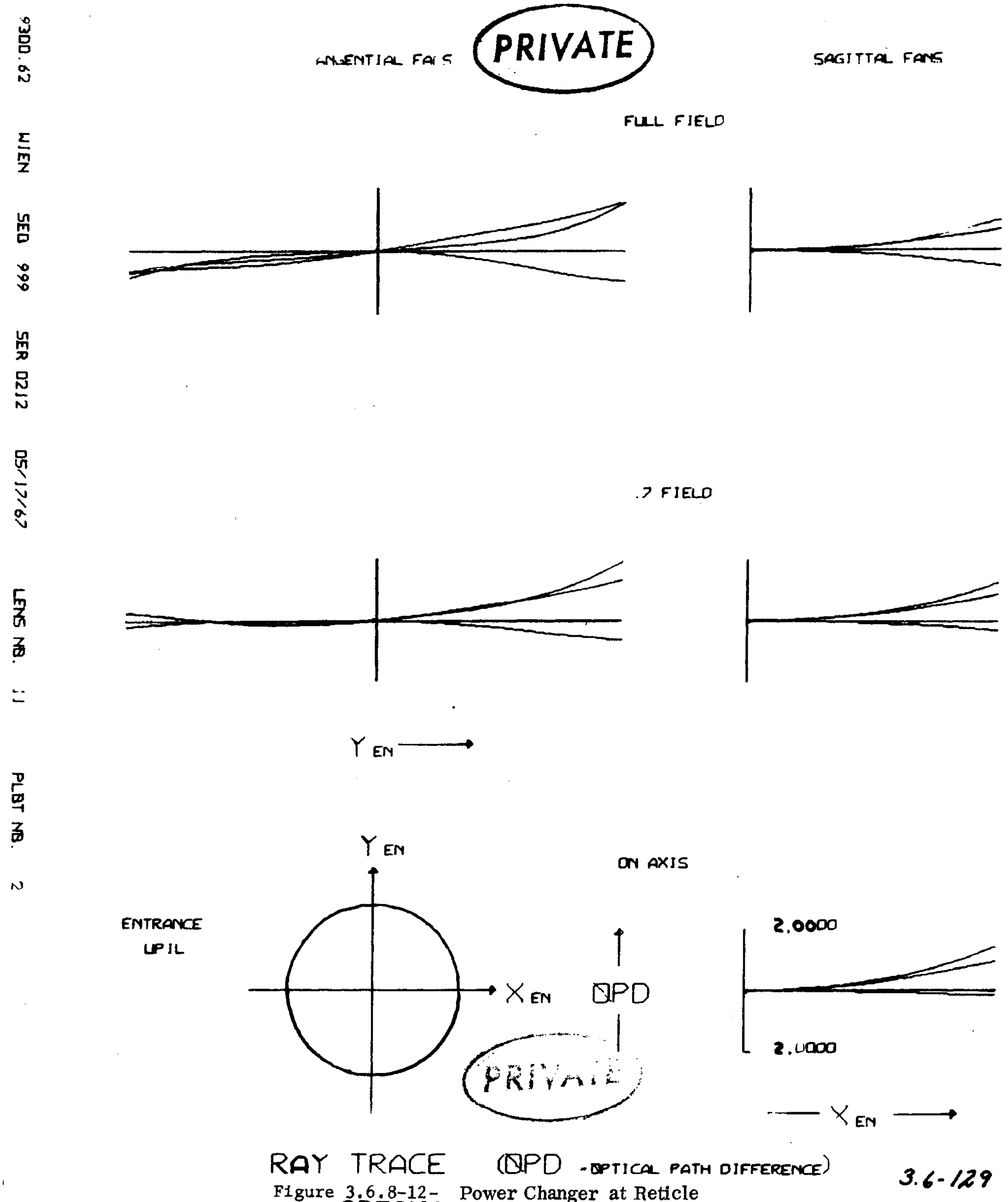


Figure 3.6.8-12- Power Changer at Reticle

3.6.9 Interior Optical-Environmental Considerations

Several thermo-optical analyses are being conducted in order to ensure optimum system performance. Dimensions that are critical to image quality are being developed to minimize the adverse influences of residual thermal soaks and shocks, axial and radial gradients, pressure shifts, dynamic loading, and thermally induced tube bending within the required temperature range. Although the specific effects of these loadings vary, in general, they consist of perturbations in thickness, airspaces, indicies of refraction of both lenses and the surrounding medium, radii of curvature, surface regularity, and structural geometry and shape, each of which may contribute to degraded performance.

De-sensitization of image quality and position as a result of the environmental perturbations is being accomplished by combining materials which are dimensionally self-compensating when subjected to environmental changes. Improved performance, lower weight, and reduced cost are realized by using this technique rather than servo-mechanical provisions for refocussing.

The different environments anticipated during a mission occasionally suggest optical materials with conflicting response characteristics. In fact,in a single environment entirely different sets of materials are often required in order to control the various aberrations that are peculiar to all optical systems. The resultant trade-offs between materials is a problem in optimization which is being accomplished with the aid of Itek developed thermo-optical computer design programs.

The final material selections will be made jointly by the structural, optical, and mechanical engineers on the basis of image quality, manufacturing tolerances, and thermal control requirements.

The operating environment must be accurately known in three dimensions if the proper compensating materials are to be selected and the system made athermal. A heat balance analysis in which optical components have been approximated by a series of nodes connected by conduction and direct and reflected radiation has produced the desired time-temperature histories. The analyses have included the effects of port cover and associated electronics, and have utilized additional Itek computer programs which calculate heat fluxes and vehicle temperatures as well as geometric and reflecting radiation view factors.

Thermal analyses have indicated that on several elements (Ref. 3.7.6.2.3.1 and 3.10.1.5.2.2.1) axial gradients are non-linear and that symmetric or non-rotationally symmetric radial gradients exist. These suggest either frame or finite element structural models to numerically predict deflected shapes. In all cases, support conditions have been and will be accurately simulated, and index gradients computed.

A sufficient number of real rays is then traced to accurately predict resulting changes in optical path difference and RMS wavefront errors so that allowance can be made for the cascade of these local component effects with the perturbation of overall system growth, to obtain the total image quality degradation. The component effects available are discussed in Sections 3.7 to 3.10.

It should be noted that rotationally symmetric and linear lateral (cf. Figure 3.6.9-1) isotherms produce defocussing and boresight errors respectively. Although either of

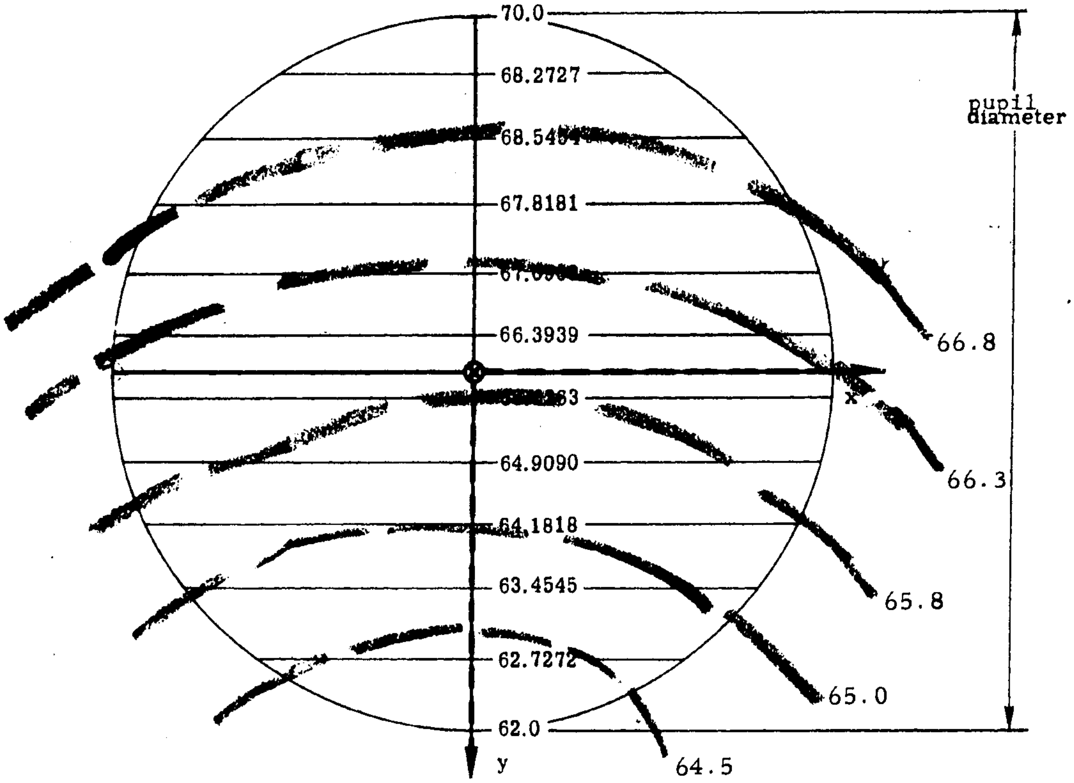


Figure 3.6.9-1. Linear Lateral Thermal Gradient, Temperature in °F For Use in Demonstration of Boresight Error. Solid Lines.

Typical Thermal Perturbation in °F For Demonstration Purposes. Dotted Lines.

these can be important in photogrametric applications, their effects may be calibrated out without great difficulty (cf. Figure 3.6.9-2). Gradients which differ from either of these symmetries, however, have effects which are not easily eliminated (cf. Figures 3.6.9-1 and 3.6.9-3) either mathematically or by a viewer in real time. Additionally, any distortion in the reseau will compound the calibration problem. For this reason every effort will be made to obtain symmetric loadings, and predicted isotherm shapes will be carefully evaluated.

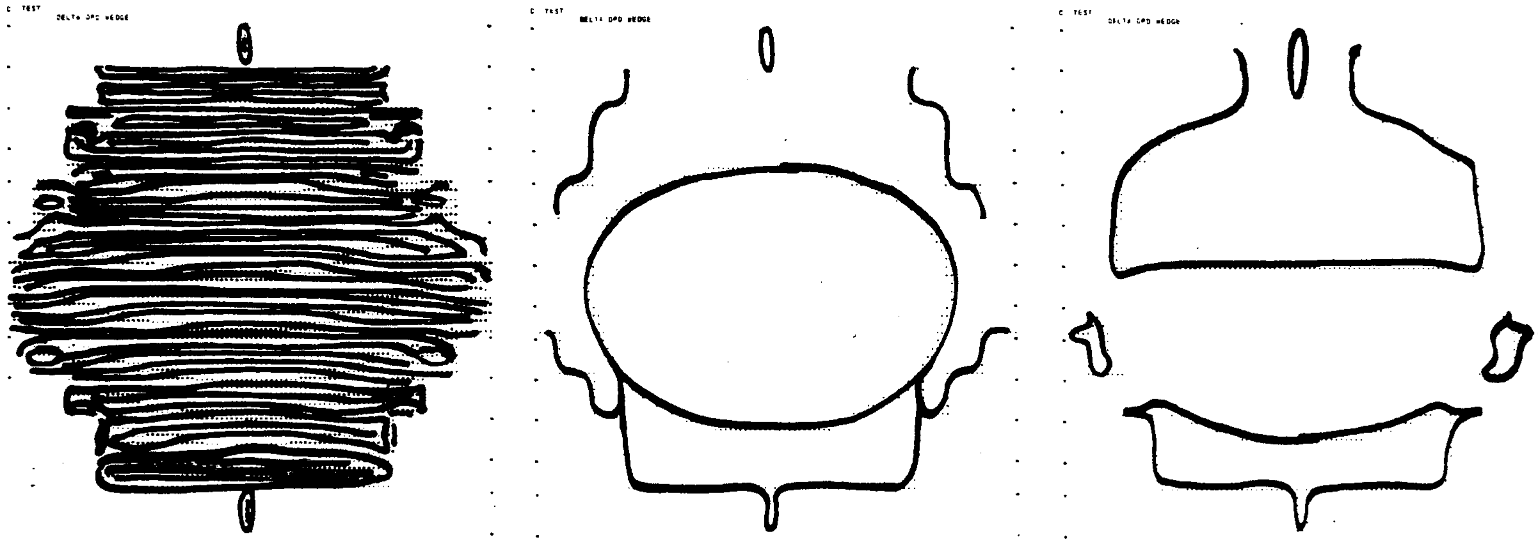
Several preliminary analyses of the proposed A O telescope system have been performed assuming four different cell materials and a uniform temperature soak of $-10^{\circ}F$ (i.e. from $21.\dot{1}^{\circ}C$ to $15.\dot{6}^{\circ}C$).

The four cell materials chosen were steel ($\alpha = 14.25 \times 10^{-6}/^{\circ}C$), aluminum ($\alpha = 24.0 \times 10^{-6}/^{\circ}C$), beryllium ($\alpha = 12.3 \times 10^{-6}/^{\circ}C$) and Invar ($\alpha = 1.5 \times 10^{-6}/^{\circ}C$) in order to evaluate a wide expansion coefficient range. Results are shown in Table 3.6.9-1 It is apparent that the material selection must be carefully considered in order to minimize the aberrations. Although a sufficient number of analyses have not been performed to permit final selection (i.e. the most recent mounting techniques must be evaluated and several temperatures remain to be predicted), it is probable that aluminum is the best choice from a self-compensation point of view.

RMS = 1/3 λ

RMS = 1/116λ

RMS = 1/296λ



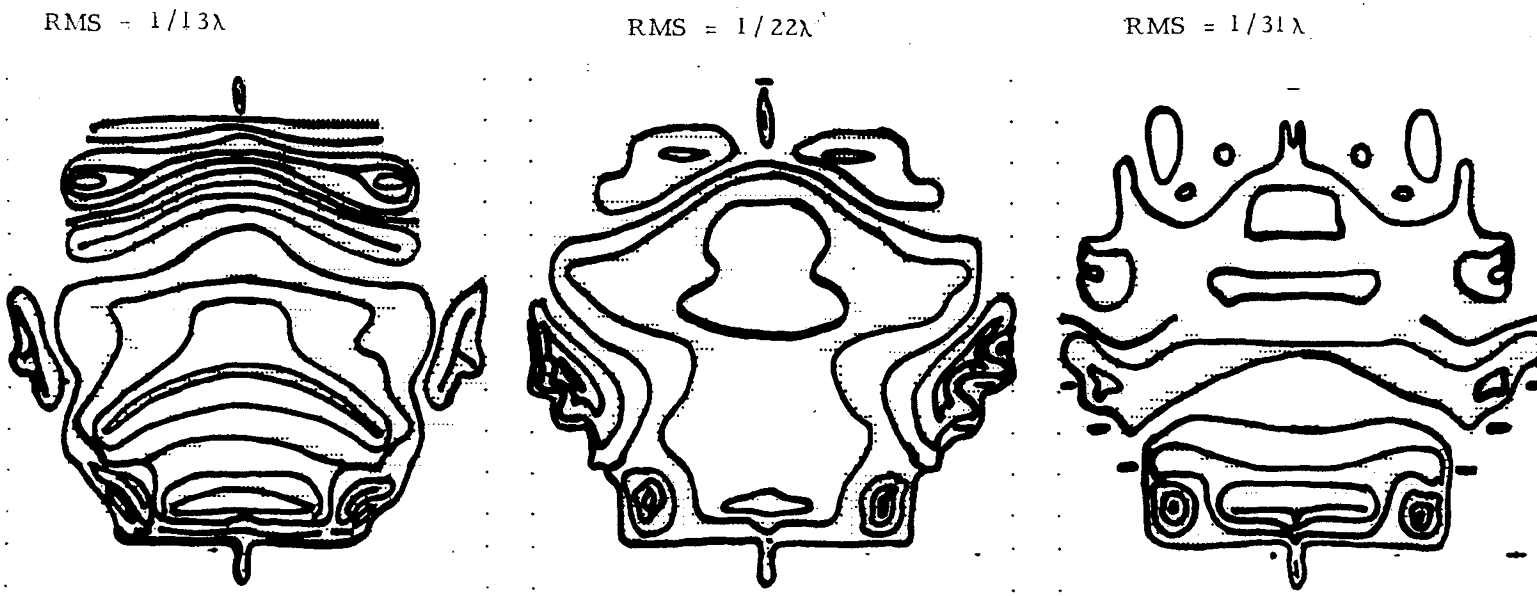
0.02 Wavelength contour plot of the thermally perturbed wavefront emerging from a lens under a linear lateral thermal gradient.

0.02 Wavelength contour plot of the thermally perturbed wavefront emerging from a lens under a linear lateral thermal gradient. Boresight error eliminated.

0.02 Wavelength contour plot of the thermally perturbed wavefront emerging from a lens under a linear lateral thermal gradient. Boresight error and defocusing eliminated.

Figure 3.6.9-2

Demonstration of Boresight Error



0.02 Wavelength contour plot of a typical thermally perturbed wavefront emerging from a lens.

0.02 Wavelength contour plot of a typical thermally perturbed wavefront emerging from a lens Boresight error eliminated.

0.02 Wavelength contour plot of a typical thermally perturbed wavefront emerging from a lens Boresight error and defocusing eliminated.

Figure 3.6.9-3

Typical Wavefront Contour Plots

TABLE 3.6.9-1

Effects of Uniform Temperature Soak from 21.1°C to 15.6°C on A/O Telescope *

Defocussing of both Reticle and Object Expressed in Diopters. Standard Convention, Nominal System in Focus

Power	Material Type	Object Defocus	Reticle Defocus	Difference between Object and Reticle Defocus
127	Aluminum	+ 0.06	+ 0.11	- 0.05
	Stainless Steel	- 0.35	+ 0.10	- 0.45
	Beryllium	- 0.43	+ 0.10	- 0.53
	Invar	- 0.90	+ 0.10	+ 0.17
31.75	Aluminum	+ 0.02	0.00	+ 0.02
	Stainless Steel	+ 0.01	0.00	+ 0.01
	Beryllium	+ 0.01	0.00	+0.01
	Invar	0.00	- 0.01	+ 0.01

*Pressure is constant in all cases. Lenses are mounted directly off the tube with no substructure employed for preliminary design. Values apply at $\lambda = 5600$ Å.

Table 3.6.9-2 indicates that even though the beryllium system is essentially compensated at both 70°F and 64°F, aluminum still has over four times the allowable temperature range, based upon uniform soaks and a 0.12 diopter object-reticle defocussing difference criterion. The possibility of selecting additional compensating materials for a predominantly beryllium system is presently unknown. A design study to determine the value of such an approach will be initiated.

Table 3.6.9-3 indicates that the system must have both the reticle and eyepiece set out of focus prior to the mission to compensate for temperature changes. The required defocussings to compensate for pressure changes will be determined.

TABLE 3.6.9-2

Effects of Differing Uniform Temperature Soaks from 70°F ($21.\dot{1}$°C) on A O Telescope with Simple Beryllium Tube *

Defocussing Expressed in Diopters as in Table 3.6.9-1

Temperature Change (°F)	Object Defocus	Reticle Defocus	Difference between Object and Reticle Defocus
- 10°	- 0.43	+ 0.10	- 0.53
$- 6.\dot{6}$	- 0.12	+ 0.06	- 0.18 **
$- 3.\dot{3}$	+0.19	+ 0.02	+ 0.17 **

---

* Pressure is constant in all cases. Values apply at $\lambda = 5600\ \text{Å}$, 127X.

** Note that this function goes through zero at both 70°F and 64°F, and therefore, a double tolernace on temperature (e.g. 70°F ± 2.35°F, 64°F ± 2.35°F) is given in the text for Beryllium. Aluminum's range is much larger (70°F ± 24°F) and so only a single tolerance is given (Tolerances based upon 0.12 diopters assumed allowable Object vs. Reticle defocus for trained observers.)

TABLE 3.6.9-3

Effects of a Uniform Pressure Drop from 14.7 psi to 5.0 psi

No Structural Deformations Considered

Defocussing of both Reticle and Object Expressed in Diopters

Standard Convention, Nominal System in Focus

Object Defocus	Reticle Defocus	Difference between Object and Reticle Defocus *
- 3.95	- 0.14	- 3.81

* May be focussed out prior to mission. Movements of elements required to obtain this compensation for 5.0 psi will be determined.

Changes in eye relief due to the imposition of the -10°F thermal soaks are in all cases less than 0.1% and are, therefore, felt to be insignificant.

The relative thermal sensitivities of the different elements in the AO telescope have been determined with and without refocussing on axis and at full field at both 127X and 31.75X magnifications. The ordinal representation of these values is presented in Table 3.6.9-4, averaged over field position, and has been used both as a guide in determining areas of interest for thermal study and in checking the validity of extrapolating the effects of a temperature distribution on one component to other lens elements. The order was determined in part by weighting resultant ΔOPD's caused by the curvature, thickness, and index changes which resulted from an imposed uniform temperature soak.

TABLE 3.6.9-4

Thermal Sensitivities of Optical Elements based upon ΔOPD's caused by weighted curvature thickness and index change resulting from a uniform thermal soak. Values shown represent element numbers from most (top) to least (bottom) sensitive, as averaged over Field Height.

Without Refocussing		With Refocussing	
31.75 X	127X	31.75X	127X
6	1	7	1
7	2	3	2
4	17	17	17
8	9	4	25
3	16	6	15
17	15	25	16
11	25	1	18
9	29	16,15	19
1	11	18	20
16	18	8	28
10	19	19	13,26
15	20	20	10
2	13	28	14
25	26	26,13	24
29	22	14	12
18	28	10	29
19	10	2	22
20	24	24	27
13	14	29	9
26	12	22	11,21
12, 22	21	27	23
28	27	12	
24	23		
14			
21			
27			
5, 23			

Thermally induced bending of the telescope tube also degrades performance through the decentration and rotation of the optical elements. The deflected tube shape has recently been calculated for both an aluminum and a beryllium structure under conditions of end restraint which simulates both the case of a simply supported elbow at the shear mount and a fixed objective, and the case where both the shear mount and objective are assumed simply supported. (By using both support conditions, the actual shape will have been bracketed.) Temperature loadings in one system have not yet been defined due to a lack of information concerning the position of the tube with respect to bay electronics; however, several simple 4°F to 10° F linear transverse gradients have been assumed in the interim in order to determine the order of magnitude of the resultant image degradation. The calculation and evaluation of this change in image quality is currently under investigation in both the 127X and 15.88X systems.

3.6.10 Effects of Window and Objective Pressure Differentials

The performance of the A/O optical system was evaluated for three pressure conditions on the window and element No. 1.

The three pressure conditions considered are shown in Figure 3.6.10-1.

3.6.10.1 Analytical Approach

A structural analysis was accomplished to determine the deformation or sag of the optical elements due to the pressure intensities as shown in Figure 3.6.10-1. The resultant axial displacments of the surfaces at specific locations (nodal points) was expressed in a coordinate-axis system.

A 10th order polynomial equation was fitted to the sag data over the clear aperture and study conducted on the CDC-3300 computer to evaluate the optical significance of the imposed pressure conditions on the performance of the A/O system.

3.6.10.2 Structural Evaluation

The window configuration of BK-7 glass, 10.75 inches in diameter, and 0.5 inches thick was analyzed using the conventional two dimensional plate theory. The pressure was assumed to be acting on the 10 inch diameter clear aperture with the window mount configuration as shown in Drawing No. 115202.

Three support conditions were evaluated, fixed edge, simply supported and supported on an elastic foundation (gasket and retaining flange). As one might surmise the clear aperture sag of the window supported on the elastic foundation is esentially the same as the simply supported condition. The main contribution of the elastic foundation is that of allowing about a 5 thousandth air gap change.

The deflection curves for the 5.2 and 4.8 PSI pressure differential are shown in Figures 10.2.3-3 through 10.2.3-10 of the analyses (Addendum 3.6.10-B). The data from these curves was transferred into tabular form and is presented in Table 3.6.10-7. It should be noted that the value of column 4, which is for a 15 PSI differential, was obtained by multiplying the value of column 2 by a factor of 2.88.

The analysis of the objective element was done by Dr. Raab and is presented in Addendum 3.6.10-A. This lens was treated as a simple supported three dimensional elastic solid subjected to the three prescribed pressure intensities. A finite element method of analysis was used, together with a newly activated computer program for symmetric solids.

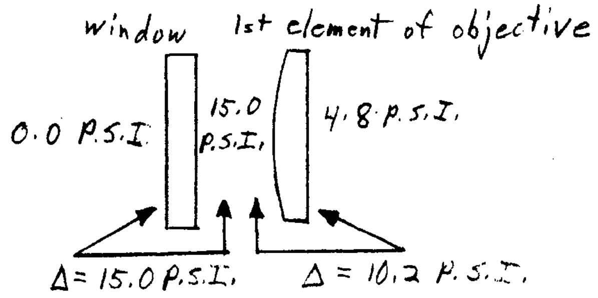
Page 6 of the Addendum presents the output data of the axial and radial displacements. This data was converted into usable sag coordinates as shown in tables 3.6.10-4 through 6.

Tables 3.6.10-2 and -3 are the initial mode coordinates for Element No. 1.

3.6.10.3 Optical Evaluation

This analysis includes the change in index of the air with pressure as well as the physical shape of the surfaces.

Of the three cases shown in Figure 3.6.10-1, the third, which is the worst case, was evaluated. The case is as follows:



The change in the optical path difference caused by the difference in the index of refraction of air in the spaces adjacent

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to the window, and the deflected window shape, is .001 waves. This change in O.P.D. has no measurable effect on the nominal transfer function.

The sag data of element No. 1.,, for this case was fitted to a 10 order polynomial over the aperture.

Surprisingly the 4th order term contributes .012 inches of sag over the clear aperture on the second surface while contributing only .0015 inches sag on the first surface. However, the fit was excellent on both surfaces across the areas used for this analysis.

The 10.2 psi difference between the spaces on either side of the first element of the telescope objective causes that element to deflect in the manner described above. The new shape of the deflected element introduces approximately 1.0 waves of defocusing into the system and approximately 0.08 waves RMS of spherical aberration, while the change in field aberrations is neglibible (Fig. 3 and 4). Thus the degradation is uniform across the field.

Even assuming that the 1.0 waves of defocus are compensated by accommodation of the observer, or refocussing of the eyepiece, the image will still be degraded by the 0.08 RMS of spherical aberration. The effects of this on the transfer function of the complete system at 127X are shown in Figure 5.

If the area between the window and the objective lens is properly vented, only the window would experience a significant pressure load.

The change in the optical path difference (OPD) at the final image of the A/O telescope (with the nominal, flat window included) was calculated for this case, which is when the window has a 5.2 psi pressure differential and an elastic support.

The change in the OPD at the final image in the 127X mode due to the window shift and deflection was calculated on axis and at full field, and was found to be less than 0.001 waves in both cases. This change is negligible and would have no measurable effect on the resolution performance of the A/O telescope.

In conclusion, even though the window deflections for all cases considered do not have a discernible effect on the nominal transfer function, a 10.2 psi difference across the front element of the objective causes 0.08 waves RMS degradation at 127X after defocussing which is intolerable. If required, a 10 psi difference across the front element could be tolerated from the image quality standpoint under severe conditions but the system should not be designed nominally this way. A 0.4 psi difference across the first element would have no discernible effect on the nominal transfer function.

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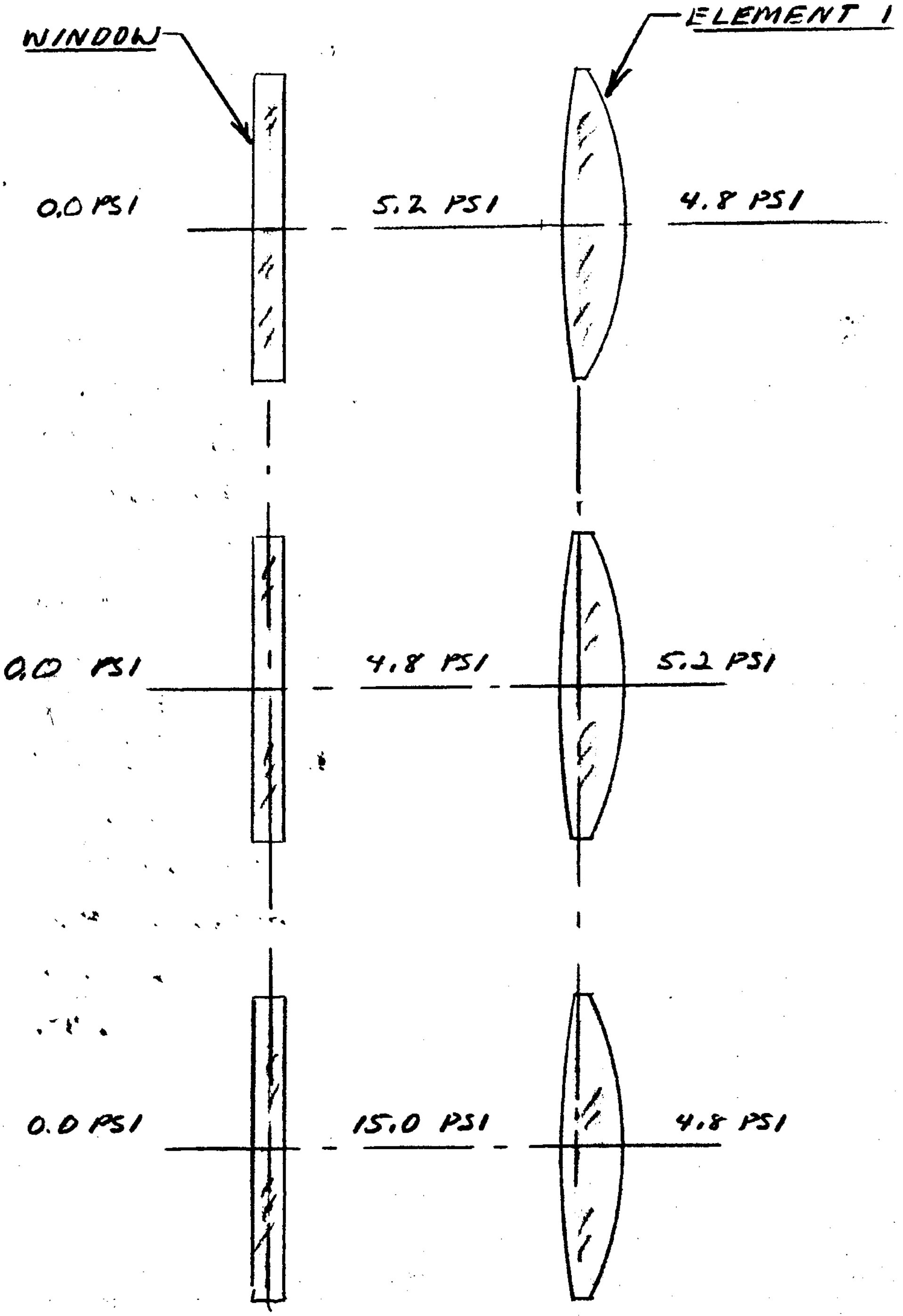

FIGURE 3.6.10-1 WINDOW-ELEMENT PRESSURE CONDITIONS

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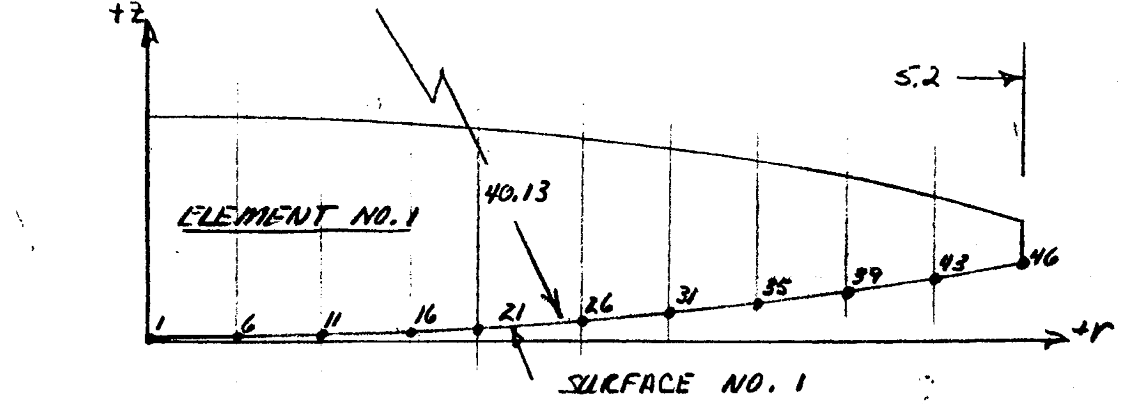
REF. FIGURE 1 AND TABLE 1



EQUATION:

$$z = 40.13 - \sqrt{(40.13)^2 - r^2}$$

TABLE 3.6.10-2 – INITIAL COORDINATES OF SURFACE NUMBER 1

NODAL POINT	INITIAL COORDINATE		
	$r (10^{-6})$ IN	$z (10^{-6})$ IN	
1	0	0	
6	520,000.	3,369.20	
11	1,040,000.	13,478.47	
16	1,560,000.	30,332.92	
21	2,080,000.	53,941.07	
26	2,600,000.	84,314.84	
31	3,120,000.	121,469.66	
35	3,640,000.	165,424.44	
39	4,160,000.	216,201.64	
43	4,680,000.	273,827.33	
46	5,200,000.	338,331.28	

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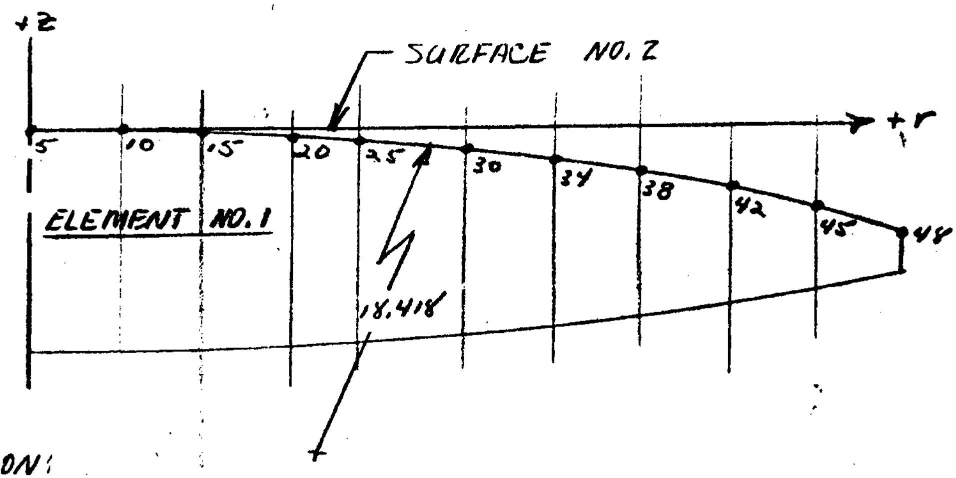

EQUATION:

$$-z = 18.418 - \sqrt{(48.418)^2 - r^2}$$

TABLE 3.6.10-3 ~ INITIAL COORDINATES OF SURFACE NUMBER 2

NODAL POINT	INITIAL COORDINATE		
	r (10⁻⁶) IN.	z (10⁻⁶) IN	
5	0	0	
10	520,000.	- 7,342,11	
15	1,040,000.	-29,386.03	
20	1,560,000.	-66,184.73	
25	2,080,000.	-117,827.22	
30	2,600,000.	-184,439.63	
34	3,120,000.	-266,186.76	
38	3,640,000.	-363,27420	
42	4,160,000.	-475,950.96	
45	4,680,000.	-604,512.87	
48	5,200,000.	-749,306.67	

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REF. TABLE I

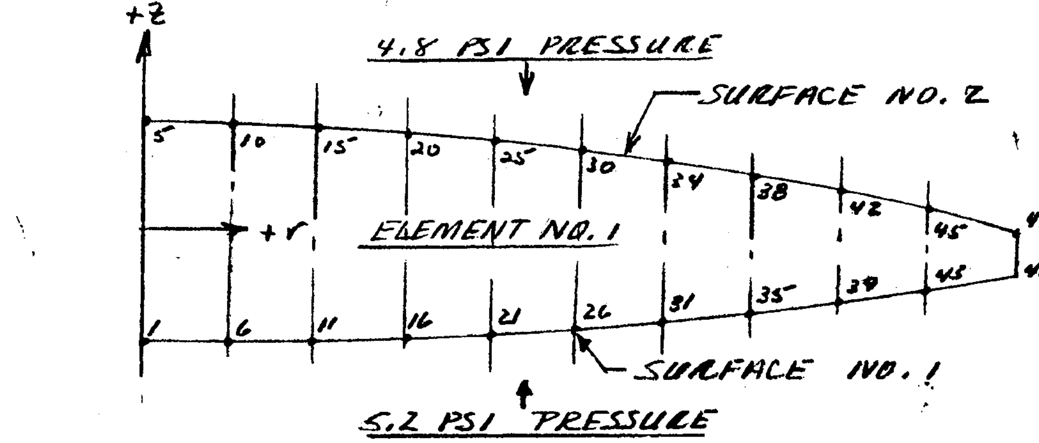

TABLE 3.6.10-4, CASE NO. 1, AXIAL AND RADIALLY COORDINATES OF SURFACE NO. 1 AND 2

NOD. POINT	SURFACE NO. 1 COORDINATE		NOD. POINT	SURFACE NO. 2 COORDINATE	
	r (10⁻⁶) IN	z (10⁻⁶) IN		r (10⁻⁶) IN	z (10⁻⁶) IN
1	0	0	5	0	0
6	519,999.62	3,369.05	10	520,000.24	- 7,342.26
11	1,039,999.26	13,477.94	15	1,040,000.45	- 29,387.16
16	1,559,998.91	30,337.77	20	1,560,000.64	- 166,185.85
21	2,079,998.57	53,939.04	25	2,080,000.80	- 117,829.20
26	2,599,998.27	84,311.65	30	2,600,000.90	- 184,442.78
31	3,119,997.99	121,465.00	34	3,120,000.94	- 266,191.82
35	3,639,997.76	165,417.93	38	3,640,000.90	- 363,280.55
39	4,159,997.60	216,192.83	42	4,160,000.73	- 475,959.56
43	4,679,997.60	273,815.69	45	4,680,000.34	- 604,524.26
46	5,199.997.90	338,316.25	48	5,199,999.62	- 749,321.38

CASE NO. 1

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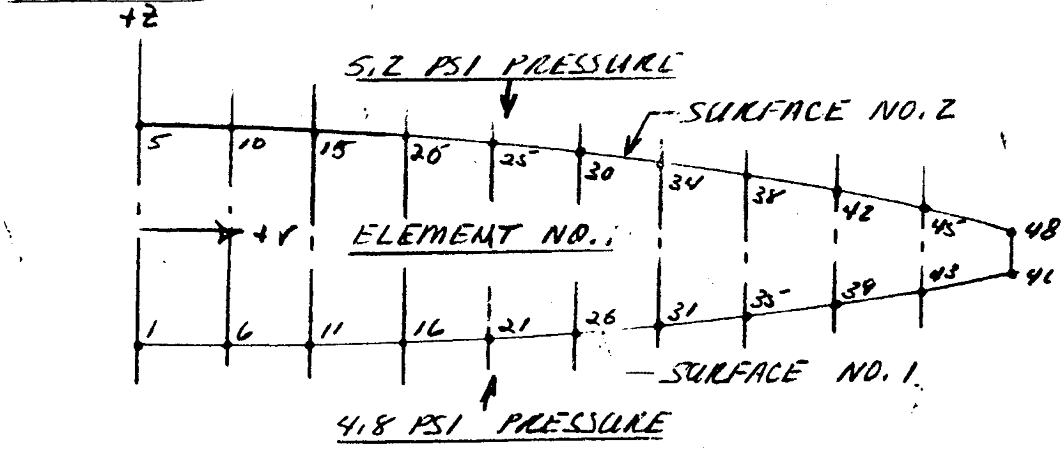

TABLE 3.6.10-5 CASE NO 2, AXIAL AND RADIAL COORDINATES OF SURFACE NO. 1 AND 2

NOD. POINT	SURFACE NO. 1 COORDINATES		NOD POINT	SURFACE NO. 2 COORDINATES	
	r(10⁻⁶) IN.	z (10⁻⁶) IN.		r(10⁻⁶) IN.	z (10⁻⁶) IN.
1	0	0	5	0	0
6	520,000.29	+ 3,369.39	10	519,999.51	− 7,341.92
11	1,040,000.56	+ 13,479.12	15	1,039,999.06	− 29,385.38
16	1,560,000.81	+ 30,384.33	20	1,559,998.65	− 66,183.31
21	2,080,001.05	+ 53,943.56	25	2,079,998.28	−117,824.71
26	2,600,001.26	+ 84,318.74	30	2,599,997.98	−184,435.69
31	3,120,001.43	+121,475.86	34	3,119,997.77	−266,181.00
35	3,640,001.58	+165,432.39	38	3,639,997.68	−363,266.16
39	4,160,001.65	+216,212.39	42	4,159,997.78	−475,940.09
43	4,680,001.58	+273,841.53	45	4,679,998.19	−604,498.51
46	5,200,001.24	+338,349.56	48	5,199,999.11	−749,288.16

CASE NO. 2

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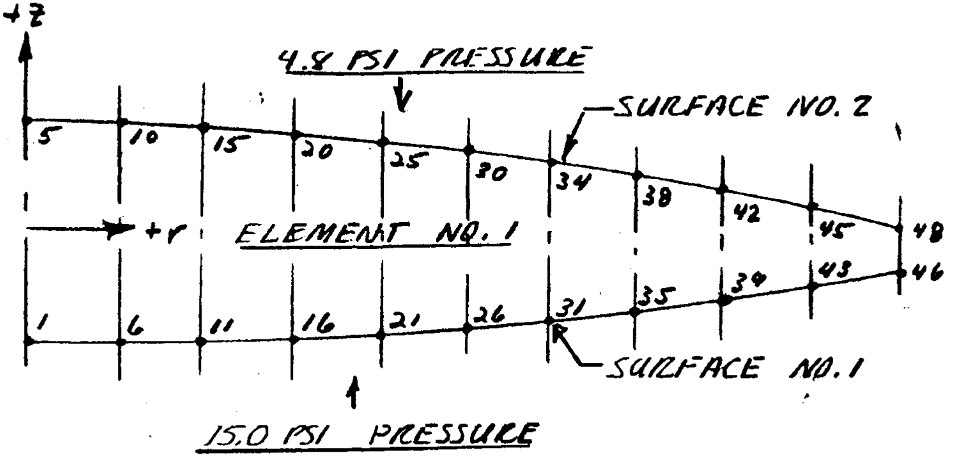

TABLE 3.6.10-6: CASE NO. 3, AXIAL AND RADIAL COORDINATES OF SURFACE NO. 1 AND 2

NOD POINT	SURFACE NO. 1 COORDINATES		NOD. POINT	SURFACE NO. 2 COORDINATES	
	r(10⁻⁶) IN.	z(10⁻⁶) IN.		r(10⁻⁶) IN.	z(10⁻⁶) IN.
1	0	0	5	0	0
6	519,991.28	3,364.89	10	520,009.04	- 6,505.97
11	1,039,983.21	13,463.52	15	1,040,017.24	- 28,560.45
16	1,559,975.45	30,300.53	20	1,560,024.74	- 65,376.45
21	2,079,968.08	53,883.92	25	2,080,031.24	- 117,043.50
26	2,599,961.42	84,225.17	30	2,600,036.22	- 183,688.20
31	3,119,955.60	121,338.54	34	3,120,039.15	- 265,476.62
35	3,639,950.65	165,241.47	38	3,640,039.62	- 363,615.57
39	4,159,947.65	215,954.31	42	4,160,036.12	- 475,356.43
43	4,679,948.51	273,500.44	45	4,680,025.89	- 603,997.79
46	5,199,956.57	337,909.89	48	5,200,005.22	- 749,886.06

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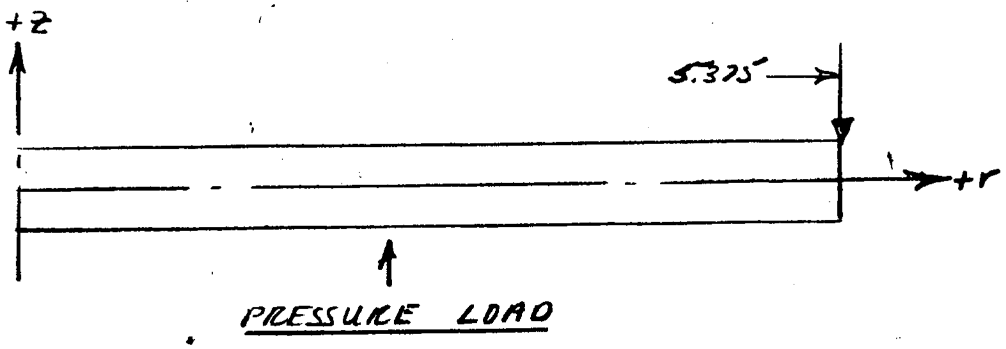
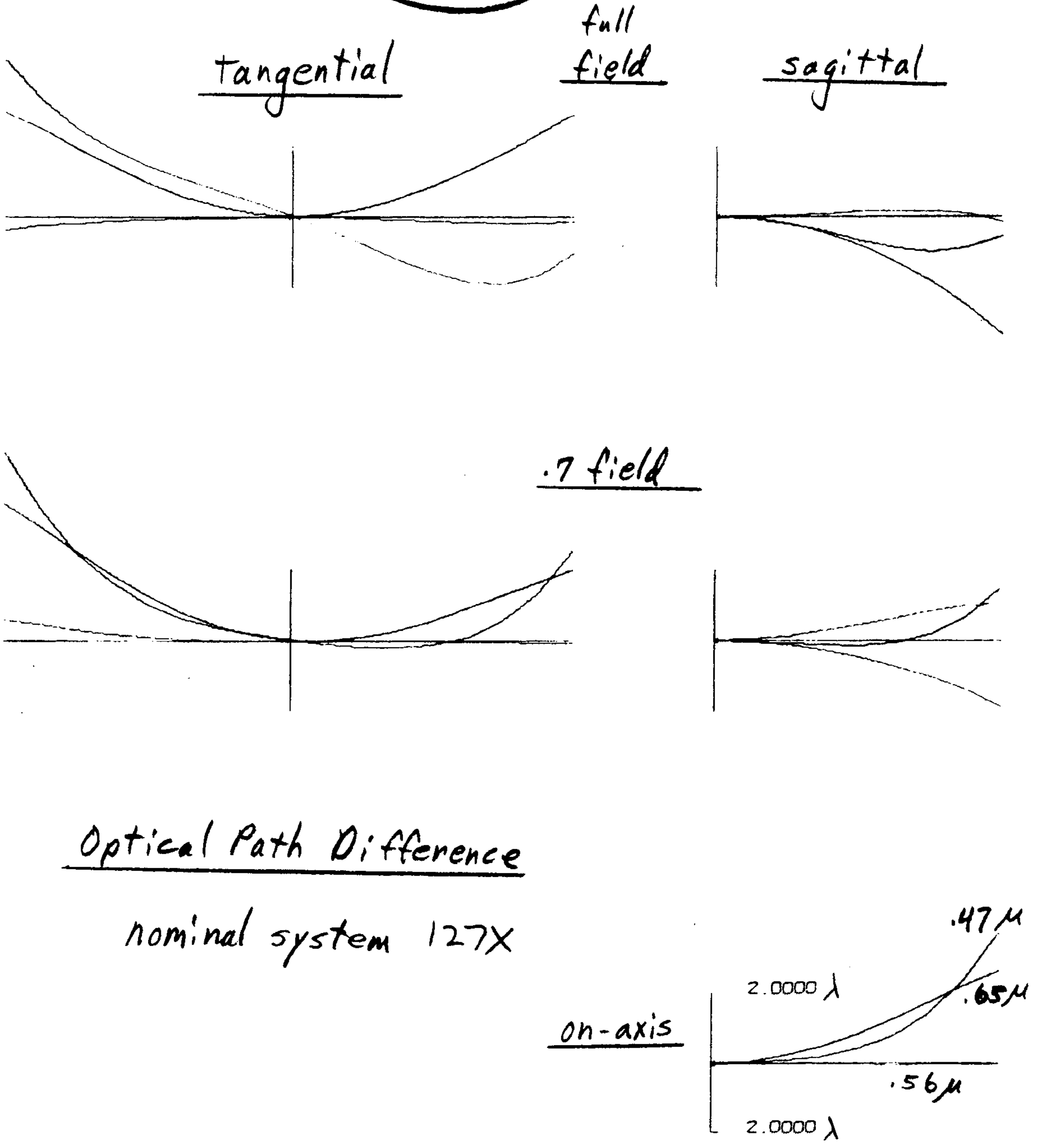


TABLE 3.6.10-7 WINDOW COORDINATES FOR PRESSURE LOADINGS OF 5.2, 4.8, AND 15.0 PSI

①	②	③	④
r	CASE NO. 1 5.2 PSI Z (10^{-6}) IN.	CASE NO. 2 4.8 PSI Z (10^{-6}) IN.	CASE NO. 3 15 PSI Z (10^{-6}) IN.
0	0	0	0
0.25	- 5,99	-5,53	-17,28
0,50	- 23.94	-22,10	- 69.06
0.75	- 53.75	-49,61	-155.05
1.00	- 95,28	-87.95	-274.85
1.50	-212,59	-196,24	-613,24
2,00	- 373,52	-344.78	-1077.49
2.50	- 574,73	-530.52	-1657.88
3,00	-811,95	-749.50	-2342.16
3.50	-1079.98	-994.91	-3115,33
4,00	-1372,65	-1267.06	-3959.57
4,50	-1682.83	-1553.38	-4854.32
5.00	-2002.47	-1848,44	-5776.36
5.25	-2139,18	-1974.62	-6170,71
5,375	-2243.11	-2070.56	-6470.51

SHAFER 9300.62 08/15/67

PRIVATE



Optical Path Difference

nominal system 127X

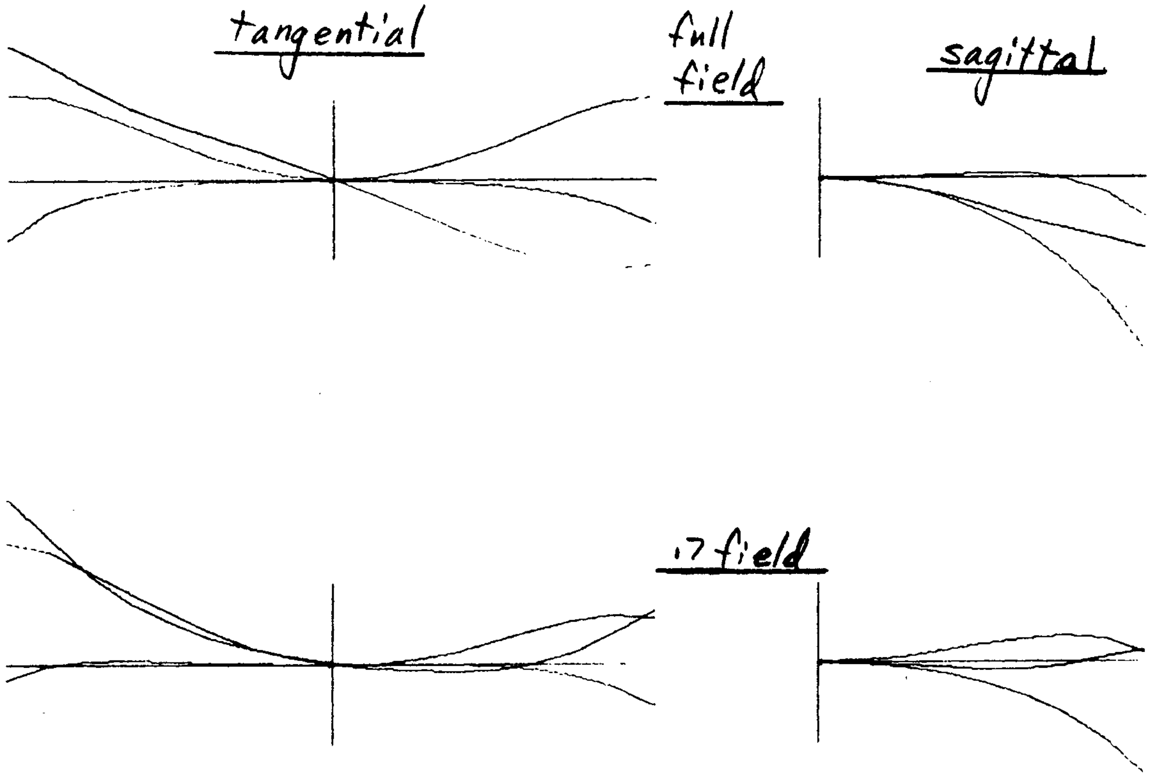
Figure 3.6.10-2

PRIVATE

SHAFER 9300.62 08/15/67*

PRIVATE

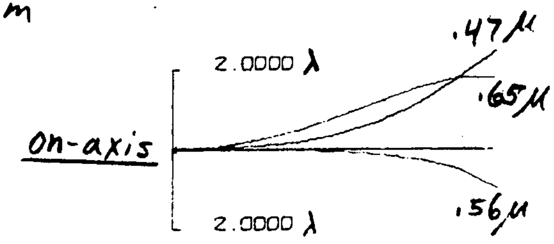
9300.62 SHAF SED 999 SER 0195 08/15/67 LENS NO. 663 PLOT NO. 4



Optical Path Difference

pressure deflected system

Δ P.S.I. = 10.2
Across First Element



Note: Defocusing has been compensated for here

Figure 3.6.10-3

PRIVATE

PRIVATE

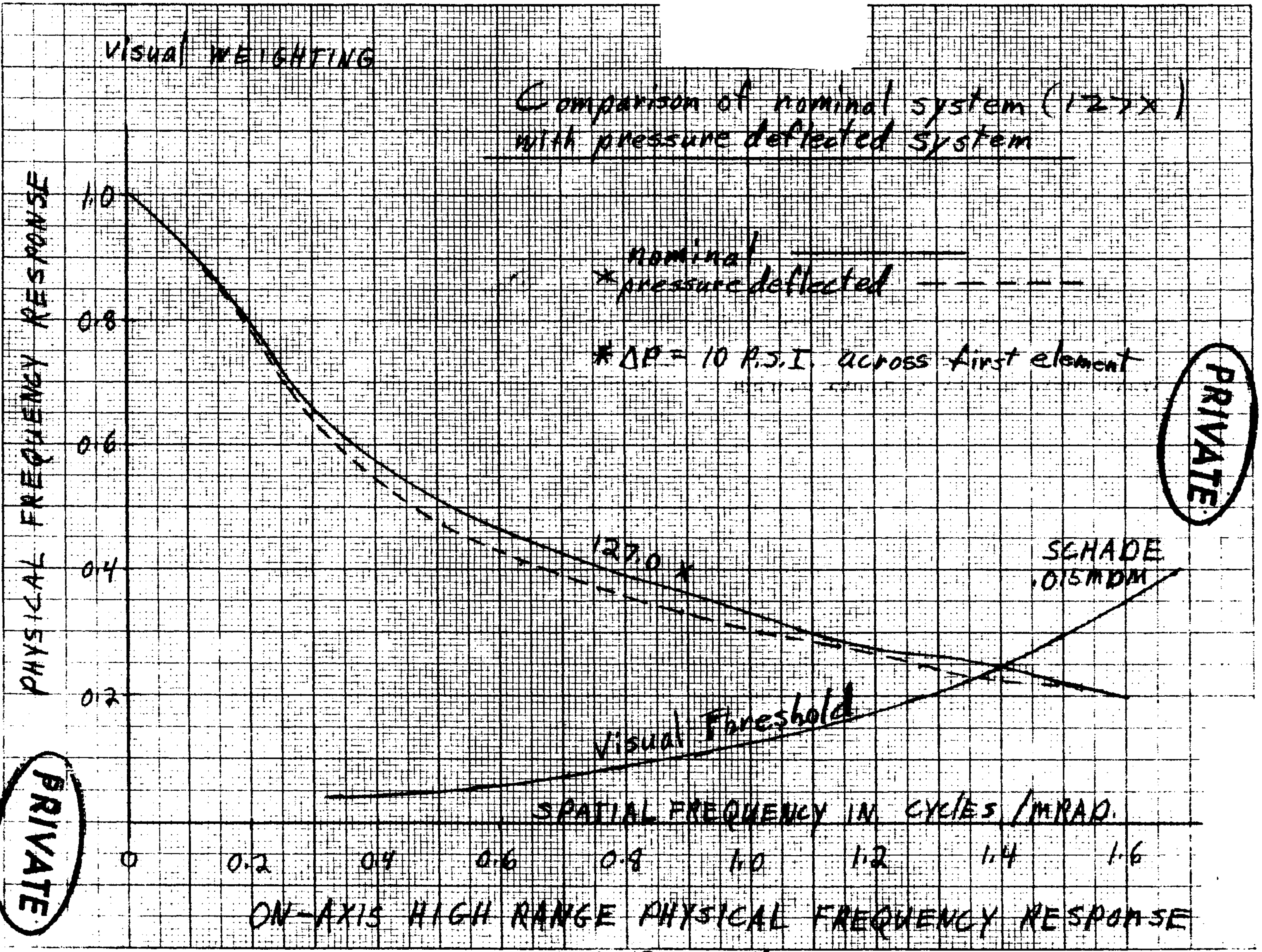


FIGURE 3.6.10-4

PRIVATE

SPECIAL HANDLING ~~SECRET~~

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ADDENDUM 3.6.10-A

25 July 1967

Page 1 of 1 Pages

To: G. Lenertz Facility: Burlington 9

From: A. R. Raab Facility: Burlington 10

Subject: Lens Element No. 1 of Project 9300.47M

Attached are the summarized results of my analysis of the deformations of Lens Element No. 1 when it is subjected to the pressure loadings that you specified.

Page 2 indicates the finite element subdivision and the relative positions of the nodes. Also given is a table of the pressure intensities for the three loading conditions. Pages 3 through 5 show the axial displacements of the surface 1-46 due to each loading condition. Page 6 contains a tabular listing of the axial and radial displacements of all nodes for each loading condition.

This lens has been treated as a three dimensional elastic solid subjected to surface pressures. The finite element method of analysis has been used, together with a newly activated computer program designed to treat axi-symmetric solids.

It is interesting to note that the results for Cases 1 and 2 do not exhibit merely the reversal of the pressure differential, as would have been the case if a two dimensional analysis had been used. Instead we find that the maximum surface displacement is 15.08 micro-inches for Case 1 and -18.57 micro-inches for Case 2. As I indicated previously, this is due to the different radii of curvature of the two surfaces, as well as to local compression of the material near each surface.

Also of interest is the fact that the results for Case 3 differ from those to be expected from a scaling of Case 1 to produce a pressure differential of 10.2 psi. This scaling factor (25.5) would be applied to all load values, and consequently to all displacements, associated with Case 1. The displacement of surface 1-46 determined in this manner is shown as the broken line on Page 5. The maximum surface displacement would then be 384.52 micro-inches instead of the value of 421.60 micro-inches evaluated in Case 3.

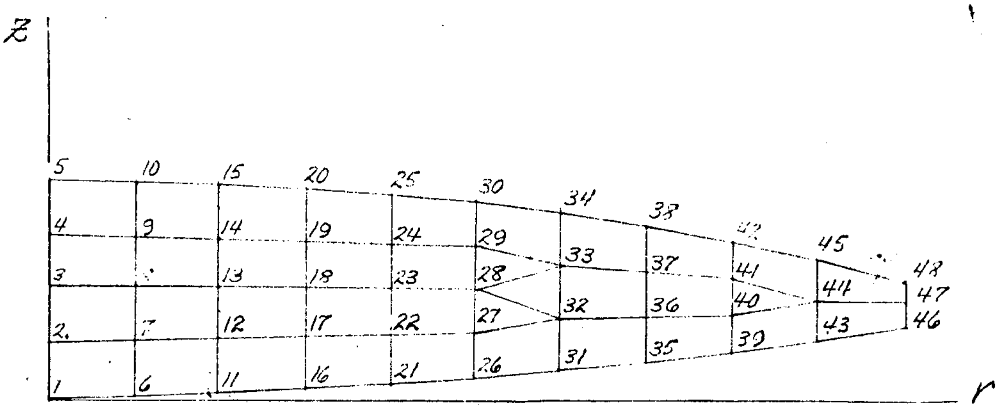
ARRaab

A. R. Raab

/pb

cc: W. P. Barnes, Jr.
R. Carignan
A. Van Sickel
M. Kahan
S. Robinson
A. Wright

BY: [illegible]	**TITLE:** [illegible] 2500 [illegible] ELEMENT NO. 1	**PAGE** OF
DATE: [illegible]		**MODEL:**
DWG:		**CHKD BY:**
LOADS:		**DATE:**



FINITE ELEMENT SUBDIVISION

PRESSURE LOADS

	1-46	5-48	
CASE 1	5.2	4.8	PSI
CASE 2	4.8	5.2	PSI
CASE 3	15.0	4.8	PSI

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DATE: [illegible]	PROJECT 9300 LENS ELEMENT NO. 1	**MODEL:**
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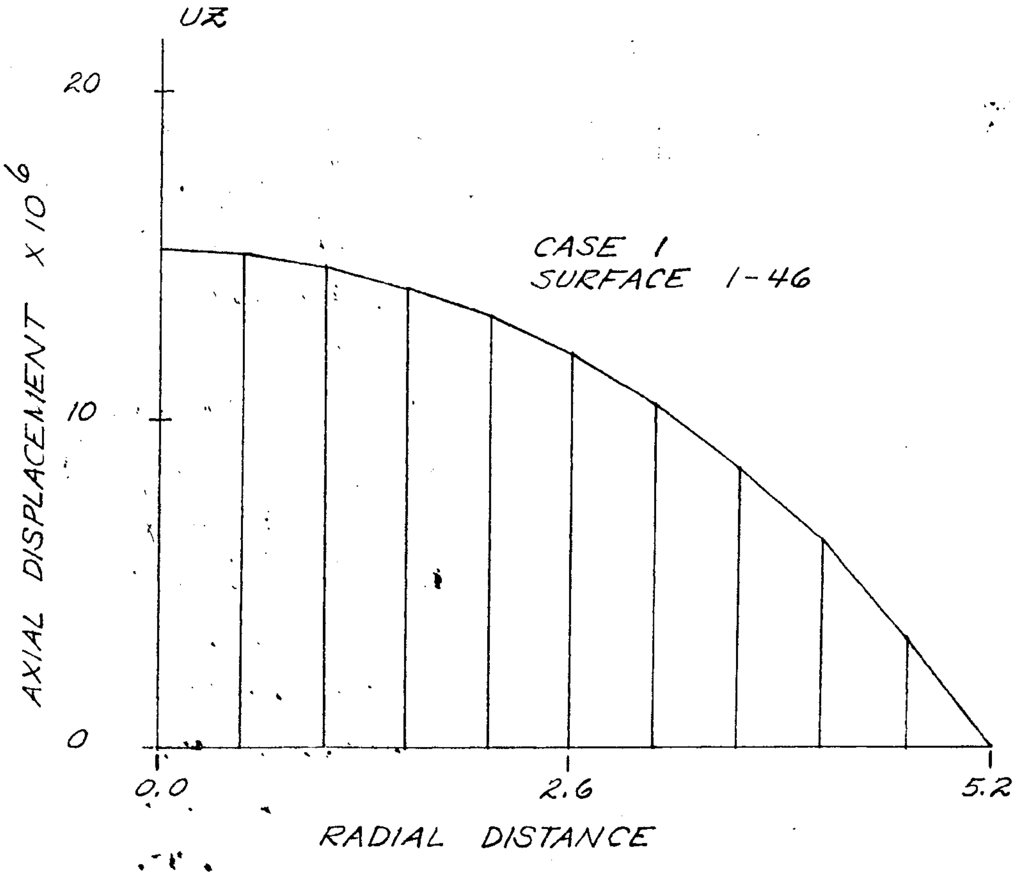

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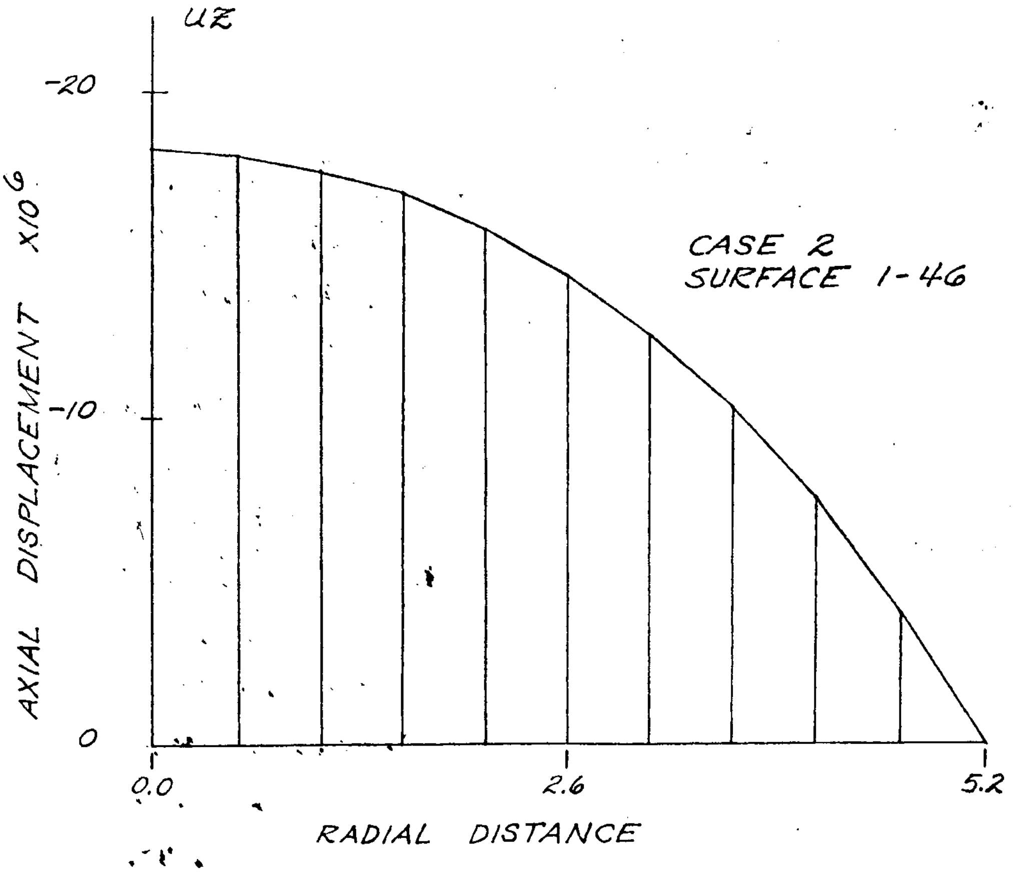

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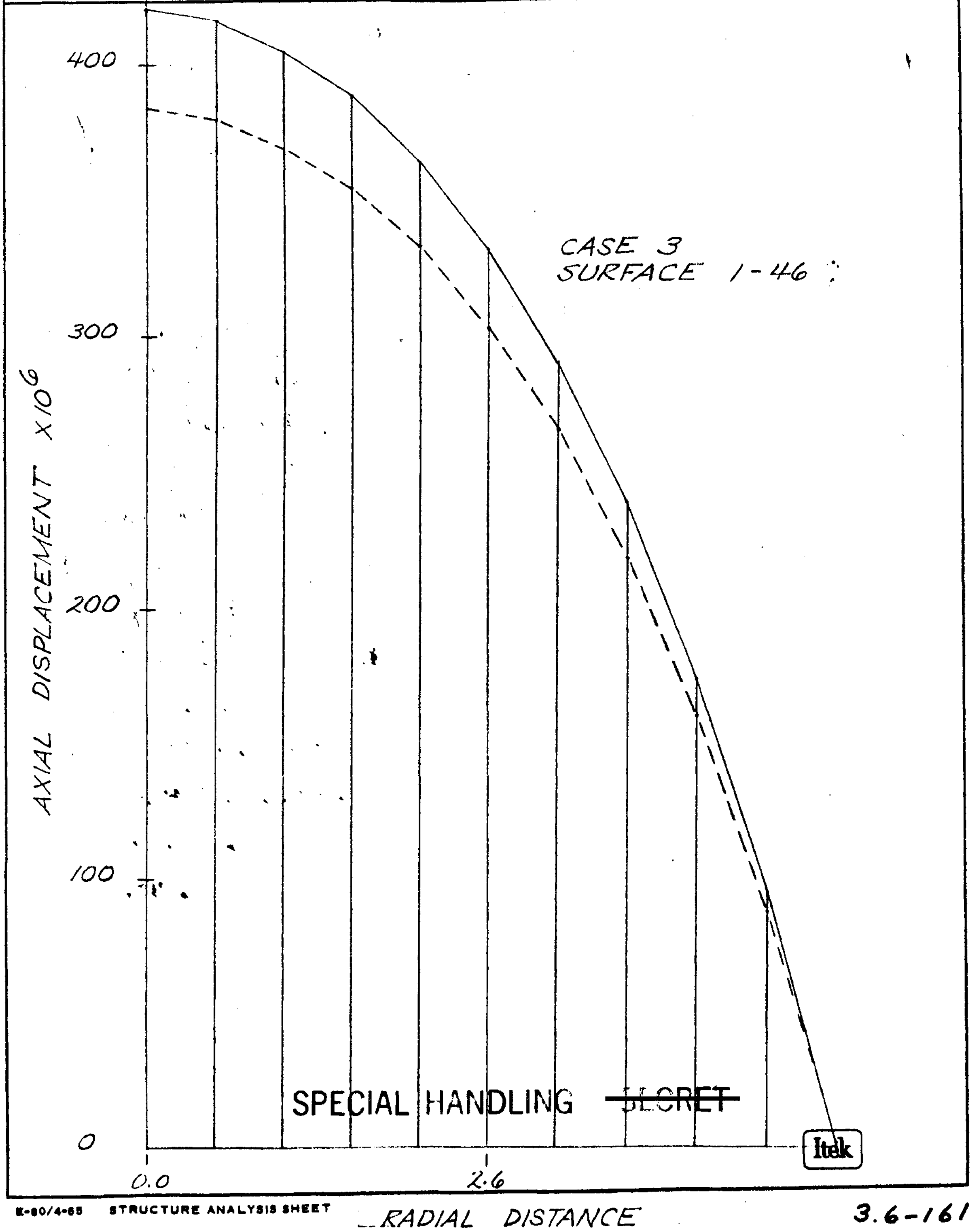
DATE: 7.24.67
DWG:
LOADS: UZ

TITLE:
PROJECT 9300
LENS ELEMENT
NO. 1

PAGE **OF**
MODEL:
CHKD BY:
DATE:



SPECIAL HANDLING ~~SECRET~~

36-162

PROJECT 5 10.47M

ARR(UCALC,A)

NODE	COORDINATES		CASE 1		CASE 2		CASE 3	
			$P_1 = 5.2$	$P_2 = 4.8$	$P_1 = 4.8$	$P_2 = 5.2$	$P_1 = 15.0$	$P_2 = 4.8$
	r	z	u_R	u_Z	u_R	u_Z	u_R	u_Z
1	0.000	0.000	-0.0000000E-38	0.1507923E-04	0.0000000E-38	-0.1823736E-04	-0.0000000E-38	0.4216601E-03
2	0.000	0.339	-0.0000000E-38	0.1505538E-04	0.0000000E-38	-0.1841379E-04	-0.0000000E-38	0.4234072E-03
3	0.000	0.677	-0.0000000E-38	0.1497940E-04	0.0000000E-38	-0.1852614E-04	-0.0000000E-38	0.4236845E-03
4	0.000	1.015	-0.0000000E-38	0.1485676E-04	0.0000000E-38	-0.1857984E-04	-0.0000000E-38	0.4226308E-03
5	0.000	1.354	-0.0000000E-38	0.1468702E-04	0.0000000E-38	-0.1857300E-04	-0.0000000E-38	0.4202182E-03
6	0.520	0.003	-0.3844270E-06	0.1492604E-04	0.2920230E-06	-0.1804947E-04	-0.8716221E-05	0.4173456E-03
7	0.520	0.339	-0.2212808E-06	0.1490087E-04	0.9145468E-07	-0.1822292E-04	-0.4115906E-05	0.4190396E-03
8	0.520	0.675	-0.6541296E-07	0.1482601E-04	-0.1016758E-06	-0.1833534E-04	0.2969350E-06	0.4193330E-03
9	0.520	1.011	0.8733039E-07	0.1470352E-04	-0.2925587E-06	-0.1838789E-04	0.4640411E-05	0.4182680E-03
10	0.520	1.347	0.2412272E-06	0.1453656E-04	-0.4864386E-06	-0.1838314E-04	0.9034982E-05	0.4159181E-03
11	1.040	0.013	-0.7454718E-06	0.1454755E-04	0.5563748E-06	-0.1758685E-04	-0.1678575E-04	0.4067049E-03
12	1.040	0.341	-0.4390490E-06	0.1452214E-04	0.1798677E-06	-0.1775547E-04	-0.8147778E-05	0.4093386E-03
13	1.040	0.669	-0.1338215E-06	0.1444939E-04	-0.1982709E-06	-0.1786599E-04	0.4929598E-06	0.4086387E-03
14	1.040	0.997	0.1651978E-06	0.1432996E-04	-0.5719477E-06	-0.1791784E-04	0.8995926E-05	0.4076074E-03
15	1.040	1.325	0.4536260E-06	0.1416849E-04	-0.9356424E-06	-0.1791536E-04	0.1723598E-04	0.4053597E-03
16	1.560	0.030	-0.1094529E-05	0.1392740E-04	0.8085113E-06	-0.1682917E-04	-0.2454692E-04	0.3892736E-03
17	1.560	0.345	-0.6521821E-06	0.1390200E-04	0.2652458E-06	-0.1699026E-04	-0.1208027E-04	0.3908190E-03
18	1.560	0.659	-0.2082974E-06	0.1383215E-04	-0.2845121E-06	-0.1709686E-04	0.4839557E-06	0.3911129E-03
19	1.560	0.973	0.2265245E-06	0.1371835E-04	-0.8278488E-06	-0.1714816E-04	0.1284795E-04	0.3901524E-03
20	1.560	1.288	0.6426890E-06	0.1356547E-04	-0.1352717E-05	-0.1714876E-04	0.2473851E-04	0.3880590E-03
21	2.080	0.054	-0.1428223E-05	0.1304631E-04	0.1045834E-05	-0.1575288E-04	-0.3192279E-04	0.3645102E-03
22	2.080	0.349	-0.8618341E-06	0.1302403E-04	0.3506939E-06	-0.1590729E-04	-0.1595576E-04	0.3660199E-03
23	2.080	0.645	-0.2920928E-06	0.1295882E-04	-0.3546292E-06	-0.1600914E-04	0.1570852E-06	0.3663216E-03
24	2.080	0.941	0.2659209E-06	0.1285241E-04	-0.1051751E-05	-0.1605907E-04	0.1602235E-04	0.3654467E-03
25	2.080	1.236	0.7984405E-06	0.1270895E-04	-0.1723402E-05	-0.1606081E-04	0.3123779E-04	0.3634962E-03
26	2.600	0.084	-0.1733909E-05	0.1188888E-04	0.1254481E-05	-0.1433976E-04	-0.3857662E-04	0.3319988E-03
27	2.600	0.356	-0.1072995E-05	0.1186181E-04	0.4447310E-06	-0.1447430E-04	-0.1997390E-04	0.3331991E-03
28	2.600	0.627	-0.3891228E-06	0.1180576E-04	-0.4012730E-06	-0.1457419E-04	-0.6275791E-06	0.3336037E-03
29	2.600	0.898	0.2798250E-06	0.1170656E-04	-0.1236747E-05	-0.1461973E-04	0.1838894E-04	0.3327763E-03
30	2.600	1.170	0.9036331E-06	0.1158238E-04	-0.2024137E-05	-0.1463137E-04	0.3621977E-04	0.3312069E-03
31	3.120	0.121	-0.2005731E-05	0.1041307E-04	0.1431894E-05	-0.1253955E-04	-0.4439782E-04	0.2995407E-03
32	3.120	0.444	-0.9986420E-06	0.1037986E-04	0.1969134E-06	-0.1270044E-04	-0.1603705E-04	0.2919764E-03
33	3.120	0.766	-0.1405692E-07	0.1028652E-04	-0.1026098E-05	-0.1278689E-04	0.1187377E-04	0.2917107E-03
34	3.120	1.088	0.9415417E-06	0.1014080E-04	-0.2229180E-05	-0.1280530E-04	0.3915195E-04	0.2899249E-03
35	3.640	0.165	-0.2241013E-05	0.8566766E-05	0.1577993E-05	-0.1028752E-04	-0.4934972E-04	0.2386987E-03
36	3.640	0.441	-0.1172741E-05	0.8537364E-05	0.2703934E-06	-0.1042703E-04	-0.1929329E-04	0.2399253E-03
37	3.640	0.716	-0.1146514E-06	0.8459449E-05	-0.1042676E-05	-0.1050649E-04	0.1068656E-04	0.2397991E-03
38	3.640	0.991	0.8989535E-06	0.8338892E-05	-0.2318843E-05	-0.1052989E-04	0.3962122E-04	0.2394079E-03
39	4.160	0.216	-0.2397579E-05	0.6273598E-05	0.1649928E-05	-0.7494444E-05	-0.5234589E-04	0.1743339E-03
40	4.160	0.437	-0.1344986E-05	0.6239099E-05	0.3669136E-06	-0.7595958E-05	-0.2279501E-04	0.1759537E-03
41	4.160	0.657	-0.2787930E-06	0.6177971E-05	-0.9546380E-06	-0.7667533E-05	0.7375929E-05	0.1759555E-03
42	4.160	0.878	0.7266238E-06	0.6093302E-05	-0.2222213E-05	-0.7703113E-05	0.3611703E-04	0.1743106E-03
43	4.680	0.274	-0.2398418E-05	0.3435336E-05	0.1576637E-05	-0.4044864E-05	-0.5149552E-04	0.9476913E-04
44	4.680	0.512	-0.1007958E-05	0.3391224E-05	-0.1165733E-06	-0.4155999E-05	-0.1247944E-04	0.9546880E-04
45	4.680	0.749	0.3373237E-06	0.3302481E-05	-0.1807349E-05	-0.4208848E-05	0.2598925E-04	0.9487215E-04
46	5.200	0.338	-0.2101836E-05	0.5043189E-07	0.1237241E-05	0.3594685E-07	-0.4342918E-04	0.2701091E-06
47	5.200	0.472	-0.1226998E-05	0.0000000E-38	0.1791242E-06	0.0000000E-38	-0.1896546E-04	0.0000000E-38
48	5.200	0.605	-0.3805071E-06	-0.2256144E-07	-0.8887131E-06	-0.5957655E-07	0.5223100E-05	0.3906260E-06

BY: GEORGE LENERTZ
DEPT: 9-520 DATE: 15 MAY

Addendum 3.6.10-B

0.2.3-1
9300.WAM

10.2 WINDOW DEFLECTION ANALYSIS ~ PRESSURE LOADING CONTINUE

10.2.3 DEFLECTION DUE TO PRESSURE VARIATION

10.2.3.1 DISCUSSION

THE CONTRACTOR'S SPECIFICATION DR-1100 STATES THAT THERE WILL BE A PRESSURE VARIATION OF ±.2 PSI FROM THE MEAN 5 PSI LEVEL.

AN ACTION ITEM OF 4 MAY 67 T.D. MEETING REQUEST THE EFFECT OF THIS PRESSURE VARIATION ON THE PERFORMANCE OF THE OPTICAL SYSTEM BE INVESTIGATED.

A SCHEMATIC OF THE WINDOW AND ITS MOUNT AS OF 3 MAY 67 (SK 115282) IS SHOWN IN FIGURE 10.2.3-1. MATERIAL PROPERTIES USED IN THIS ANALYSIS ARE PRESENTED IN TABLE 10.2.3-1.

THE APPROACH THAT WE BE TAKEN IS TO EVALUATE THE SAG ASSUMING A FIXED EDGE CONDITION. (WHICH IS THE WORST POSSIBLE CONDITION.) TO APPROXIMATE THE ACTUAL SUPPORT CONDITION, THE METHOD OF A BEAM ON AN ELASTIC FOUNDATION WILL BE USED. IF THE RESULTS OF THESE TWO APPROACHES

BY: GEORGE LENERTZ
DEPT: 9-520
DATE: 15 MAY
TITLE: 9300 OPTICAL SYSTEM
PAGE: 10.2.3-2
PROJECT: 9380.62M

REF. DWG. NO. 115282

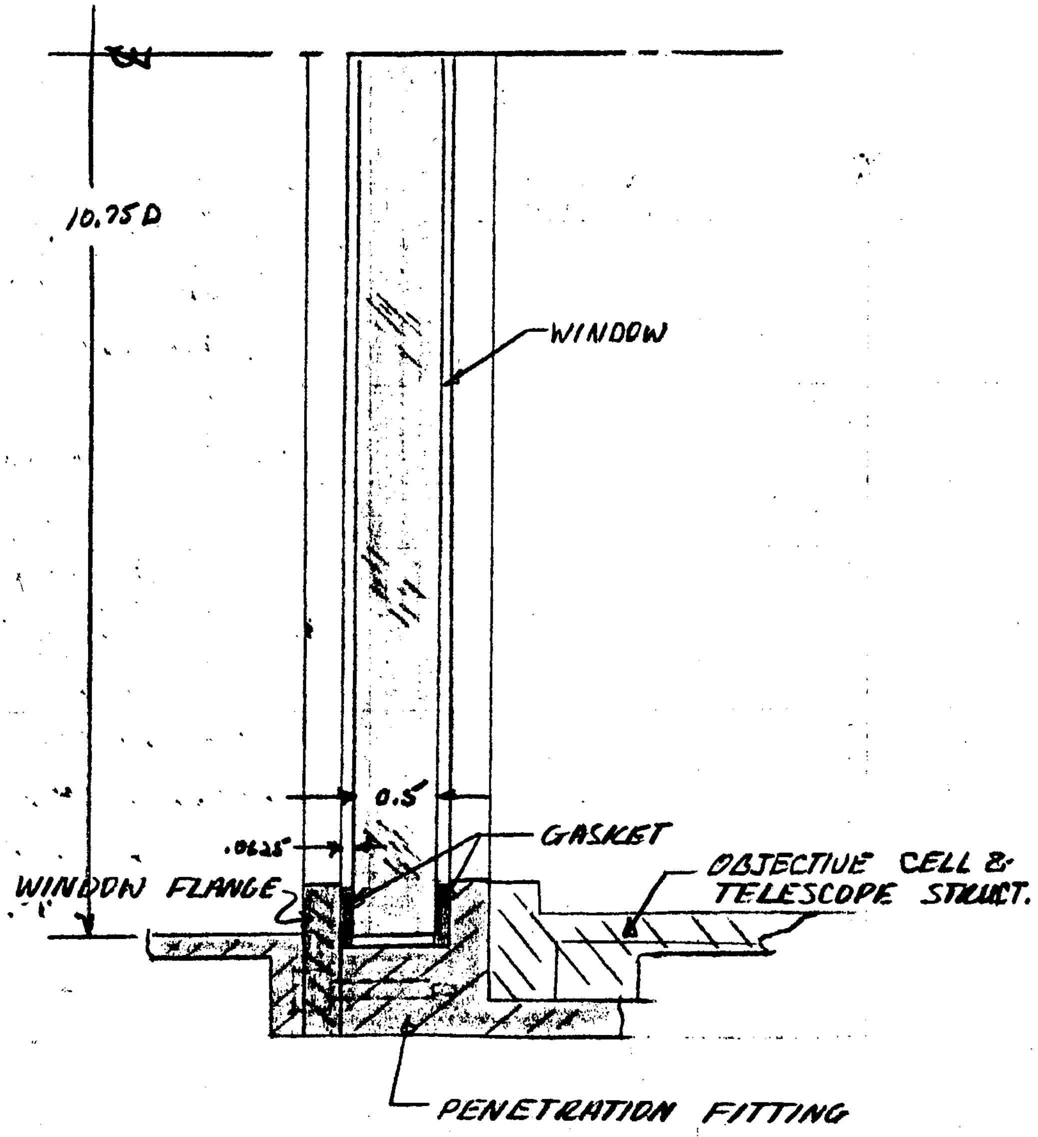


FIGURE 10.2.3-1 ~ WINDOW MOUNT SCHEMATIC

BY: GEORGE LENERTZ
DATE: 15 May 67
DWG:
LOADS:

TITLE: 9300 OPTICAL SYSTEM

PAGE 10.2.3-3OF
MODEL: 9300.62m
CHKD BY:
DATE:

TABLE 10.2.3-1 - MATERIAL PROPERTIES

PROPERTIES	WINDOW BK-7	GASKET RUBBER	FLANGE AL 7075			
F_{tu} (psi)						
F_{ty} (psi)						
F_{cy} (psi)						
F_{su} (psi)						
F_{sy} (psi)						
E (psi)	$11.8 (10^6)$	310	$10.3 (10^{+6})$			
G (psi)						
α (IN/IN/°F)						
ρ (#/in.^{3})	.091		.101			
Q		K = .73 SHORE A = 50				
P.E.L.	SCOTT DATA SHEET	N.R.P.R.A TECH. BULL NO. 8	MIL-HNBB-5			
U	.208					
E/ρ						

F_{tu} = Tensile Ultimate Strength
F_{ty} = Tensile Yield Strength
F_{cy} = Compressive Yield Strength
F_{su} = Shear Ultimate Strength
F_{sy} = Shear Yield Strength
E = Modulus of Elasticity
U = Poisson's Ratio
G = Shear Modulus of Elasticity
α = Linear Coef. of Thermal Expansion
ρ = Density of Material
Q = Dynamic Damping Coef.
P.E.L. = Precision Elastic Limit - stress at which 1×10^{-6} inches of permanent set occurs.

Itek

BY: GEORGE LENERTZ		TITLE: 9300 OPTICAL SYSTEM	PAGE: 10.2.3-4
DEPT: 9-520	DATE: 18 MAY		PROJECT: 9300.62M

10.2.3 (CONT)

INDICATES AN OPTICAL PROBLEM, THEN THE COMPLETE WINDOW MOUNT WILL BE ANALYZED BY USE OF A COMPUTER.

10.2.3.2 SAG FOR FIXED EDGE CONDITION

FIGURE 10.2.3-2 SHOWS THE ASSUMED FIXED EDGE CONDITION. FROM REFERENCE NO. 5, PG 196, CASE 7:

FOR $r < r_0$

$$y_1 = \frac{3(W)(m^2-1)}{16(\pi)(E)(m^2)(t^3)}\Big[4a^2 - (8r^2+4r_0^2)\ln\frac{a}{r_0} - \frac{2r^2r_0^2}{a^2} + \cdots$$

$$+ \frac{r^4}{r_0^2} - 3r_0^2\Big] \qquad (10.2.3-1)$$

FOR $r > r_0$

$$y_1 = \frac{3(W)(m^2-1)}{16(\pi)(E)(m^2)(t^3)}\Big[4a^2 - (8r^2+4r_0^2)\ln\frac{a}{r} - \frac{2r^2r_0^2}{a^2} - \cdots$$

$$- 4r^2 + 2r_0^2\Big] \qquad (10.2.3-2)$$

WHERE:

$W = w\pi r_0^2$

w = PRESSURE LOAD

r_0 = 5 IN. (FIGURE 10.2.3-2)

$m = 1/\mu = 4.8076$ (TABLE 10.2.3-1)

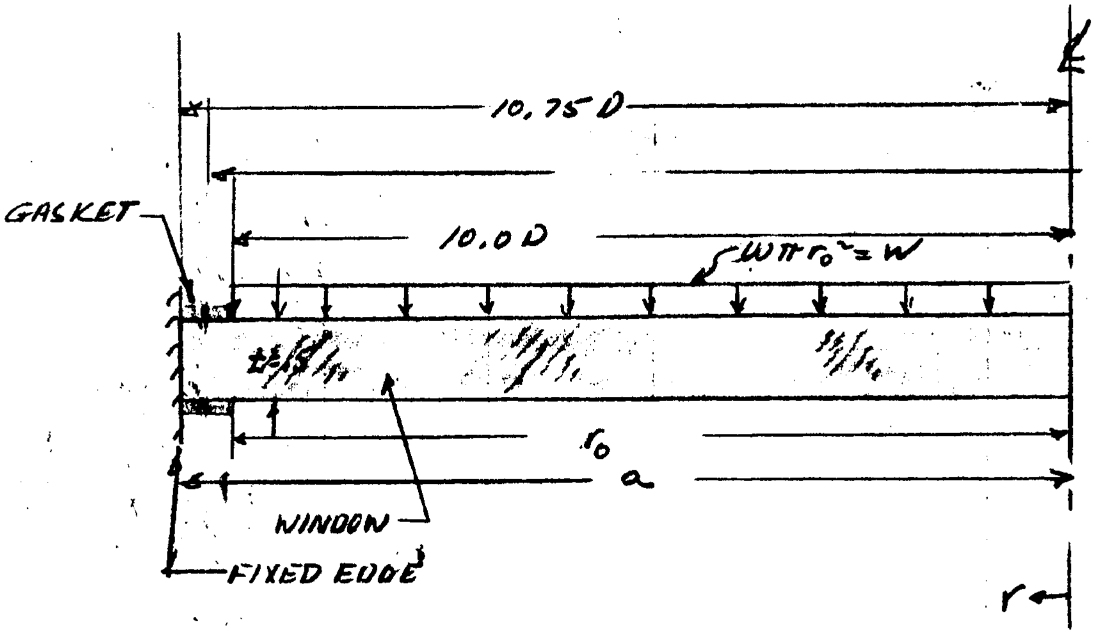
$E = 11.8(10^{+6})$ PSI (")

t = .5 IN (FIGURE 10.2.3-2)

BY: GEORGE LENERTZ	TITLE: 9300 OPTICAL SYSTEM	PAGE: 10.2.3-5
DEPT: 9-520 DATE: 18 MAY		PROJECT: 9300.62A

10.2.3 CONT

REF. FIGURE 10.2.3-1



MAT'L BK-7

$E = 11.8(10^{+6})$ PSI

$\mu = .208$

FIGURE 10.2.3-2 ~ WINDOW FIXED EDGE CONDITION

BY: GEORGE LENERTZ	TITLE: 9300 OPTICAL SYSTEM	PAGE: 10.2.3-6
DEPT: 9-520 DATE: 14 MAY		PROJECT: 9300.62M

10.2.3 (CONT)

$a = 5.375$ IN. (FIGURE 10.2.3-2)

THE ASSUMPTIONS ARE GIVEN IN THE REFERENCE.

THEREFORE:

$0 \rightarrow 5$

$$y_1 = \frac{(3)(W)(22.1130)}{(16)(3.14)(11.8)(10^{+6})(23.1130)(.5)^3}\Big[4(28.8906) - \cdots$$

$$-[8r^2+4(25)]\ln\frac{5.375}{5} - \frac{(2)(r^2)(25)}{28.8906} + \frac{r^4}{25} - 3(25)\Big]$$

$$y_1 = 38.7318(10^{-9})\Big[115.5624 - [8r^2+100]\underset{.0723}{\ln 1.075} - \cdots$$

$$-1.7306r^2 + .04r^4 - 75\Big]$$

$$y_1 = 38.7318(10^{-9})[33.3324 - 2.3090r^2 + .04r^4]$$

$$y_1 = W(10^{-9})[1291.0239 - 89.4317r^2 + 1.5493r^4]$$

@ $r=0$

$$y_1 = W(10^{-9})[1291.0239]$$

AND:

$5 \rightarrow 5.35$

$$y_2 = (38.7318)(W)(10^{-9})\Big[4(28.8906) - [8r^2+100]\ln\frac{a}{r}, + \cdots$$

$$-\frac{2(r^2)(25)}{28.8906} - 4r^2 + (2)(25)\Big]$$

BY: GEORGE LENERTZ	TITLE: 9300 OPTICAL SYSTEM	PAGE: 10,2,3-7
DEPT: 9-520 DATE: 8 MAY		PROJECT: 9300.62m

EPIC 2000 PROGRAM

NAME OR DISCRIPTION:

EQUATION: $\underset{c_1}{1291.0239} - \underset{c_2}{89.4317} r^2 + \underset{c_3}{1.5493} r^4$

CONSTANT REGISTER	REGISTER 4	3	2	1	ENTER KEYBRD	CONTROL	PRINT OUT
						MAN	
c_1						STORE	
				c_3	c_3	ENT	
			c_3	c_3		"	
		c_3	c_3	c_3		"	
						LEARN	
					r^2		
		c_3	c_3	$c_3 r^2$		×	
					c_2		
		c_3	c_3	$c_3 r^2 - c_2$		−	
					r^2		
		c_3	c_3	$[\ ] r^2$		×	
	c_3	c_3	$[\ ] r^2$	c_1		REG	
	c_3	c_3	c_1	$[\ ] r^2$		I	
		c_3	c_3	$c_1 + [\ ] r^2$		+	
		c_3	c_3	$c_1 + [\ ] r^2$			$c_1 + [\ ] r^2$
			c_3	c_3		C	
		c_3	c_3	c_3		"	
						AUTO	
					r^2	ENT	
					c_2	ENT	
					r^2	ENT	

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$$y_2 = 38.7318(W)(10^{-9})\left[115.5624 - \left[8r^2+100\right]\ln\frac{a}{r} + \cdots\right.$$

$$\left. - 1,7306\,r^2 - 4r^2 + 50\right]$$

For!

$r = 5.0$

$$y_2 = 38.7318\,W(10^{-9})\left[115.5624 - \left[8r^2+100\right].0723 + \cdots\right.$$

$$\left. - 1,7306\,r^2 - 4r^2 + 50\right]$$

$$y_2 = 38.7318(W)(10^{-9})\left[115.5624 - 7.23 - .5784r^2\right.$$

$$-1,7306\,r^2 - 4r^2 + 50$$

$$y_2 = W(10^{-9})\left[6132.4984 - 244.3589\,r^2\right]$$

$$y_2 = W(10^{-9})\left[23.5264\right]$$

$r = 5.25$

$$y_2 = 38.7318(W)(10^{-9})\left[115.5624 - \left[8r^2+100\right].01882 + \cdots\right.$$

$$\left. - 1,7306\,r^2 - 4r^2 + 50\right]$$

$$y_2 = 38.7318(W)(10^{-9})\left[115.5624 - 1.882 - .1506\,r^2\right.$$

$$\left. - 1,7306\,r^2 - 4r^2 + 50\right]$$

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PROJECT:

10.2.3 CONT

$$y_2 = 38.7318(w)(10^{-9})[163.6804 - 5.8812r^2]$$

$$y_2 = w(10^{-9})[6339.6365 - 229.78946r^2]$$

$$y_2 = w(10^{-9})(41.6884)$$

$r = 5.35$

$$y_2 = 0$$

FIGURE 10.2.3-3 PRESENTS A PLOT OF THE SAG VERSES THE RADIAL DISTANCE FROM THE WINDOW CENTER FOR A PRESSURE DIFFERENTIAL OF 5.2 AND 4.8 PSI.

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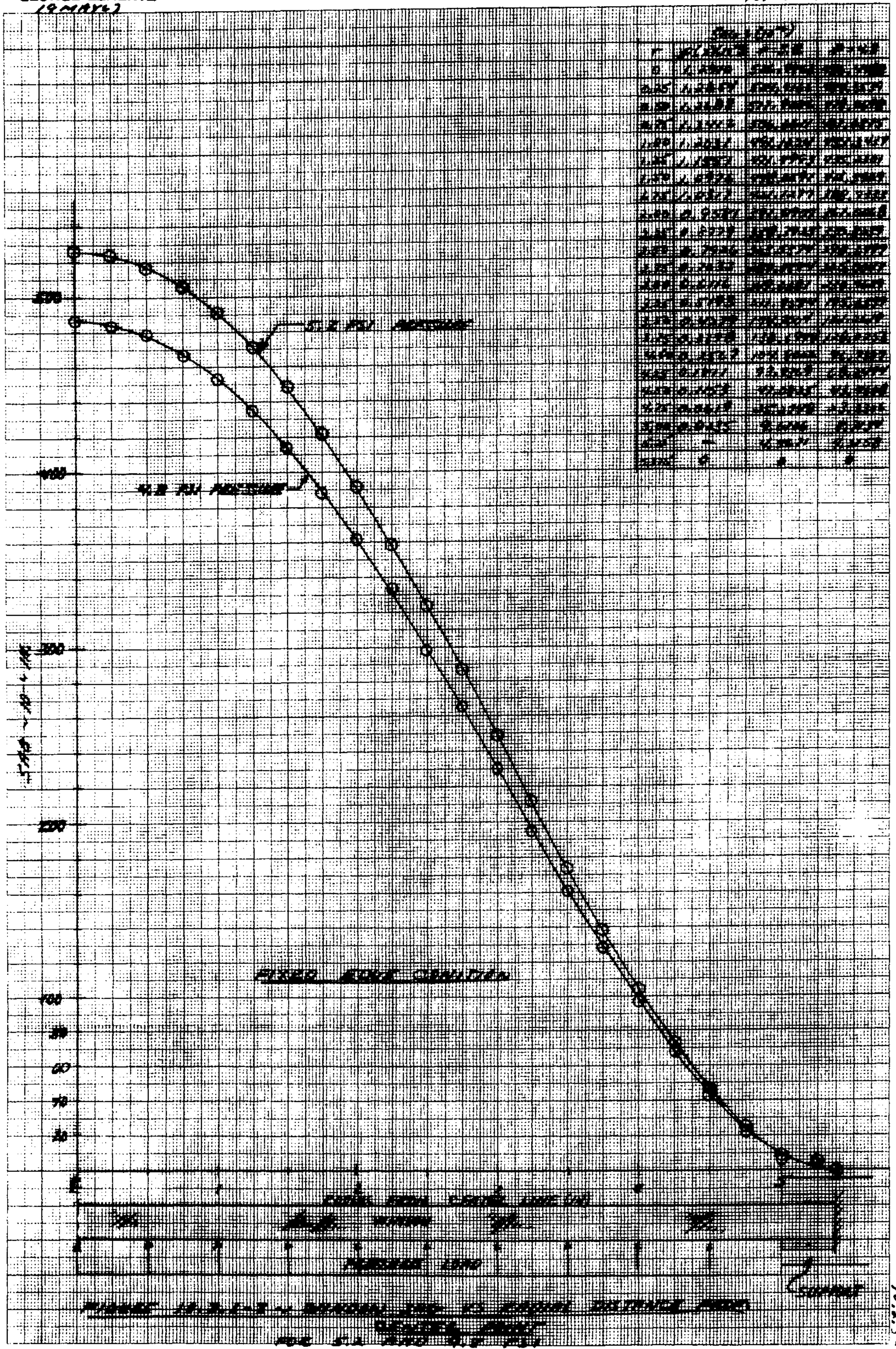
(9 MAY 62)

9300 OPTICAL SYSTEM

10,2,3-90



r	[illegible]	[illegible]	[illegible]
0	[illegible]	[illegible]	[illegible]
0.25	[illegible]	[illegible]	[illegible]
0.50	[illegible]	[illegible]	[illegible]
0.75	[illegible]	[illegible]	[illegible]
1.00	[illegible]	[illegible]	[illegible]
1.25	[illegible]	[illegible]	[illegible]
1.50	[illegible]	[illegible]	[illegible]
1.75	[illegible]	[illegible]	[illegible]
2.00	[illegible]	[illegible]	[illegible]
2.25	[illegible]	[illegible]	[illegible]
2.50	[illegible]	[illegible]	[illegible]
2.75	[illegible]	[illegible]	[illegible]
3.00	[illegible]	[illegible]	[illegible]
3.25	[illegible]	[illegible]	[illegible]
3.50	[illegible]	[illegible]	[illegible]
3.75	[illegible]	[illegible]	[illegible]
4.00	[illegible]	[illegible]	[illegible]
4.25	[illegible]	[illegible]	[illegible]
4.50	[illegible]	[illegible]	[illegible]
4.75	[illegible]	[illegible]	[illegible]
5.00	[illegible]	[illegible]	[illegible]
[illegible]	—	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

FIGURE 10.2.1-3 – [illegible] VS. RADIAL DISTANCE FROM CENTER [illegible] FOR 5.2 AND 9.2 PSI

10.2.3-10

3.6-172

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10.2.3 (CONT)

10.2.3.3 SAG FOR SIMPLY SUPPORTED EDGE CONDITION

FIGURE 10.2.3-4 SHOWS THE ASSUMED SIMPLY SUPPORTED EDGE CONDITION, FROM REFERENCE NO. 5, PG. 194, CASE 2:

FOR $r < R_0$

$$y_1 = \frac{3(W)(m^2-1)}{16(\pi)(E)(m^2)(t^3)}\left[4a^2 - 5r_0^2 + \frac{r^4}{r_0^2} - 8r^2 \ln\frac{a}{r_0} + \ldots\right.$$

$$- 4r_0^2 \ln\frac{a}{r_0} - \frac{2(m-1)(r_0^2)(a^2)}{(m+1)(a^2)} + \frac{2(m-1)(r_0^2)(r^2)}{(m+1)(a^2)} + \ldots$$

$$\left. + \frac{8(m)(a^2)}{(m+1)} - \frac{8(m)(r^2)}{(m+1)}\right] \qquad (10.2.3-3)$$

FOR $r > r_0$

$$y_2 = \frac{3(W)(m^2-1)}{16(\pi)(E)(m^2)(t^3)}\left[\frac{(12m+4)}{(m+1)}a^2 - \frac{(12m+4)}{(m+1)}r^2 + \ldots\right.$$

$$- \frac{2(m-1)(r_0^2)(a^2)}{(m+1)(a^2)} + \frac{2(m-1)(r_0^2)(r^2)}{(m+1)(a^2)} - 8r^2 \ln a/r + \ldots$$

$$\left. - 4r_0^2 \ln\frac{a}{r}\right] \qquad (10.2.3-4)$$

WHERE NOTATION AND VALUES ARE THOSE GIVEN IN SECTION 10.2.3.2.

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10.2.3 (CONT)

REF. FIGURES 10.2.3-1 & -2

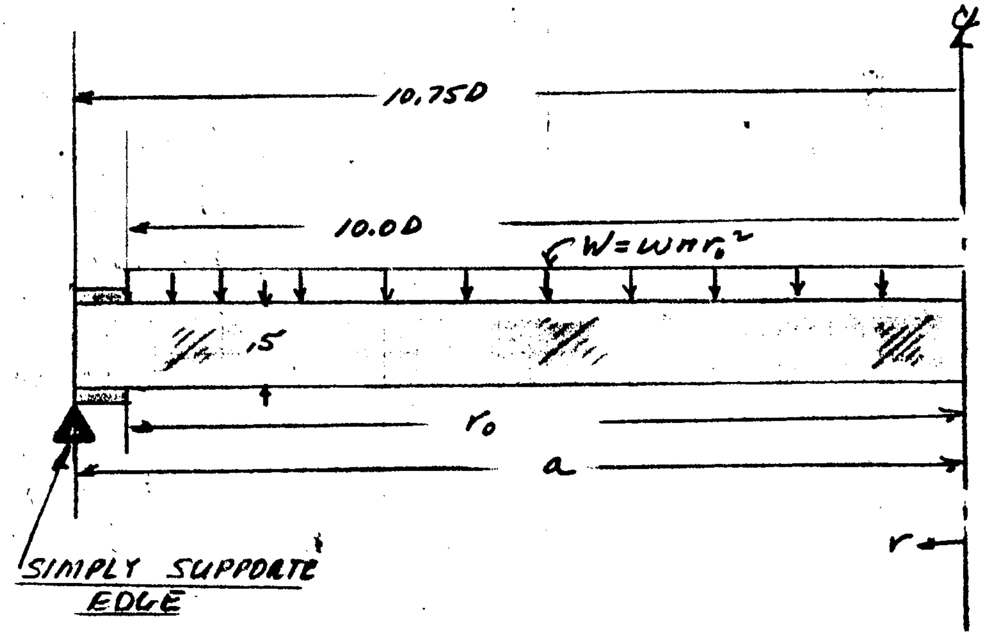

FIGURE 10.2.3-4 ~ WINDOW SIMPLY SUPPORTED CONDITION

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10.2.3 (CONT)

THEREFORE:

$0 \rightarrow 5 = r$

$$y_1 = \frac{3(W)(22.1130)}{(16)(3.14)(11.8)(10^{+6})(23.113)(.5)^3}\Big[4(28.8906 - 5(25) + \ldots$$

$$+\frac{r^4}{25} - 8(r^2)(.0723) - 4(25)(.0723) - \frac{2(3.8076)(25)}{5.8076} + \ldots$$

$$+ \frac{2(3.8076)(25)(r^2)}{5.8076\ (28.8906)} + \frac{8(4.8076)(28.8906)}{(5.8076)} - \frac{8(4.8076)\ r^2}{(5.8076)}\Big]$$

$$y_1 = 38.7318(10^{-9})(W)\big[115.5624 - 125 + .04r^4 + \ldots$$

$$-.5784r^2 - 7.23 - 32.7811 + 1.1346r^2 + \ldots$$

$$+ 191.3251 - 6.6024r^2\big]$$

$$y_1 = 38.7318(10^{-9})\,W\big[141.8764 - 6.0662\,r^2 + .04r^4\big]$$

$$y_1 = W(10^{-9})\big[5495.1283 - 234.9548\,r^2 + 1.5492\,r^4\big]$$

$r = 5$

$$y_2 = 38.7318(10^{-4})\,W\left[\frac{(12)(4.8076)+4}{5.8076}\right](28.8906) - \left[\frac{(12)(4.8076)+4}{5.8076}\right]r^2$$

$$+ \frac{2(3.8076)(25)}{5.8076} + \frac{(2)(3.8076)(25)(r^2)}{(5.8076)(28.8906} - 8(r^2)\ln\frac{a}{r}$$

$$- 4(25)(\ln\frac{a}{r})$$

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$r = 5$

$$y_2 = 38.7318(10^{-9})W[306.8902 - 10.6225 r^2 - 32.7811$$

$$+1.1346 r^2 - .5784 r^2 - 7.23]$$

$$y_2 = 38.7318(10^{-9})W'[266.8791 - 10.0663 r^2]$$

$$y_2 = 589.5599\, W(10^{-9})$$

$r = 5.25$

$$y_2 = 38.7318(10^{-9})W[306.8902 - 10.6225 r^2 - 32.7811$$

$$+ 1.1346 r^2 - .1504 r^2 - 1.880]$$

$$y_2 = 38.7318(10^{-9})W[272.2291 - 9.6383 r^2]$$

$$y_2 = 254.6189\, W(10^{-9})$$

$r = 5.3$

$$y_2 = 38.7318(10^{-9})W[306.8902 - 10.6225 r^2 - 32.7811$$

$$+1.1346 r^2 - .1111 r^2 - 1.389$$

$$y_2 = 38.7318(10^{-9})W[272.7201 - 9.5990 r^2]$$

$$y_2 = 119.4562(10^{-9})(W)$$

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EPIC 2000 PROGRAM

NAME OR DISCRIPTION:

EQUATION: $5495.1283 + r^2[1.5492 r^2 - 234.9546]$

$c_1 + r^2[c_2 r^2 - c_3]$

CONSTANT REGISTER	REGISTER 4	REGISTER 3	REGISTER 2	REGISTER 1	ENTER KEYBR'D	CONTROL	PRINT OUT
						MAN	
C_1						STORE	
				C_3	C_3	ENT	
			C_3	C_3		"	
		C_3	C_3	C_3	"	"	
						LEARN	
	C_3	C_3	C_3	C_2	C_2	ENT	
					r^2		
	C_3	C_3	C_3	$C_2 r^2$		X	
	C_3	C_3	$C_2 r^2$	C_3		I	
		C_3	C_3	$[C_2 r^2 - C_3]$		−	
					r^2		
		C_3	C_3	$[\ ] r^2$		X	
	C_3	C_3	$[\ ] r^2$	C_1		REC	
		C_3	C_3	$[\ ] r^2 + C_1$		+	
		C_3	C_3	$[\ ] r^2 + C_1$		PRINT	$[\ ] r^2 + C_1$
			C_3	C_3		C	
		C_3	C_3	C_3		"	
						AUTO	
					C_2	ENT	
					R^2	ENT	
					R^2	ENT	

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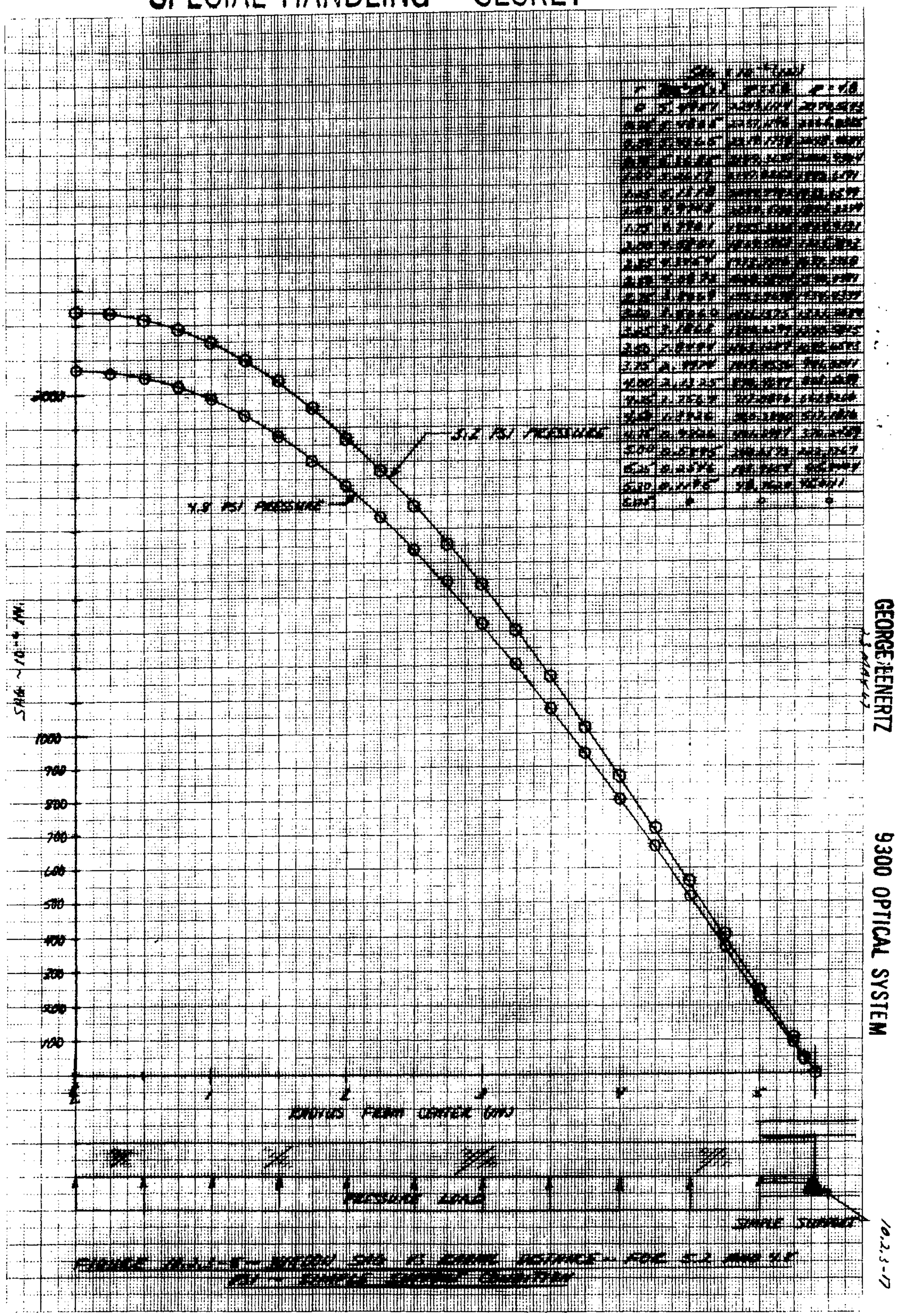
$r=0 \quad y_2 = w(10^{-9})(5495.1283)$

FIGURE 10.2.3-5 PRESENTS A PLOT OF THE SAG VERSES THE RADIAL DISTANCE FROM THE WINDOW CENTER FOR A PRESSURE DIFFERENTIAL OF 5.2 AND 4.8 PSI.



SAG x 10^-4 (IN)

r	[illegible]	P = 3.2	P = 4.8
0	[illegible]	[illegible]	[illegible]
0.25	[illegible]	[illegible]	[illegible]
0.50	[illegible]	[illegible]	[illegible]
0.75	[illegible]	[illegible]	[illegible]
1.00	[illegible]	[illegible]	[illegible]
1.25	[illegible]	[illegible]	[illegible]
1.50	[illegible]	[illegible]	[illegible]
1.75	[illegible]	[illegible]	[illegible]
2.00	[illegible]	[illegible]	[illegible]
2.25	[illegible]	[illegible]	[illegible]
2.50	[illegible]	[illegible]	[illegible]
2.75	[illegible]	[illegible]	[illegible]
3.00	[illegible]	[illegible]	[illegible]
3.25	[illegible]	[illegible]	[illegible]
3.50	[illegible]	[illegible]	[illegible]
3.75	[illegible]	[illegible]	[illegible]
4.00	[illegible]	[illegible]	[illegible]
4.25	[illegible]	[illegible]	[illegible]
4.50	[illegible]	[illegible]	[illegible]
4.75	[illegible]	[illegible]	[illegible]
5.00	[illegible]	[illegible]	[illegible]
5.25	[illegible]	[illegible]	[illegible]
5.50	[illegible]	[illegible]	[illegible]
[illegible]	0	0	0

FIGURE 10.2.3-17 — MIRROR SAG VS RADIAL DISTANCE — FOR 3.2 AND 4.8 PSI — SIMPLE SUPPORT CONDITION

10.2.3-17

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10.2.3 (CONT)

10.2.3.4 EDGE MOMENT ACCOUNTING FOR GASKET AND FLANGE STIFFNESS

TO EVALUATE TO THE ACTUAL SUPPORT CONDITION AND ITS EFFECT ON THE WINDOW, THE STIFFNESS OF THE SEAL AND FLANGE WILL BE ACCOUNTED FOR IN USING BEAMS ON ELASTIC FOUNDATION THEORY.

THE DESIGN OF THE WINDOW MOUNT IS VERY PRELIMINARY, SO THAT ASSUMPTIONS AS TO MATERIAL PROPERTIES AND DIMENSIONS WILL HAVE TO BE MADE. FIGURE 10.2.3-1 SHOWS THE MOUNT CONFIGURATION ASSUMED AND TABLE 10.2.3-1 THE MATERIAL PROPERTIES.

THIS ANALYSIST DOES NOT KNOW OF ANY LITURATURE PERTAINING TO FLATE PLATES ON A PARTICAL ELASTIC FOUNDATION AND TIME DOES NOT PERMIT DERIVING THE EQUATION. WHEN MORE IS KNOWN ABOUT THE DESIGN, A COMPUTER PROGRAM AVAILABLE AT ITEK WILL BE USED.

THUS A UNIT ELEMENT OF THE WINDOW GASKET AND FLANGE WILL BE ASSUMED AS SHOWN IN FIGURE 10.2.3-2.

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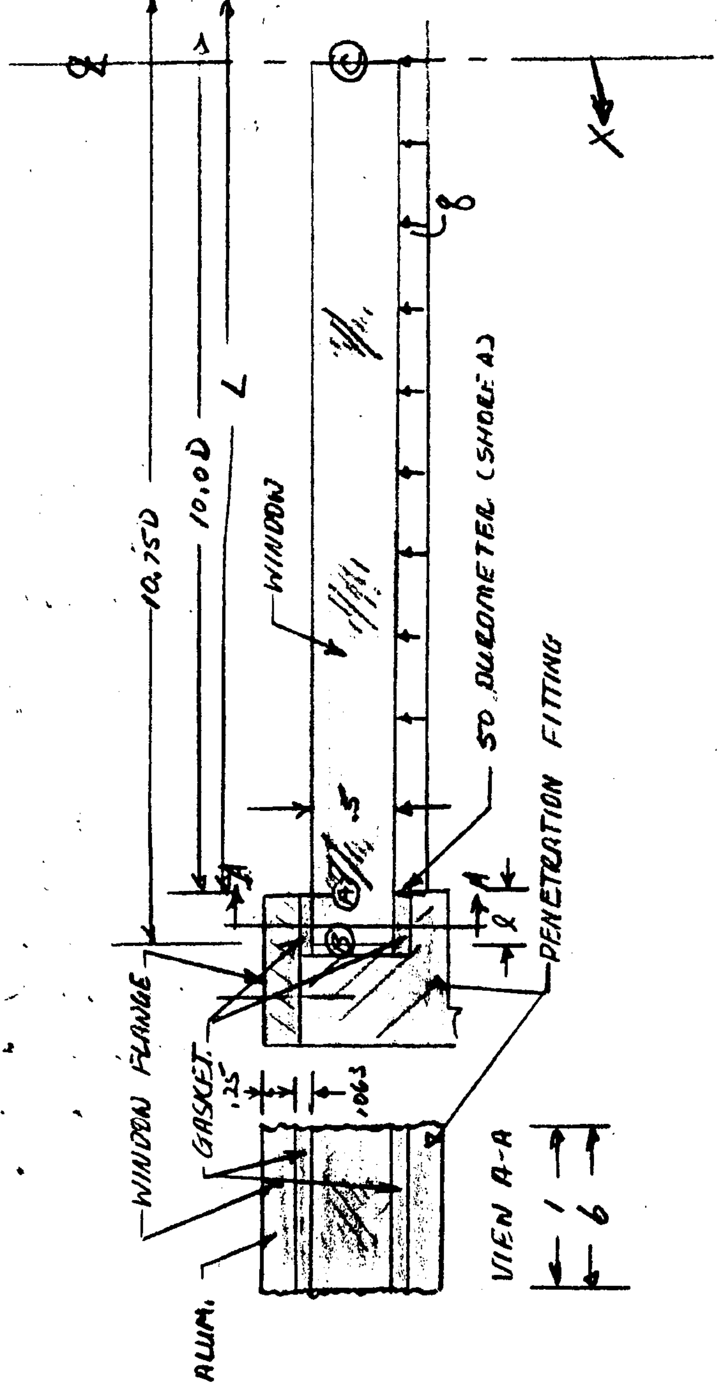

FIGURE 10.2.3-6 ~ UNIT ELEMENT CONFIGURATION WINDOW, GASKET AND FLANGE

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10.2.3 (CONT)

FROM PAGE 68 OF REFERENCE NO. 17, FOR A UNIFORMLY DISTRIBUTED LOAD OVER A FREE SPAN, THE BEAM RESTING ON AN ELASTIC FOUNDATION:

$$M_A = -\frac{gL}{12\lambda}\left\{\frac{\lambda^2 L^2(\sinh^2\lambda l - \sin^2\lambda l) - 6(\sinh^2\lambda l + \sin^2\lambda l)}{\lambda L(\sinh^2\lambda l - \sin^2\lambda l) + \sinh 2\lambda l + \sin 2\lambda l}\right. \qquad (10.2.3\text{-}5)$$

$$Q_A = \frac{gL}{2} \qquad (10.2.3\text{-}6)$$

$$g = pb \quad \text{LB}/\text{IN}^2\ (\text{IN}) \qquad (10.2.3\text{-}7)$$

$$\lambda = \sqrt[4]{K/4E_W I} \qquad (10.2.3\text{-}8)$$

K = SPRING CONST. OF FOUNDATION LB/IN²
(POUNDS / IN. DEFL / IN. WIDTH)

E_W = YOUNG'S MODULUS OF BEAM

I = CROSS SECTION INERTIA OF BEAM

L = 10 IN. (FIGURE 10.2.3-6)

l = 0.38 IN. (FIGURE 10.2.3-6)

<u>SPRING CONSTANT OF GASKET:</u>

REFERING TO FIGURE 10.2.3-7:

$$K_G = \frac{4}{3} E_0 (\pi)(D_m) \frac{b'}{t'}\left\{1 + \frac{k' b'^2}{4t'^2}\right\}^{*} \qquad (10.2.3\text{-}9)$$

WHERE;

K_G = STIFFNESS OF GASKET

E_0 = YOUNG'S MODULUS *

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K' = NUMERICAL FACTOR*

D_M = MEAN DIAMETER

b' = RADIAL WIDTH

t' = THICKNESS

* FROM ENGINEERING DESIGN WITH NATURAL RUBBER, N.R.P.R.A. TECH. BULLETIN NO. 8

ASSUMING A SHORE A DUROMETER = 50

$E_0 = 310$ PSI (TABLE 10.2.3-1)

$K' = .73$

$$\left.\begin{aligned} D_M &= 10.38 \text{ IN.} \\ b' &= 0.38 \text{ IN.} \\ t' &= 0.063 \text{ IN.} \end{aligned}\right\} \text{REF. FIGURE 10.2.3-7}$$

THEREFORE SUBSTITUTING INTO EQUATION 10.2.3-9:

$$K_4 = \frac{4}{3}(310)(3.14)(10.38)\frac{.38}{.063}\left\{1 + \frac{(.73)(.38)^2}{(4)(.063)^2}\right\}$$

$$\underline{K_4 = 620{,}793.5790 \text{ LB/IN}} \qquad (10.2.3\text{-}10)$$

SPRING CONSTANT OF FLANGE

FROM REFERENCE NO. 5, PAGE 210, CASE 60 AND FIGURE 10.2.3-8:

$$K_F = \frac{2\pi(E_0)(m^2)(t^3)}{3(m^2-1)\{X\}} \qquad (10.2.3\text{-}11)$$

$$X = \left[\frac{(a^2+r_0^2)(a^2-b^2)}{2a^2} - (b^2+r_0^2)\ln\frac{a}{b}\right] - \left[.5(m+1)\left(2\ln\frac{b}{r_0} + \frac{r_0^2}{a^2} - 1\right)\right] \times$$

$$\left[\frac{b^4 + 2a^2b^2\ln\frac{a}{b} - a^2b^2}{b^2(m+1) + a^2(m-1)}\right]$$

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10.2.3 (CONT)

REF. FIGURE 10.2.3-6

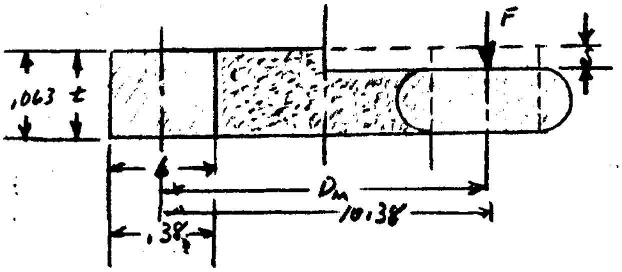

FIGURE 10.2.3-7 ~ GASKET SECTION

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10.2.3 (CONT)

WHERE:

E_F = YOUNG'S MODULUS OF FLANGE (PSI)
μ = POISSON'S RATIO
$m = 1/\mu$
t = THICKNESS OF FLANGE
a = OUTER RADIUS OF FLANGE (IN)
b = INNER RADIUS (IN)
r_0 = RADIUS OF APPLIED LOAD

AND:

$E_F = 10.3 (10^{+6})$ PSI (TABLE 10.2.3-1)
$\mu = .101$ (TABLE 10.2.3-1)
$m = 9.9010$
$t = 0.25$ IN.
$a = 5.75$ IN.
$b = 5.0$ IN.
$r_0 = 5.19$ IN.
(FIGURE 10.2.3-8)

THEREFORE;

$$X = \left[\frac{\{(33.0625)+(26.9361)\}\{(33.0625)-(25.0)\}}{2(33.0625)} - (25.0 + 26.9361)\times \ldots\right.$$

$$\left. \ldots \ln\frac{5.75}{5}\right] - \left[.5(10.9010)\left(2\ln\frac{5.75}{5.19} + \frac{26.9361}{33.0625} - 1\right)\right]\times\ldots$$

$$\left[\frac{625 + 2(33.0625)(25)\ln\frac{5.75}{5} - (33.0625)(25)}{(25)(10.9010) + 33.0625(8.9010)}\right]$$

$$X = \left[\frac{(59.9986)(8.0625)}{66.125} - (51.9361)\ln \overset{.1398}{1.15}\right] - \left[(5.4505)\right.$$

$$\left.\left(2\ln \overset{.1025}{1.1079} + .8147 - 1\right)\right]\left[\frac{625 + 1653.125\ln 1.15 - 82[illegible]}{272.525 + 294.2893}\right. -$$

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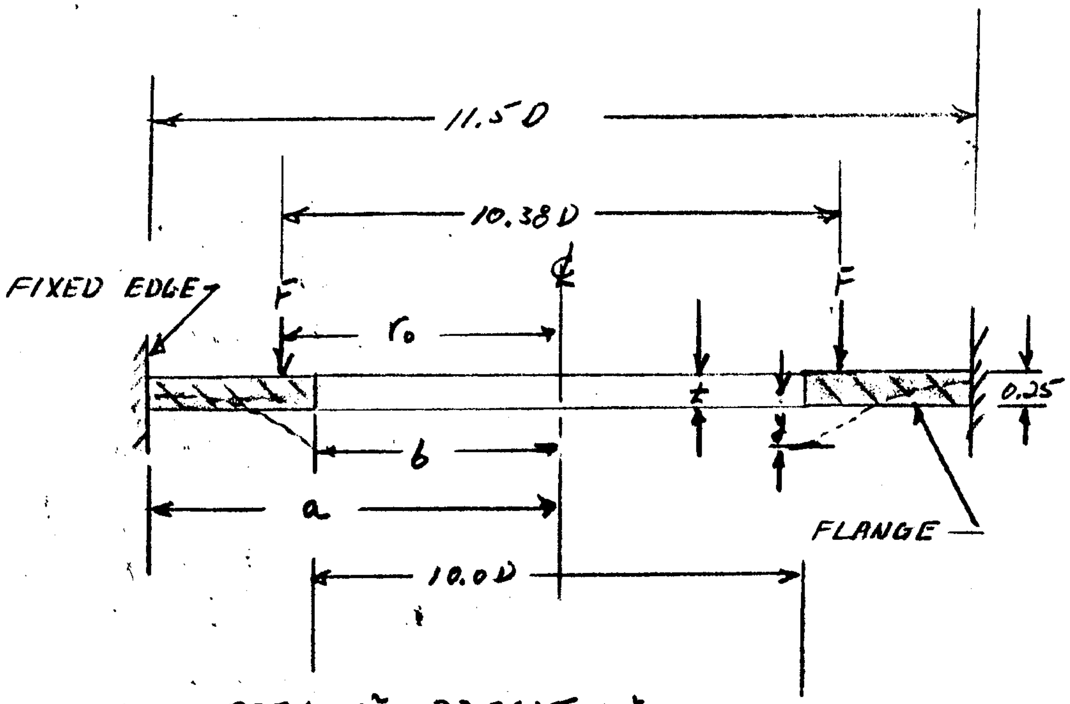
10.2.3 (CONT)

REF. FIGURE 10.2.3-6



$a = 5.75$; $a^2 = 33.0625$ IN²

$r_0 = 5.19$ IN. ; $r_0^2 = 26.9361$ IN²

$b = 5.0$ IN ; $b^2 = 25.0$ IN²

FIGURE 10.2.3-8 ~ FLANGE RING

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10.2.3 (CONT)

$$X = [.0549] - [.1074][.0521]$$

$$X = .0493$$

SO THAT EQUATION 10.2.3-11 BECOMES:

$$K_F = \frac{2(\pi)(10.3)(10^{+6})(9.9010)^2(.25)^3}{3[(9.9010)^2-1](.0493)}$$

$$\boxed{K_F = 6.904\,(10^{+6})\ \text{LB/IN}} \qquad (10.2.3-12)$$

FOR SPRINGS IN SERIES:

$$K' = \frac{1}{1/K_G + 1/K_F} \qquad (10.2.3-13)$$

SUBSTITUTING EQUATIONS 10.2.3-10 AND -12 INTO -13:

$$K' = \frac{1}{\frac{1}{.6208(10^{+6})} + \frac{1}{6.904(10^{+6})}} \quad \text{LB/IN}$$

$$K' = \frac{1}{1.7557(10^{-6})}$$

$$\boxed{K' = .5696\,(10^{+6})\ \text{LB/IN}} \qquad (10.2.3-14)$$

SPRING CONSTANT OF THE FOUNDATION IS PER UNIT WIDTH, EQUATION 10.2.3-14 IS DIVIDED πD, WHERE D IS ASSUMED:

$$D = 10.38$$

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10.2.3 (CONT)

$$K = \frac{K'}{\pi D} = \frac{.5696(10^{+6})}{\pi(10.38)} \ \ LB/IN/IN$$

$$\boxed{K = .0175(10^{+6}) \ LB/IN/IN} \qquad (10.2.3-15)$$

AND FOR THE WINDOW:

$$I = \frac{b}{12} h^3 = \frac{1(.5)^3}{12}$$

$$I_w = .0104 \ IN^4$$

FROM TABLE 10.2.3-1:

$$E_w = 11.8(10^{+6}) \ PSI$$

THEREFORE:

$$\lambda = \sqrt[4]{\frac{.0175(10^{+6})}{4(11.8)(10^{+6})(.0104)}}$$

$$\lambda = \sqrt[4]{.0357}$$

$$\lambda = .4345 \qquad (10.2.3-16)$$

ALSO:

$$q = p\,b = p(1) \ LB/IN \qquad (UNIT \ WIDTH)$$

$$\lambda l = .1651$$

$$2\lambda l = .3302$$

NOW SUBSTITUTING THE APPROPRIATE VALUES INTO EQUATION 10.2.3-5:

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10.2.3 (CONT)

$$M_A = -\frac{p(10)}{12(.4345)}\left\{\quad\right\}$$

$$\left\{\frac{(.4345)^2(10)^2(\sinh^2 .1651 - \sin^2 .1651) - 6(\sinh^2 .1651 + \sin^2 .1651)}{(.1651)(\sinh^2 .1651 - \sin^2 .1651) + \sinh .3302 + \sin .3302}\right\}$$

$\sinh .1651 = .1658$ ~ $\sinh^2 .1651 = .0275$

$\sin .1651 = .1650$ ~ $\sin^2 .1651 = .0273$

$\sinh .3302 = .3362$ ~ $\cosh .1651 = 1.0135$

$\sin .3302 = .3256$ ~ $\cos .1651 = .9863$

$$\left\{\frac{(.4345)^2(10)^2(.0275 - .0273) - 6(.0275 + .0273)}{(.4345)(10)(.0275 - .0273) + .3362 + .3256}\right\}$$

$$\left\{-.4905\right\}$$

THEREFORE THE MOMENT AT POINT Ⓐ FIGURE 10.2.3-6;

$$M_A = -\frac{p(10)(-.4905)}{12(.4345)} = \boxed{+.9407\,p} \quad \text{LB-IN} \qquad (10.2.3\text{-}17)$$

AND;

$$Q_A = \frac{p(10)}{2} = \boxed{p(5) \quad (\text{LBS})} \qquad (10.2.3\text{-}18)$$

10.2.3.5 SAG FOR SEMI-FIXED SUPPORT CONDITION

FOR THE UNSUPPORTED SPAN (Ⓐ-Ⓒ FIGURE 10.2.3-6) REFERING TO REFERENCE NO. 5, PG 194, CASE 1 AND PG 197, CASE 12 PLUS EQUATIONS 39A AND 40a, PG 52, OF REFERENCE NO. 17:

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10,2,3 (CONT)

$$y_{A-c} = \frac{(3)\,p\,(m^2-1)}{(8)(E)(m^2)(t^3)}\left[\frac{(5m+1)a^4}{2(m+1)} + \frac{r^4}{2} - \frac{(3m+1)r^2a^2}{m+1}\right] + \ldots$$

$$+ \frac{6(m-1)(M_A)(a^2)}{E(m)(t^3)} + \frac{6(m-1)(M_A)(r^2)}{E(m)(t^3)} + \ldots$$

$$+ \frac{2Q_A\lambda}{K}\left[\frac{(\sinh\lambda l)(\cosh\lambda l) - (\sin\lambda l)(\cos\lambda l)}{\sinh^2\lambda l - \sin^2\lambda l}\right]$$

$$+ - \frac{2(M_A)\lambda^2}{K}\left[\frac{\sinh^2\lambda l + \sin^2\lambda l}{\sinh^2\lambda l - \sin^2\lambda l}\right] \qquad (10.2.3-19)$$

FOR THE NUMERICAL VALUES ON PAGE 10,2,3-26 AND 10,2,3-27 AND FIGURE 10,2,3-6:

$$y_{A-c} = \frac{(3)(p)(22.1130)}{8(11.8)(10^{+6})(23{,}1130)({,}5)^3}\left[\frac{(25.038)(5)^4}{2(5.8076)} + {,}5r^4 + \ldots\right.$$

$$\left. + \frac{(15{,}4228)(r^2)(25)}{(5.8076)}\right] + \frac{6(3{,}8076)({,}9407)(p)(25)}{(11.8)(10^{+6})(4.8076)({,}5)^3} + \ldots$$

$$+ \frac{6(3{,}8076)(.9407)(p)(r^2)}{(11.8)(10^{+6})(4.8076)({,}5)^3} + \ldots$$

$$+ \frac{10(p)({,}4345)}{{,}0175(10^{+6})}\left[\frac{({,}1658)(1.0135) - ({,}1650)({,}9863)}{{,}0275 - .0273}\right] + \ldots$$

$$+ \frac{(2)({,}9407)(p)({,}4345)^2}{.0175(10^{+6})}\left[\frac{{,}0275 + {,}0273}{{,}0275 - {,}0273}\right]$$

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10.2.3 (CONT)

$$y_{A-C} = p(10^{-6})\Big[327.7053 + ,1216\, r^4 - 16,1487\, r^2 + \cdots$$

$$+ 75,7658 - 3,0306\, r^2 + 6578.0817 + \cdots$$

$$+ 5561,2602\Big]$$

$$y_{A-C} = p(10^{-6})\Big[1420.2926 - 19,1793\, r^2 + ,1216\, r^4\Big]$$

(10.2.3-20)

FOR THE SUPPORTED SPAN (Ⓐ-Ⓑ FIGURE 10.2.3-6) AND REFERENCE 17, PAGE 52, EQU. 39a & 40a:

$$y_{A-B} = \frac{2}{K}\Big[Q_A \lambda \Big(\frac{(\sinh \lambda l)(\cos \lambda x)(\cosh \lambda x') - (\sin \lambda l)(\cosh \lambda x)(\cos \lambda x')}{\sin^2 \lambda l - \sin^2 \lambda l}\Big)$$

$$+ \frac{-M_A \lambda^2}{\sinh^2 \lambda l - \sin^2 \lambda l}\Big[\quad\Big]$$

$$\downarrow$$

$$\Big[(\sinh \lambda l)(\cosh \lambda x' \sin \lambda x - \sinh \lambda x' \cos \lambda x) + \cdots$$

$$+ \sin \lambda l (\sinh \lambda x \cos \lambda x' - \cosh \lambda x \sin \lambda x')\Big]$$

(10.2.3-21)

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EPIC 2000 PROGRAM

NAME OR DISCRIPTION: ______

EQUATION: $y_{A-C} = p(10^{-6})[1420.2926 - 19.1793\, r^2 + .1216\, r^4]$

$$[\ \ ] = \underset{C_1}{1420.2926} + r^2[\underset{C_2}{.1216}\, r^2 - \underset{C_3}{19.1793}]$$

CONSTANT REGISTER	REGISTER 4	REGISTER 3	REGISTER 2	REGISTER 1	ENTER KEYBRD	CONTROL	PRINT OUT
					C_1	MAN	
C_1						STORE	
					C_2		
				C_2		ENT	
			C_2	C_2		"	
		C_2	C_2	C_2		"	
						LEARN	
	C_2	C_2	C_2	r^2	r^2		
		C_2	C_2	$C_2 r^2$		×	
					C_3		
		C_2	C_2	$[C_2 r^2 - C_3]$		−	
					r^2		
		C_2	C_2	$r^2[\ \ ]$		×	
	C_2	C_2	$r^2[\ \ ]$	C_1		R	
	C_2	C_2	C_1	$r^2[\ \ ]$		I	
		C_2	C_2	$C_1 + r^2[\ \ ]$		+	
		C_2	C_2	$C_1 + r^2[\ \ ]$		♦	$C_1 + r^2[\ \ ]$
			C_2	C_2		C	
		C_2	C_2	C_2		"	
						AUTO	
					r^2	ENT	
					C_3	ENT	
					r^2	ENT	

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10.2.3 (CONT)

THEREFORE FOR $X = .1 \quad X' = .28$

$$\lambda X = .4345(.1) = .0435$$

$$\lambda X' = .4345(.28) = .1217$$

$$\cos \lambda X = \cos .0435 = .9989$$

$$\cosh \lambda X = \cosh .0435 = 1.001$$

$$\cos \lambda X' = \cos .1217 = .9925$$

$$\cosh \lambda X' = \cosh .1217 = 1.0072$$

$$\sin \lambda X = \sin .0435 = .0435$$

$$\sinh \lambda X = \sinh .0435 = .0435$$

$$\sin \lambda X' = \sin .1217 = .1218$$

$$\sinh \lambda X' = \sinh .1217 = .1220$$

$$y_{A-B} = \frac{2}{.0175(10^{+6})}\Big[(5p)(.4345)\big(\quad \big) + \ldots$$

$$\left(\frac{(.1658)(.9989)(1.0072) - (.1650)(1.001)(.9925)}{.0275 - .0273}\right) + \ldots$$

$$+ \frac{(.9407p)(.4345)^2}{.0275 - .0273}\Big[\quad \Big]\Big]$$

$$\Big[(.1658)\big((1.0072)(.0435) - (.1220)(.9989)\big) + .1650\big(\underset{.0174}{(.0435)(.9925)} + \ldots$$

$$- (1.001)(.1218)\big]\Big]$$

$$\underline{y_{A-B} = 948.1207\, p(10^{-6}) \text{ IN.}} \qquad (10.2.3\text{-}22)$$

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10,2,3 (CONT)

FOR $X = ,28 \quad X' = ,1$

$\lambda X = .4345(,28) = ,1217$

$\lambda X' = ,4345(,1) = ,0435$

$\cos \lambda X = \cos ,1217 = ,9925$

$\cosh \lambda X = \cosh ,1217 = 1,0072$

$\cos \lambda X' = \cos .0435 = .9989$

$\cosh \lambda X' = \cosh .0435 = 1,001$

$\sin \lambda X = \sin ,1217 = ,1218$

$\sinh \lambda X = \sinh ,1217 = ,1220$

$\sin \lambda X' = \sin ,0435 = ,0435$

$\sinh \lambda X' = \sinh ,0435 = ,0435$

$$y_{A-B} = \frac{2}{,0175(10^{+6})}\Bigg[(5p)(,4345)(\quad) + \cdots$$

$$\left(\frac{(,1658)(.9925)(1.001) - (,1650)(1.0072)(,9989)}{,02275 - ,0223}\right) + \cdots$$

$$+ \frac{(,9407)(p)(,4345)^2}{,02275 - .0223}\Big[\quad\Big]$$

$$\Big[(,1658)\big[(1,001)(,1218) - (,0435)(,9925)\big] + \cdots$$

$$+ (,1650)\big[(,1220)(,9989) - (1.0072)(,0435)\big]\Big]$$

$$\underline{y_{A-B} \doteq 1037,7919(10^{-6})\,p \text{ IN}} \qquad (10,2,3-23)$$

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10.2.3 (CONT)

FOR $x = .38 \quad x' = 0$

$\lambda x = .4345(.38) = .1651$

$\lambda x' = 0$

$\cos \lambda x = \cos .1651 = .9863$

$\cosh \lambda x = \cosh .1651 = 1.0135$

$\cos \lambda x' = \cos 0 = 1$

$\cosh \lambda x' = \cosh 0 = 1$

$\sin \lambda x = \sin .1651 = .1650$

$\sinh \lambda x = \sinh .1651 = .1658$

$\sin \lambda x' = \sin 0 = 0$

$\sinh \lambda x' = \sinh 0 = 0$

$$y_{AB} = \frac{2}{.0175(10^{+6})}\Big[(5p)(.4345)\big(\qquad \big) + \ldots$$

$$\downarrow$$

$$\left(\frac{(.1658)(.9863)(1) - (.1650)(1.0135)(1)}{.0275 - .0273}\right) + \ldots$$

$$+ \frac{(.9407)(p)(.4345)^2}{.0275 - .0273}\Big[\qquad \Big]$$

$$\Big[(.1658)\big((1)(.1650) - 0(.9863)\big) + .1650\big((.1658)(1) - 0\big)\Big]$$

$$\underline{y_{A-B} = 960.5310\, p\, (10^{-6})} \qquad (10.2.3\text{-}24)$$

A PLOT OF EQUATIONS 10.2.3-22, -23 AND -24 IS SHOWN IN FIGURE 10.2.3-9.

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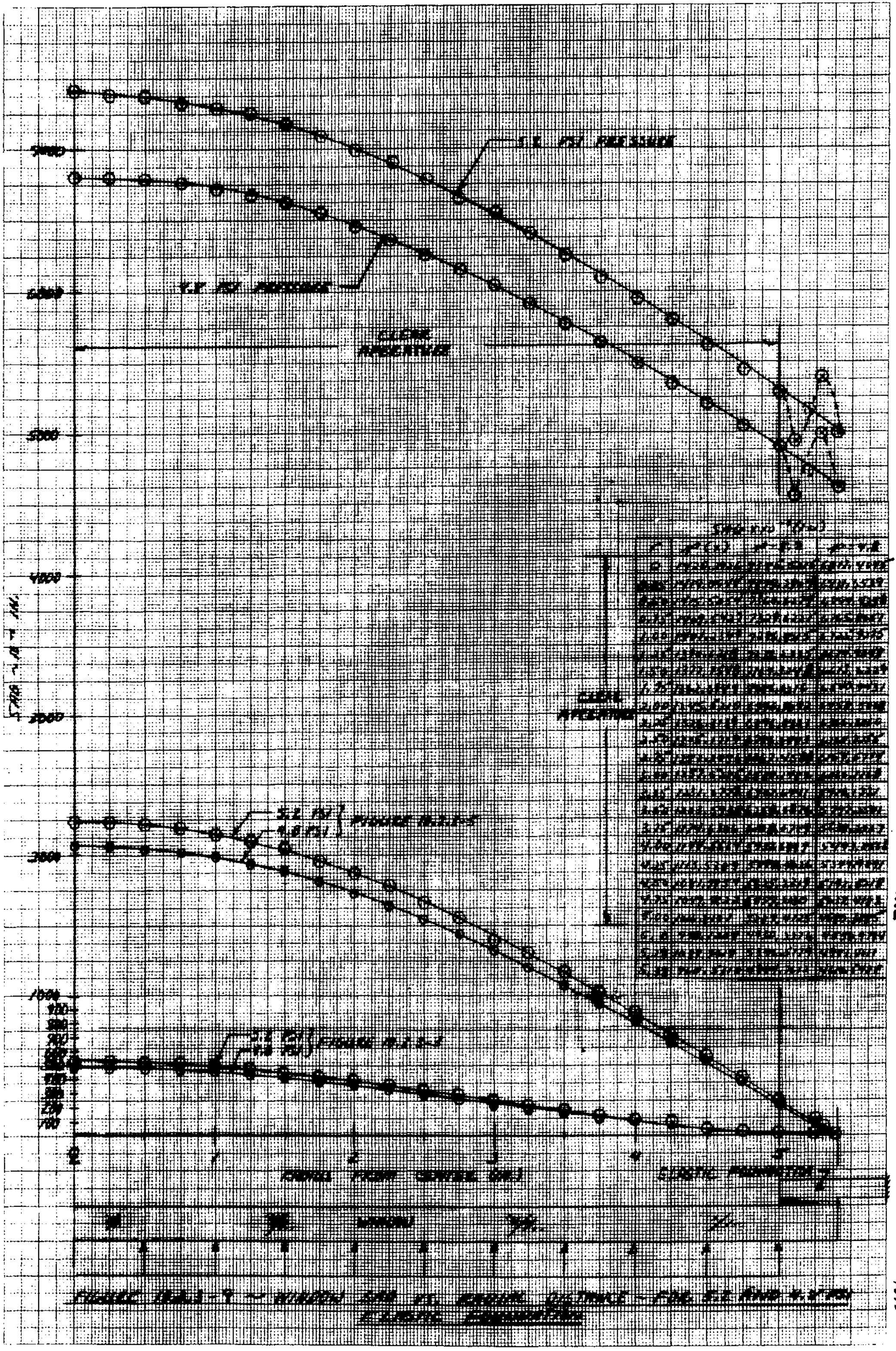

FIGURE 10.2.1-9 ~ WINDOW SAG VS. RADIAL DISTANCE - FOR 5.2 AND 4.8 PSI ELASTIC FOUNDATION

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10.2.1-34

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10.2.3 (CONT)

10.2.3.5 RESULTS AND CONCLUSIONS

THE WINDOW SAG DUE TO THE PRESSURE DIFFERENTIAL OF 5.2 AND 4.8 PSI WAS EVALUATED FOR THREE CONDITIONS, FIXED EDGE SUPPORT, SIMPLE SUPPORTED AND SUPPORTED ON AN ELASTIC FOUNDATION. THIS ANALYSIST IS NOT CERTAIN WHICH VARIABLIES AND MAGNITUDE ARE SIGNIFICANT FROM THE STANDPOINT OF OPTICAL PERFORMANCE OF THE TELESCOPE SYSTEM.

REFERING TO FIGURE 10.2.3-3, FOR THE FIXED EDGE CONDITION, THE MAXIMUM SAG IS 526.+ (10^{-6}) IN. THE SHAPE OF THE SURFACE WOULD BE ASPHERIC. WHETHER THIS IS SIGNIFICANT IS QUESTIONABLE AT THIS TIME. UNDER THE ASSUMPTIONS MADE, THERE WOULD ALSO BE AN AIR GAP CHANGE OF APPROXIMATELY 10 (10^{-6}) IN.

FOR THE SIMPLE SUPPORTED CONDITION, FIGURE 10.2.3-5 SHOWS THE SAG PLOT. THE MAXIMUM SAG IS 2002 + (10^{-6}) IN. WITH AN AIR GAP CHANGE OF ABOUT 250 (10^{-6}) IN. THE SAG CURVE MATCHES VERY CLOSELY A SPHERICAL CURVE WITH A RADIUS OF 5572 INCHES. THIS

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10.2.3(CONT)

ANALYSIS, INCIDENTLY, DID NOT ACCOUNT FOR WHAT WOULD BE A VERY SMALL CHANGE IN THICKNESS AND DIEFFERENCE IN RADII OF THE TWO SURFACES OF THE WINDOW.

SECTION 10.2.3.4 ASSUMED THE GASKET AND WINDOW FLANGE AS AN ELASTIC FOUNDATION. FIGURE 10.2.3-9 SHOWS THE SAG PLOTS FOR THE 5.2 AND 4.8 PSI DIFFERENTIAL. THE MAXIMUM CLEAR APERATURE SAG IS $2098+(10^{-6})$ IN. OR ALMOST THE SAME AS THE SIMPLY SUPPORTED CONDITION. THE AIR GAP CHANGE, HOWEVER, IS ABOUT $5287+(10^{-6})$ INCHES.

3.6.11 Lab Module Atmosphere Effects on Optical Design

In section 3.6.9 the effects of pressure changes from air at STP to air 5.0 psi are discussed. Table 3.6.9-3 indicates a focal shift of -3.81 diopters.

This sections shows the effects of changing from air to an environment of a 30% He/70% O_2 mix (by volume) at STP. Table 3.6.11-1 shows the results of our analysis.

As indicated in the footnote of Table 3.6.11-1, the effect of reducing the pressure to 5.0 psi would be 33% of the focal shift at STP.

To sum up the final focal shift between the object and the reticle for the change from air at STP to 30% He/70% O_2 at 5.0 psi, we use the values of both Table 3.6.9-3 and Table 3.6.11-1.

Focal Shift due to 5.0 psi	-3.81 D
33% of focal shift due to 30% He/70%O_2	-0.07 D
Total focal shift	-3.88 D

The defocussing required to compensate for the environment is built into the telescope at assembly. Performance tests are conducted by defocussing the test collimator to compensate for the laboratory environment.

TABLE 3.6.11-1

Effects of a Shift from Air Environment to a 30% He, 70% O_2 mix (by volume) at STP

Defocussing of both Reticle and Object Expressed in Diopters

Standard Convention, Nominal System in Focus

Object Defocus	Reticle Defocus	Difference between Object and Reticle Defocus *
-0.21	- 0.01	-0.20

* May be compensated for prior to mission once mix is selected. Actual effect at 5.0 psi will be approximately 33% as big, or - 0.07 diopters difference between Object and Reticle as caused by an air - He/O_2 shift, alone.

3.6.12 Relationship between Field Curvature and Off-axis Performance

This report discusses the effects of various balancings of the astigmatic field curves of the AO Telescope upon best focus image quality and also the accommodation required of the eye to reach this best focus.

3.6.12.1 Introduction

The Optical Design Department at Itek has completed a trade-off study to determine the effect of various balancings of the astigmatic field curves upon best-focus image quality, and also the accommodation required of the eye to reach this best focus. The data resulting from this study is based upon third-order aberration theory and assumes a 2 mm exit pupil diameter for the AO telescope.

3.6.12.2 Discussion

The mean astigmatic field curve is defined as the locus of points midway between the tangential and sagittal astigmatic field curves. In third-order aberration theory, if astigmatism is the predominant off-axis aberration present, the mean astigmatic field curve will also be the curve of best focus.

The angular resolution in minutes of arc observed at the eye has been calculated for various mean astigmatic field curves which correspond to various balancings of the tangential and sagittal field curves. It is assumed here that the eye accommodates to this mean astigmatic curve. This data is presented in Figure 3.6.12-1. The deviation of the mean astigmatic field curve from a flat image plane at a half-field angle of 30 degrees is expressed in diopters and is labeled $D_B$max.

In the AO design, the mean astigmatic field curve has a value of 2.0 diopters. As can be seen from Figure 3.6.12-1, the design case of D_B max. = 2.0 diopters represents a good balance between resolution across the field and the amount of eye accommodation required to reach best focus. It is, therefore, apparent that the off-axis resolution of the telescope can be improved only at the expense of a larger required eye accommodation.

Because of higher order astigmatism (6th, 7th, etc.) and also the presence of other aberrations, the best focal positions at any field angle will not, in general, lie midway between the tangential and sagittal astigmatic field curves. In the telescope design, the best focus is at 1.5 diopters at full field, and the modulation transfer function curves give resolutions better than that predicted by the D_B max. = 2.0 curve in Figure 3.6.12.-1. Thus the model we have been using is a good but slightly pessimistic one for this specific design.

3.6.12.3 Comparison of Theoretical Analysis with Actual Performance

The mean astigmatic field curve has a value of 2.0 diopters at 127X. However, because of higher order aberrations, the best focus lies at a position of 1.5 diopters at full field. The effects of higher order aberrations vary greatly and are beyond the scope of the preceding analysis. However, by comparing the actual performance with that predicted by the preceding theoretical analysis, it can be shown that a fair agreement has been achieved. The improved performance of the optical design comparison to the theoretical model is due to the optimum state of the actual design.

The ground resolution at best focus over the 60 degree apparent field of the telescope at 127X is presented in Figure 3.6.12-2. This data is based on the current normalization of the Schade threshold, and a distance of 80 nautical miles at nadir. From Figure 3. 6. 12. -2, it is seen that the nominal system under the stated conditions resolves 2. 8 feet on axis and 10. 4 feet at full field at best focus (1. 5D at full field) at 127X and 80 nautical miles; these values correspond to angular resolutions (observed at the eye) of 2. 4 and 9. 1 minutes, respectively. This value represents the static resolution of the optics alone, and should not be interpreted as a prediction of operational system performance, in which other degrading factors must be included. The theoretical analysis, as presented in Figure 3. 6. 12-1, predicts an angular resolution of 14 minutes at full-field for a 2. 0 D position. In conclusion, it is felt that this agreement is close and that the data in Figure 3. 6. 12-1 is valid.

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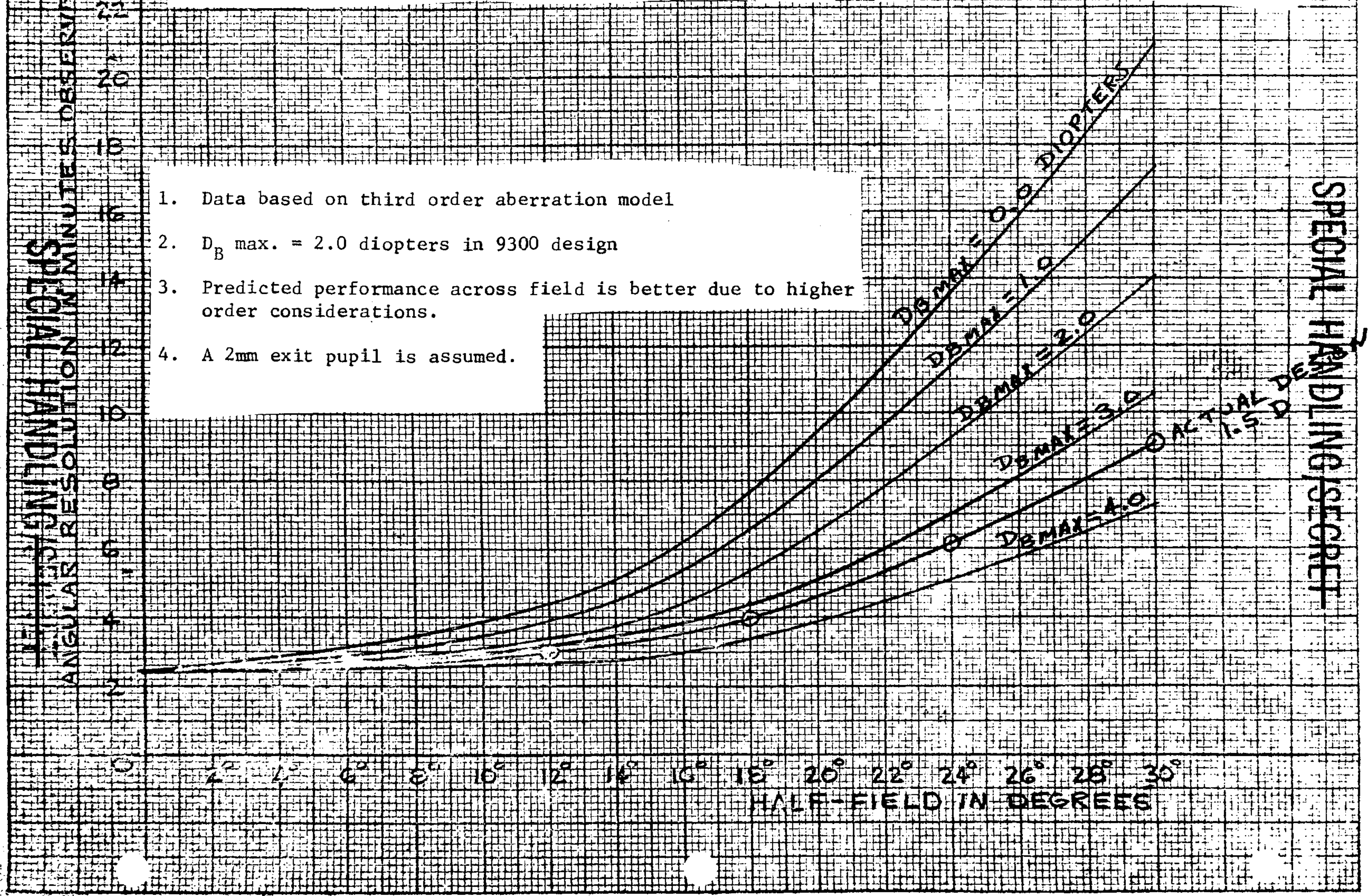
Figure 3.6.12-1 Angular resolution versus half-field for various diopters of best focus for 9300 telescope.



1. Data based on third order aberration model
2. D_B max. = 2.0 diopters in 9300 design
3. Predicted performance across field is better due to higher order considerations.
4. A 2mm exit pupil is assumed.

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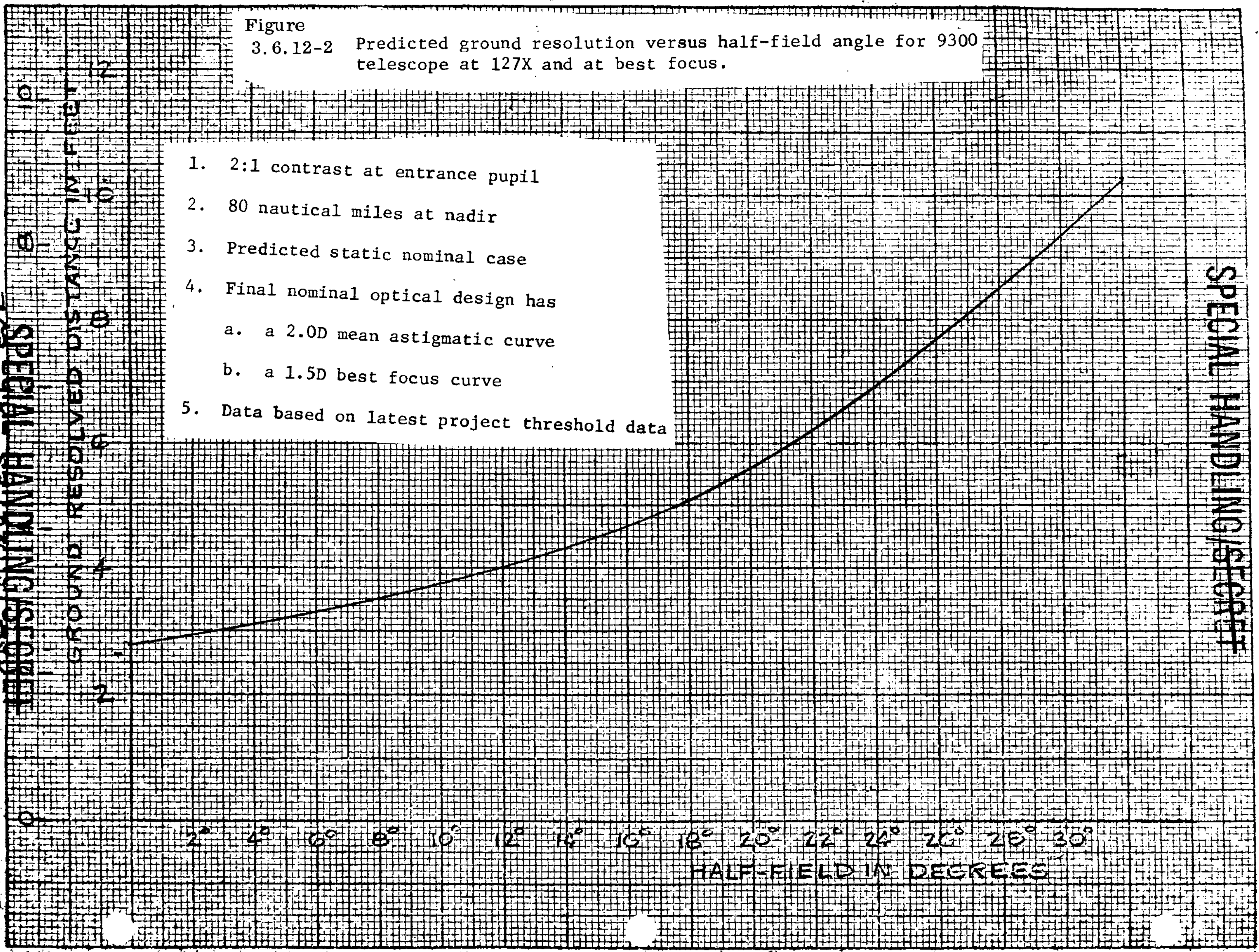

Figure 3.6.12-2 Predicted ground resolution versus half-field angle for 9300 telescope at 127X and at best focus.

1. 2:1 contrast at entrance pupil
2. 80 nautical miles at nadir
3. Predicted static nominal case
4. Final nominal optical design has
   a. a 2.0D mean astigmatic curve
   b. a 1.5D best focus curve
5. Data based on latest project threshold data

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3.6.13 Zoom Lens Type Tradeoff

The optical design tradeoffs between mechanically and optically compensated zoom configurations for the A/O telescope are discussed in this section.

The three major zoom lens types are:

1. Mechanical Compensation - two or more lens groups move with respect to the focal plane and each other.
2. Linear Compensation - A mechanically compensated lens with the added restriction that the motions of the moving groups are linearly related.
3. Optical Compensation - A linearly compensated lens with the added restriction that the moving groups move as a unit with one stationary group between each pair of moving groups.

Thus, optically compensated lenses comprise an extremely small subset of mechanically compensated zoom lenses. The reason that they are used is based on mechanical considerations when they provide satisfactory performance. The mechanical tradeoff is not straight forward since in certain mechanically compensated lenses (e.g., AO telescope) only two groups move with no stationary elements in between; whereas, in all optically compensated lenses two or more groups move with mechanical means required to keep a lens group stationary between each pair of moving groups. In addition, the defocussing as a function of zoom position is exactly zero for mechanically compensated zoom lenses but is a non-zero value for optically compensated zoom lenses reaching small values as the number of moving groups is increased.

The practical question arises of whether two conjugate pairs (in this case the object-image pair and the entrance pupil-exit pupil pair) can be kept stationary in an optically compensated zoom. This has been shown to be possible paraxially by Silvertooth in a J.O.S.A. article* and is thus clearly achievable with mechanically compensated lenses. However, the ability to control the real exit pupil position to ± 0.02 inches over a 2:1 zoom range and 60 degree apparent field is not as easily proven and in fact is a property of the higher order aspects of the design. No optically compensated or mechanically compensated lens in the open literature has been found with these properties. For this and other reasons, the A/O telescope zoom lens was designed to achieve these specifications without the added restriction of optical compensation. The resulting zoom relay-eyepiece configuration has less than 0.2 waves spherical aberration and chromatic aberration throughout the zoom on axis. The variation of field aberrations with zoom is very small and the actual field correction is limited by the eyepiece portion rather than the zoom portion of the system.

---

* Wooters and Silvertooth, J.O.S.A. 55, 347 (1965)

3.6.14 Effect of Melt Deviations

Introduction

The effect of the standard melt tolerance of ±0.001 of the n_d value and ±0.8% of the V_d value for the objective lens elements on the performance of the 9300 objective lens system has been investigated in the 127X mode of operation. This mode was chosen since this is the magnification at which the resolution requirement is to be met.

Cases Investigated

The first case investigated was that in which the indices at all wavelengths for both the SK-16 positive element and the KzFSN-4 negative element was raised by 0.001. The second case for both elements were lowered by 0.001. In both of these cases, the effect of the change of indices on image quality was negligible. However, the back focus decreased by 0.1 inch in the first case and increased by 0.1 inch in the second case. The nominal back focal length is 0.9 inch. These two cases indicate that serious losses in resolution can be avoided by proper matching of indices, i.e., an SK-16 element whose index is +0.001 from nominal should be used with a KzFSN-4 element whose index is approximately +0.001 from nominal, etc.

For worse cases, the indices of the crown and flint elements were changed by 0.001 in opposite directions. This produced approximately 2 waves of spherical aberration and changed the back focal length by 0.75 inch. The spherical aberration can be eliminated by changing the airspace between the objective elements by ±0.02 inch depending on the case. The back focal length, however, cannot be restored to its nominal value in all cases even with the aid of element thickness adjustment. Other first-order quantities such as equivalent focal length and Gauss image height can be held within 1%.

It is, therefore, felt that SK-16 and KzFSN-4 glasses can be ordered with the standard melt tolerance of ±0.001 for n_d and ±0.8% for V_d only if the mechanical adjustments shown in Figure 1 can be provided. Similar adjustments should also be provided if a melt tolerance of ±0.0002 is ordered but they could be on the order of one fifth those shown in the Figure 3.6.14.1.

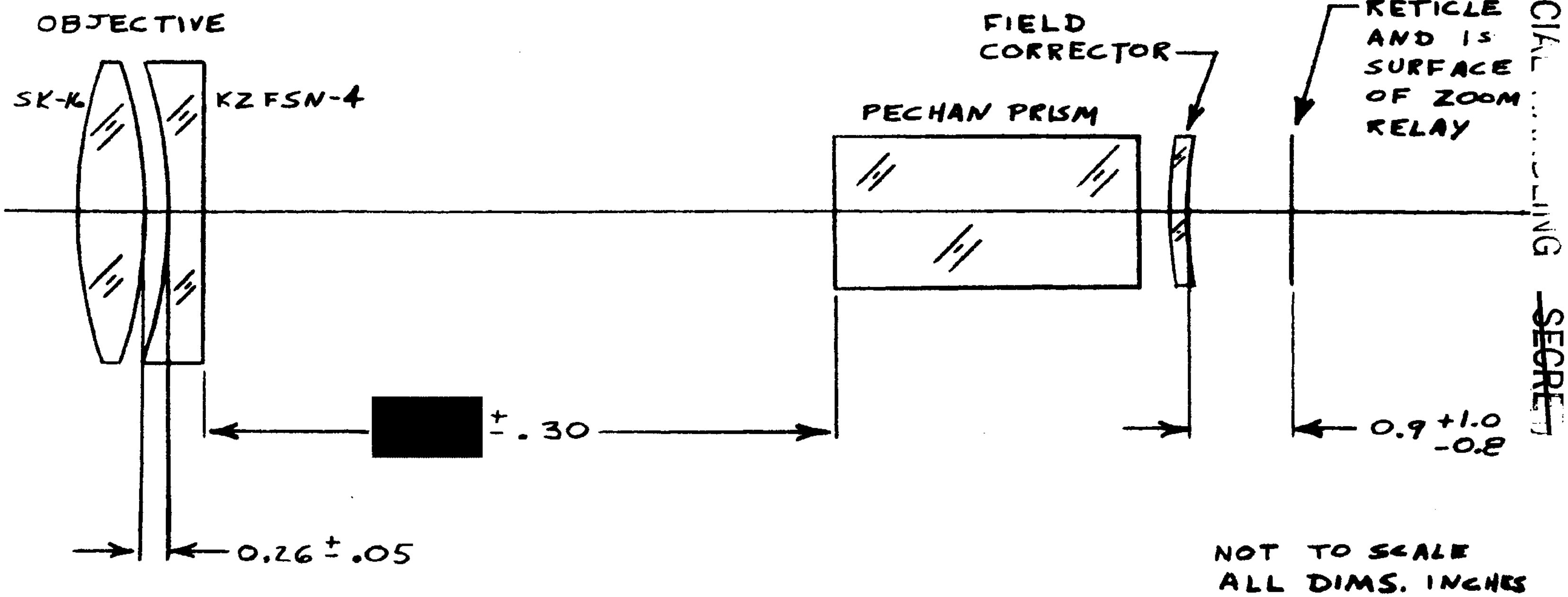

Figure 3.6.14-1 MECHANICAL ADJUSTMENTS REQUIRED IF OBJECTIVE GLASSES ARE ORDERED WITH A MELT TOLERANCE OF ±0.001 OF n_d

3.6.15 Window Thermal Analysis

There are several distinct constraints which the window must satisfy if it is to contribute to optimum system imagery. Unfortunately, many of these constraints are incompatible when considered together with the properties of commercially produced astronomical quality glass. The resultant trade-off required to select the optimum glass type is multi-dimensional and must encompass every parameter from weight to radiation-produced dispersion changes. Of critical importance are the changes in shape and index imposed by uniform temperature soaks, and both axial and radial thermal gradients. Axial gradients have as a critical parameter the linear thermal expansion coefficient while radial gradients must be additionally weighted by the thermal coefficient of the refractive index, as indicated in Table 3.6.15-4b. (The effect of $\Delta N/\Delta T$ is not felt with axial gradients as it represents a uniform change over the entire window's wavefront.) Thus, the type of gradient expected can be all important in selecting an optimum material, and this is especially the case when, as in BK-7 vs. fused silica (cf. Table 3.6.15-1), both α and dN/dT vary widely. Thermal boundary conditions are not well defined, but regardless a preliminary attempt was made at material selection.

The effects of linear axial gradients and uniform soaks are discussed in Table 3.6.15-2 and are shown not to modify image quality. Assuming a parabolic set of isotherms for a radial gradient, the maximum peak to peak tolerable temperature variations are presented in Table 3.6.15-3. For a 0.5-inch thick window, temperatures must be controlled to 2.0 degrees for fused silica but only to 4.6 degrees for BK-7 (on-axis-high power). More recent information on the thermal boundary conditions has been generated and it is expected that these isotherms will be of additional help in the selection of an optimum material. An Itek developed, Fermat's Principle Ray Trace program will be used to analyze the window in the manner described for analyzing the objective lens (cf. Section 3.10.1.5.2.), and the results interpretted with respect to material type.

TABLE 3.6.15-1

Selection of Optimum Window Material

Design Data

Parameter	BK 7	Fused Silica
Thermal Conductivity, K, $\frac{BTU}{FT\,HR\,^oF}$	.6437	.7768
Specific Heat, C_p, $\frac{BTU}{\#\,^oF}$	.205	.170
Expansion Coefficient, α, $^oC^{-1}$	7.7×10^{-6}	0.59×10^{-6}
dn/dt (Absolute)(d/He/5876Å)	0.9×10^{-6}	$10. \times 10^{-6}$
Youngs Modulus, E, psi	11.822×10^{6}	10.5×10^{6}
Poissons Ratio, μ	.208	.170
Density, ρ	2.510	2.202

TABLE 3.6.15-2

Selection of Optimum Window Material

Environmental Effects

Load Type	BK-7	Fused Silica
5.2 psi Pressure on Circular Simply-Supported Window gives maximum deflection of: (Added here for constant's effect on power only Actual pressure deflected shapes have been analyzed separately.)	.0021"	.0031"
10° F (typical) uniform axial gradient through window gives maximum deflection of:	.0012"	.0001"
	.0033" *	.0032" *

Figure changes and index shifts due to uniform thermal soaks have no effect upon image quality. Index shifts due to uniform axial gradients also have no effect, as allowable $\Delta N > .001$ for window with slight power - ($\lambda/20$ maximum Δ OPD over field/criterion)

* .0033" ± Sags < .1378" allowable sag (same $\lambda/20$ criterion)

TABLE 3.6.15-3

Non-rotationally Symmetric Radial Gradients

Allowable peak to peak variations in radial temperture distribution (^{o}F) based upon $\lambda/13$ RMS tolerable and typical parabolic gradient shape on window. On axis-high power. (Note that Gradient Shape is actually a function of window thickness, and that equation b in Table VIII is non-linear in t_o, given a non-zero power.

Window Thickness (inches)	BK-7	Fused Silica
0.25	9.16	3.06
0.50	4.58	1.96
0.75	3.42	1.47
1.00	2.32	1.16

Typical expected value must yet be fully determined. 0.50" thickness desirable from pressure test point of view and fabrication. Therefore 1/2" non-browning BK-7 seems at present thermo-optically more desirable than Fused Silica. However, as many other trade-offs are involved (e.g., there is an additional 0.5 pound per window with BK-7) and as the shape of the temperature distribution is quite important, optimum choice cannot yet be definitely determined.

TABLE 3.6.15-4

SOME CALCULATION FORMULAE, DERIVED

a. Maximum Deflection, ℄ (Pressure) $= \dfrac{3W(M-1)(5M+1)\,a^2}{16\,\pi\,EM^2 t_o^3}$

where $W = \rho a^2 \pi$, $M = 1/\mu$ and ρ = density, a = plate radius, μ = Poisson's ratio, E = Young's modulus and t_o = plate thickness

b.
$$\Delta OPD \cong (N-1)\left[\frac{-C(x^2+y^2)\,\alpha\,\Delta T}{1+\sqrt{1-C^2(x^2+y^2)}} + t_o \alpha\,\Delta T\right] + \Delta T\left[\frac{-C(x^2+y^2)}{1+\sqrt{1-C^2(x^2+y^2)}} + t_o\right]\frac{\Delta N}{\Delta T}$$

where ΔOPD = change in optical path difference due to temperature, C is an effective curvature (used to introduce approximate amounts of power), x and y are radius coordinates, N = index of refraction, α = thermal expansion coefficient, ΔT = new temperature less nominal, and $\dfrac{\Delta N}{\Delta T}$ = thermal coefficient of the refractive index.

c.
$$RMS = \sqrt{\frac{(\Delta OPD)^2}{N}}$$

where RMS = root mean square wavefront deformation