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TECHNICAL REPORT

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GROUND OPTICAL RECORDER FOR INTERCEPT DETERMINATION (GORID), MK-1A

FINAL REPORT

BY

KENNETH B. BELLINGER

MAY 1970

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INSTRUMENTATION DEVELOPMENT DIRECTORATE
NATIONAL RANGE ENGINEERING
WHITE SANDS MISSILE RANGE
NEW MEXICO

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ABSTRACT

The Ground Optical Recorder for Intercept Determination (GORID), MK-1A, is a development model of a tracking telescope with increased capability to provide optical attitude, event, and miss-distance data as compared to tracking telescopes currently in service at WSMR. Through the choice of three long focal lengths (90, 180, and 360 inches), coupled with a precise tracking mount of considerable dynamic range, the GORID offers a very versatile instrument applicable to a variety of optical recording tasks. Through the use of high resolution retrofitted shaft-angle encoding equipment, it also could provide space position at altitudes exceeding 100,000 feet.

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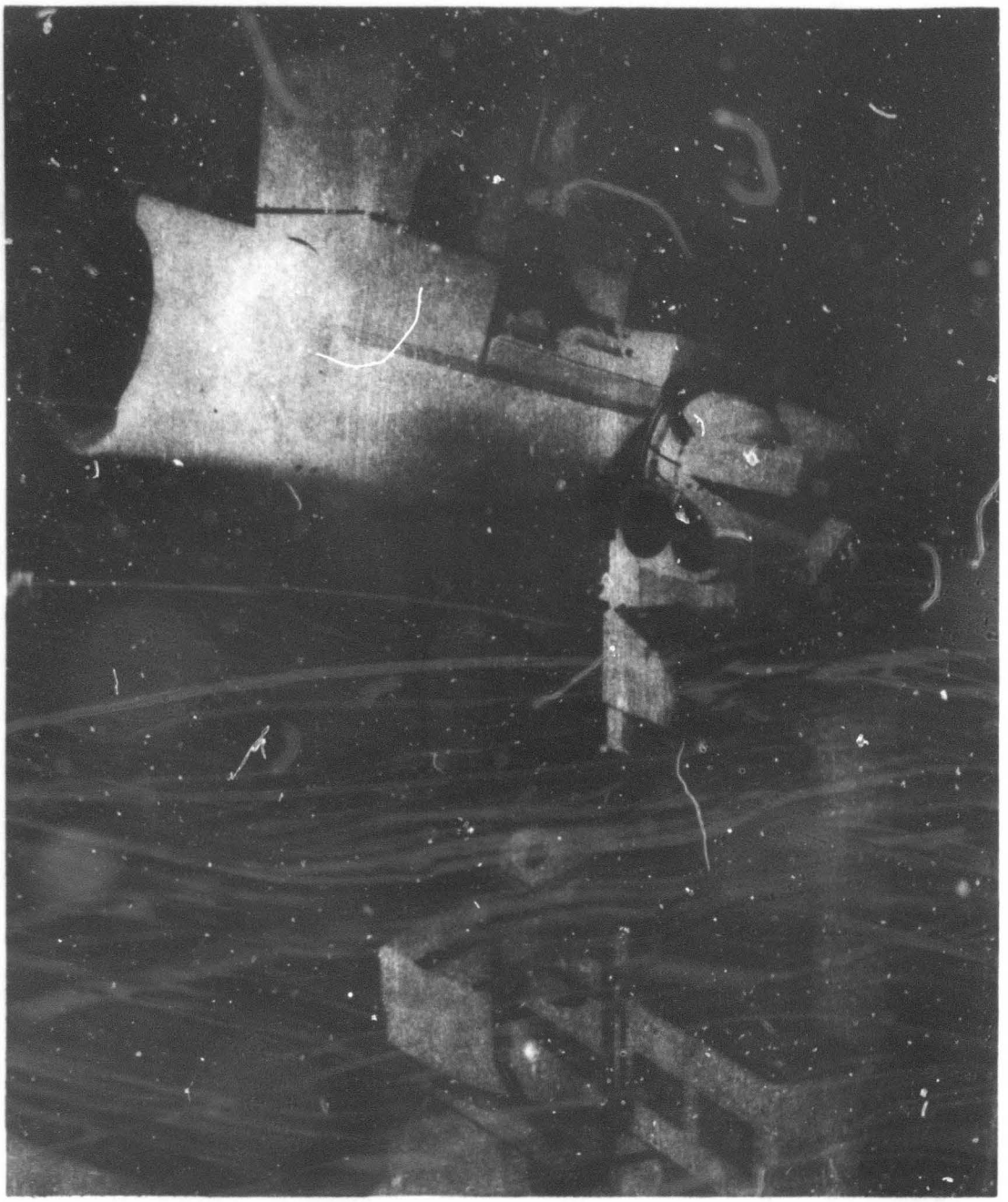

FRONTISPIECE. GROUND OPTICAL RECORDER FOR INTERCEPT DETERMINATION (GORID) MK-1A.

BACKGROUND

Within the tasks assigned to the Optics Division, Instrumentation Development Directorate, optical instrumentation for improving the attitude and event measurement capability of WSMR ranks high in priority. The development of the GORID, MK-1A, has demonstrated equipment and techniques capable of collecting high-accuracy attitude, event and miss-distance data at altitudes up to 120,000 feet, medium-accuracy miss-distance data up to 150,000 feet, and event data up to an altitude of 200,000 feet.

During 1958, WSMR experienced an increasing requirement for the instrumentation of long-range, high-altitude, high-velocity vehicles to a degree of accuracy equal to that produced by the short focal length cinetheodolites at much smaller distances. An investigation of similar, existing equipment was conducted to provide a basis for an advanced design effort. The Ballistic Research Laboratories (BRL), Aberdeen Proving Ground, had begun initial development, during 1952-1953, of several types of telescope systems tailored to particular WSMR requirements. The Warhead Function Telescope (WAFT) and the Impact Telescope (IMPT) were two instruments that were in the early phase of development when the mission was transferred to WSMR. These were not completed, but much of the engineering data and equipment, forwarded to WSMR, was useful although numerous requirements had changed in the meantime. The hardware and design information furnished by BRL provided the basis for the development of a new telescope system around the revised requirements. A new developmental plan was prepared which incorporated up-to-date requirements into a single instrument. Thus, was born the development of the Ground Optical Recorder for Intercept Determination (GORID), MK-1.

The preliminary design criteria depicted an instrument with a precision azimuth and elevation mount structure having rotational accuracies of ± 5 seconds of arc, powered by a hydraulic servo-system and controlled by a stiff-stick input arranged for a one-man operation. The optical system was to have an 18-inch diameter primary mirror with selectable focal lengths of 90, 180, 360 and 500 inches. A theodolite capability was to be provided by the digitization of shaft angle encoders and dynamic mislevel data. Target acquisition, automatic refocusing, and automatic exposure control were additional features of the design criteria. It was decided to fabricate two of these instruments in the exploratory development phase.

The following is a synopsized version of the ensuing GORID development.

1 JULY 1959 - 31 DECEMBER 1959

A study of the hydraulic drive and control system was completed. Specifications for the telescope tube and optics were prepared and submitted for bids.

1 JANUARY 1960 - 30 JUNE 1960

Drawings from BRL, applicable to GORID, were reviewed, corrected and incorporated in the GORID drawing list. Study, design and procurement of transmissions for azimuth and elevation drives, as well as hydraulic and tracking control equipment, were accomplished on a parallel basis with another development (the Small Missile Telecamera) as much of the engineering design was the same for both mounts. Studies were begun on a new design for the guide telescope which would improve tracking capability and eliminate astrodome interference. A dynamic level calibration system was under study

1 JULY 1960 - 31 DECEMBER 1960

A contract was awarded to J. W. Fecker Division of American Optical Company for the design and fabrication of two GORID telescope tubes of 18-inch aperture, complete with refocusing, auto-exposure, and selectable focal lengths. Drawings of BRL elevation and azimuth transmissions were prepared and bids for the fabrication of two sets requested. Preliminary design of several other components for GORID were prepared. These include carriage, console and angle data optical recording system. Design of an experimental hydraulic pumping unit (using pumping units left from another project) was completed and construction started. This was a packaged unit with filtering, heating, cooling, and pumping all arranged in a neat configuration. Completed specifications for a pure binary encoder, reading to 2.48 seconds of arc, with all the necessary electronic gear to record directly on computer tape in a suitable format for WSMR computers, was prepared and procurement initiated.

1 JANUARY 1961 - 30 JUNE 1961

A contract for fabrication of two carriages was awarded to Greenlee Corporation, Chicago, Illinois. A 20-power, 120-mm aperture, binocular guide-scope, which allowed the operator to face forward, was ordered for GORID use. The operator's console was reduced to about the smallest practicable physical size with the minimum of controls so that the operator could concentrate on controlling the mount.

Considerable difficulty with drift and instability was experienced with current stiff-stick tracking controls. It was necessary to abandon the original e ion and take a new approach, using low impedance stiff-stick input. A two-channel working breadboard was constructed and installed on a Small Missile Telecamera mount for evaluation. An experimental hydraulic pumping unit was completed for use with a Small Missile Telecamera mount for an evaluation study. Shaft-angle encoder system specifications were completed and advertised for bid. The specifications called for the system to provide a recorded tape, ready for the computer, giving identification, orientation, mislevel, plus azimuth and elevation angle data.

1 JULY 1961 - 31 DECEMBER 1961

The carriages were received from the contractor and installed on the bases. The elevation and azimuth transmission drives were installed and adjusted. A contract was awarded for the development and fabrication of a shaft angle encoder system for recording angular information on magnetic tape in a computer ready format. Installation of hydraulic plumbing was underway.

1 JANUARY 1962 - 30 JUNE 1962

Much progress was made on the final assembly of two mounts during this period, since the telescope tubes were received from J. W. Fecker and accepted. Carriages were fitted to the bases and finished with primer coat after extensive sanding and filling of the castings. Both elevation and azimuth transmissions, pintle bearings, hydraulic plumbing, and operator's platform were all fitted to the carriage. Two hydraulic power pumping units were assembled, painted and tested. The contract with United Electro Dynamics for the shaft angle encoding and readout system progressed satisfactorily. Preliminary in-house investigation of a dynamic electronic mislevel (and roller bearing path) measuring system, for measuring and recording this information onto magnetic tape in binary form along with shaft angle information, was completed and the design of a prototype, to be installed on a telescope, was initiated. The 20-power Buhl Binocular Guide-Scope had not been delivered, but necessary drawings to complete the scope mounting, associated operator's seat, console design, and fabrication were received.

1 JULY 1962 - 31 DECEMBER 1962

GORID No. 1 was almost completely assembled (Figure 1) with tube and tracking controls and readied for laboratory evaluation of the mount and optics, prior to moving to a range test location. The mechanism for mislevel and shaft angle encoding with associated electronics was not installed. Extensive testing on the optics, tracking control, and drive system was accomplished, and the systems appeared satisfactory. The 20-power binocular tracking guide-scopes were received and underwent evaluation. GORID No. 2 was partly assembled. Most hardware, such as the operator's platform, console, hydraulic subassemblies, and wiring of mount for the GORID No. 2 progressed slowly because of the main effort applied to the first instrument.

1 JANUARY 1963 - 30 JUNE 1963

Laboratory testing of the optics, tracking control and drive system was completed. GORID No. 1 was moved to a field site and installed (Figure 2).

1 JULY 1963 - 31 DECEMBER 1963

Instrument No. 1 was operating on the range as a tracking telescope and covering most of the missions assigned. During this period, engineering evaluation tests were performed on the tracking system electronics and

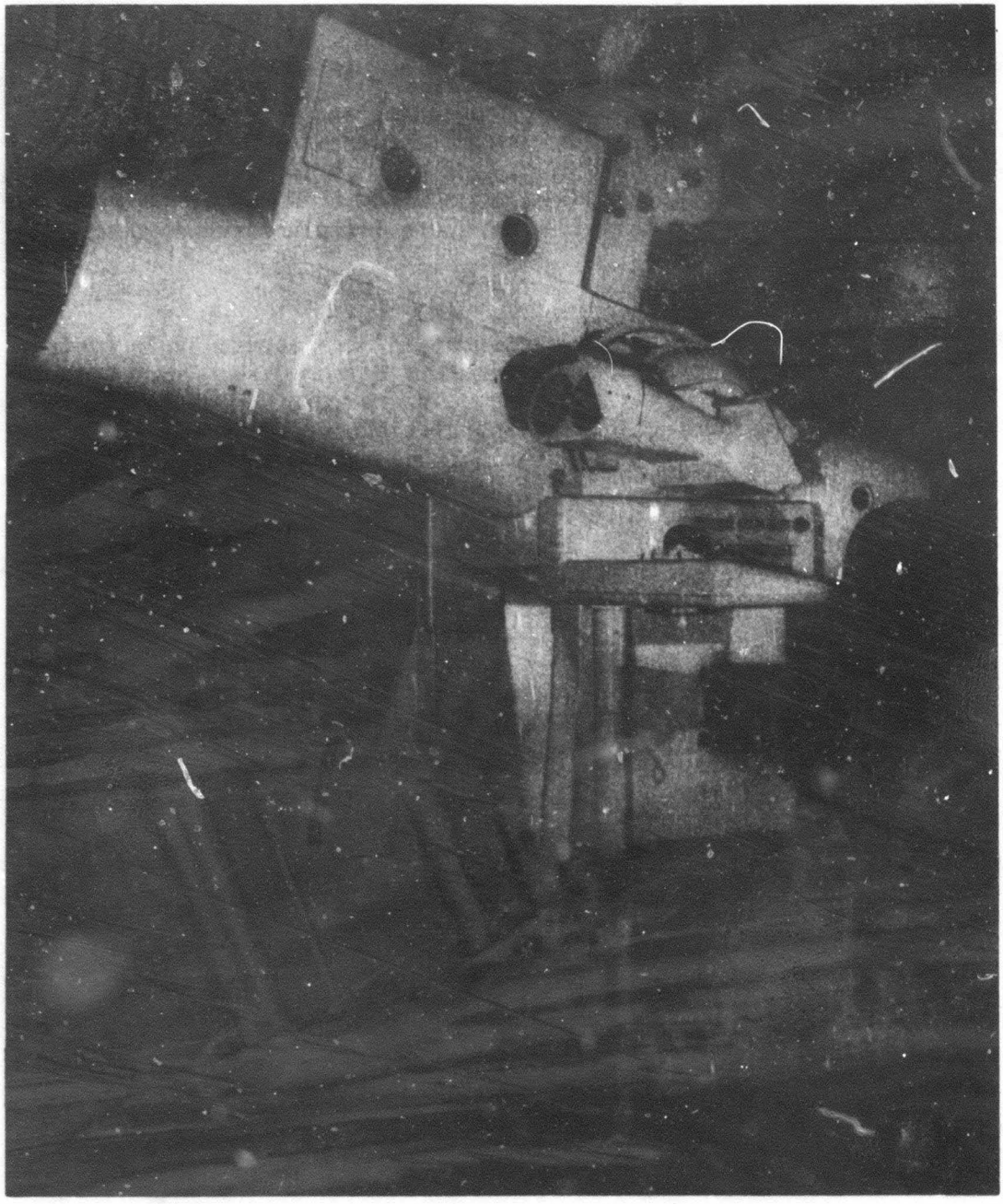

FIGURE 1. GROUND OPTICAL RECORDER FOR INTERCEPT DETERMINATION (GORID) MK-1.

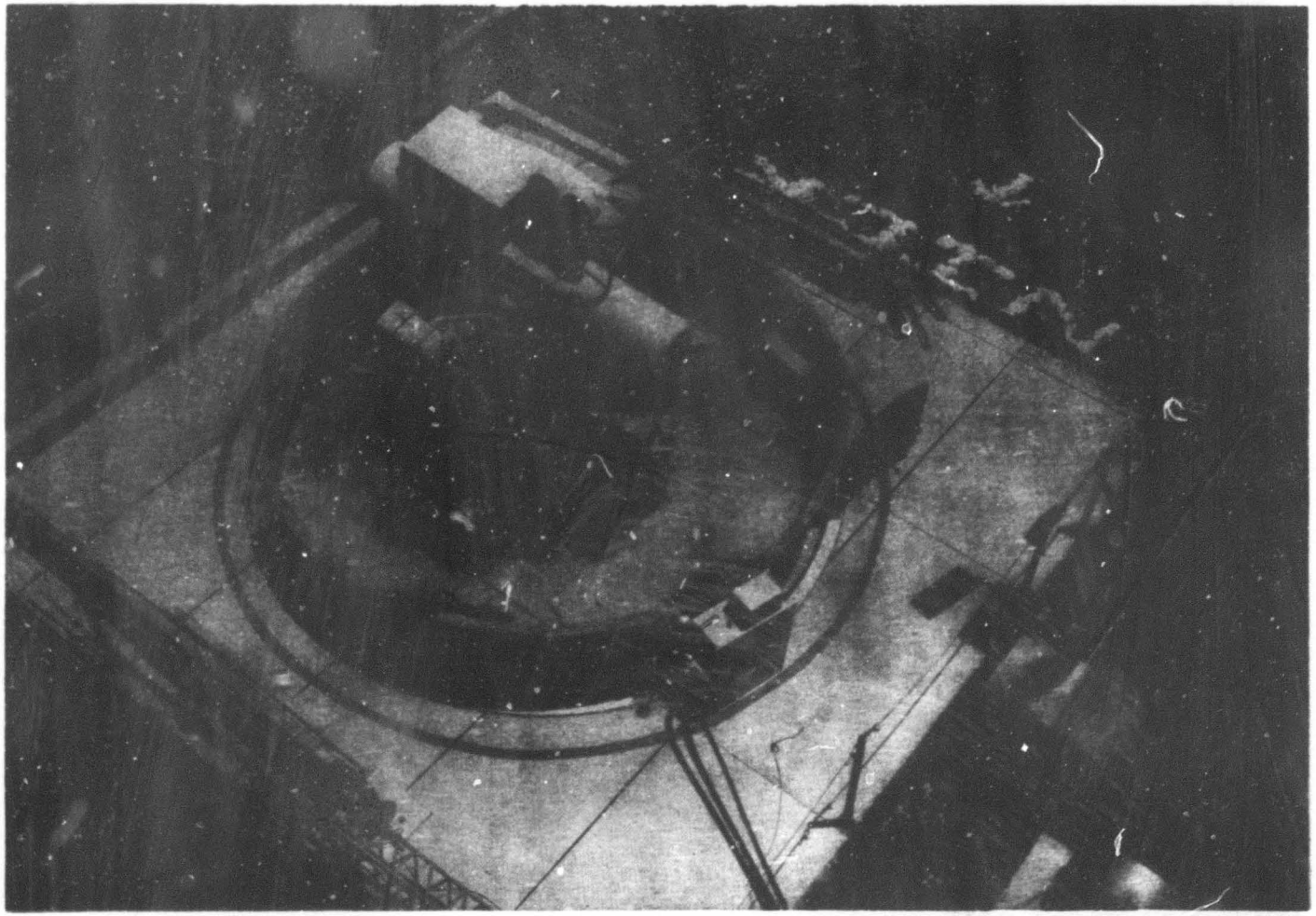

FIGURE 2. GROUND OPTICAL RECORDER FOR INTERCEPT DETERMINATION (GORID) MK-1 INSTALLATION AT NICK SITE, WSMR.

hydraulics. The basic designs seemed to be adequate, but some circuit problems existed since the mount did not perform as it should at all rates and modes. Analysis was temporarily delayed pending completion of the final circuit drawings.

The optics were not performing satisfactorily, and some adjustments were made to make them usable until remedial changes could be made. The two-shaft-angle encoding systems underwent an evaluation and corrective program. Considerable difficulties with electronics had to be corrected by the contractor. One system operated satisfactorily and was accepted. The other was being evaluated, while improvements were being made by the contractor. Work on the electronics for the mislevel recorder neared completion A prototype of the final mislevel package was fabricated.

1 JANUARY 1964 - 30 JUNE 1964

The two shaft-angle encoding systems underwent an evaluation and corrective program. Based on static tests in the laboratory, both encoding systems were accepted. Preparation of the mount to receive the encoders was completed. Work on the mislevel recorder, including static tests in the laboratory, were completed. Instrument No. 2 was equipped with the mislevel recorder in preparation for field testing. Static accuracies to 1/2 second of arc had been achieved with excellent repeatability.

Engineering evaluation tests continued on GORID No. 1, while operating it on range tracking missions. The tracking system electronics and hydraulics needed improvement and the optical system needed updating. The main problem in the optical system centered around its light losses. While the design produced in the GORID MK-1 was appropriate at one time, a faster optical system was desired by WSMR. Based upon the ever-increasing range requirements at this time, it looked doubtful that the GORID MK-1 system would be implemented when the R&D was completed.

The second GORID, MK-1, was almost completed when, during June 1964, it was decided to withdraw the first instrument from the field and accomplish some major redesign of the entire GORID, MK-1 system. The redesigned system, to be designated as the GORID, MK-1A, would remedy the problems encountered in the GORID, MK-1 instrument. The optical system was to be redesigned, addressing the problems of illumination, automatic refocusing, and a low frequency vibration which was causing image blur. (The requirement for a 500 inch focal length was removed from the design criteria as was the automatic exposure control capability.) Replacement of the rate gyroscope (for the velocity feedback to the tracking system) with tachometers necessitated a redesign of both elevation and azimuth transmissions. The replacement of hydraulic servo-motors was required to improve the 300:1 dynamic range of the mount. A transistorized tracking system, compatible

with the ARTRAC* (Advanced Range Testing, Reporting and Control) digital acquisition concept was also included in the redesign. The MK-1 operator's control station (Figure 3) required a human engineering redesign and a compensation (for focus) system was also included in the MK-1A design. It was decided that the angle encoding and mislevel system would not be installed until additional GORID MK-1A systems were procured under the range modernization program. (This was predicated on the requirement for two or more similar instruments in a theodolite instrumentation complex to produce meaningful data.) Therefore, the GORID MK-1A was not to have an immediate theodolite capability, but would retain the same potential capability of the MK-1. Ultimately, through the use of retrofitted shaft-angle encoding equipment, the GORID MK-1A could have the ability to obtain space position data at altitudes exceeding 100,000 feet.

1 JULY 1964 - 30 JANUARY 1970

The next five year period was one of frustration for the GORID, MK-1A development. It was plagued with a steady stream of delaying encounters:

> The task was deferred; carried as a low-priority effort; or incorporated into the higher-priority Small Missile Telecamera work as a slack filling effort. (During this period it was decided to complete only one GORID, MK-1A instrument and complete the second instrument when, and if, funds and manpower became available.)
>
> Difficulties in obtaining the interest of industry to bid on the manufacture of one-of-a-kind castings and the subsequent machining effort.
>
> Catastrophic failure of the new hydraulic motor upon which much of the redesign was based. The bearing race case disintegrated. The manufacturer, stating that similar problems (thought to have been caused by insufficient heat treatment) had been encountered before, took the prototype model out of circulation and initiated a redesign effort. A new hydraulic motor was searched for, found and procured, but its use required further redesign of the hydraulics and gear train.
>
> Interferometric testing of the new optical system showed excessive astigmatism in the primary mirror when the mirror was mounted in its cell. This was due, apparently, to a 0.0035 inch bevel around the mirror circumference, which resulted in bending moments and causing mirror deflection. (With this exception, the optical system appeared to be as designed.)

*ARTRAC is a control system being developed at WSMR. The data acquisition portion of this system will sample the angle position data from several tracking instruments on the range (optics as well as radar). The sampled data is fed to a central computer and the resultant refined target distance and pointing angle information is transmitted to more accurately direct tracking instruments involved in the mission.

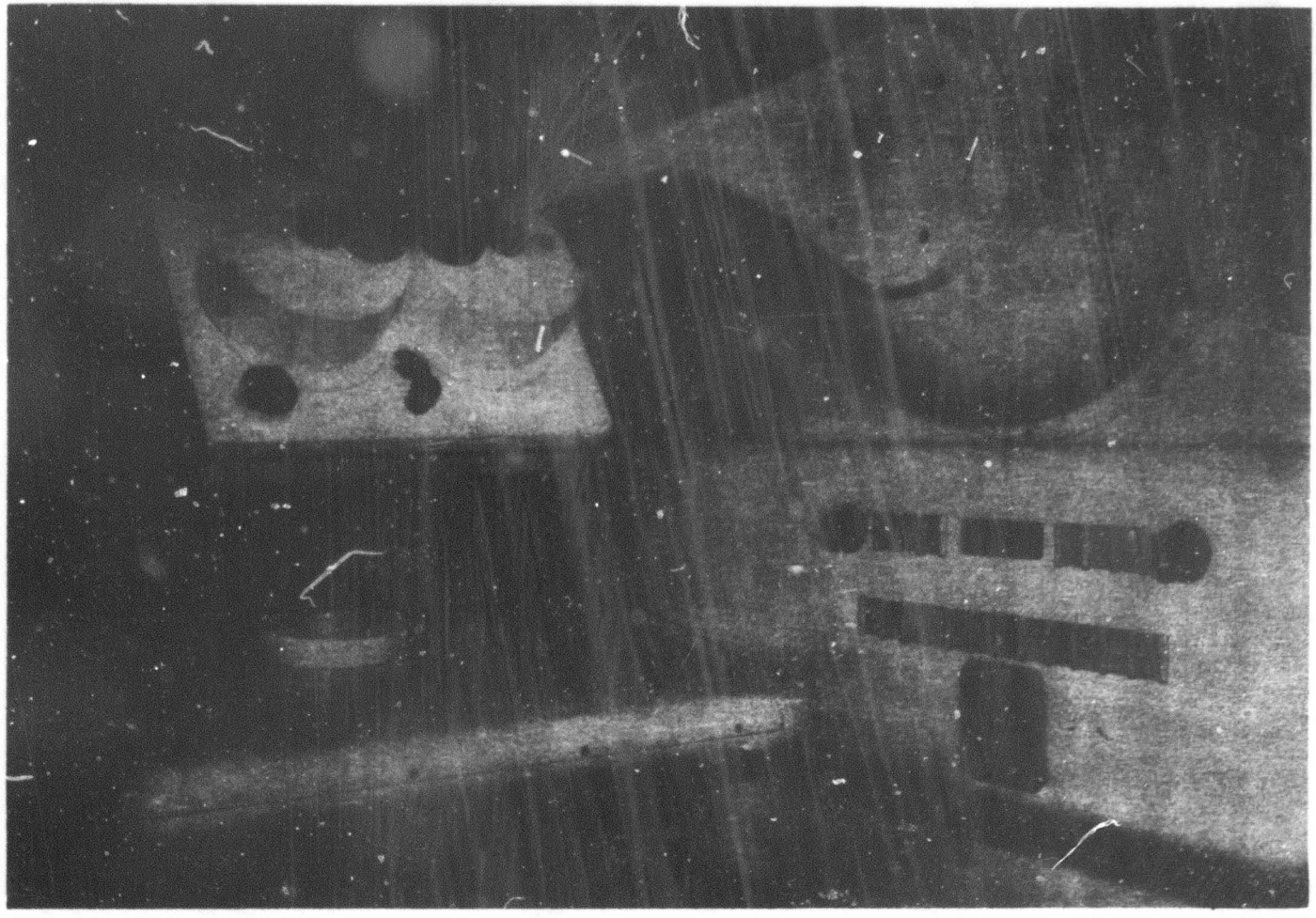

FIGURE 3. OPERATOR CONTROL STATION, GROUND OPTICAL RECORDER FOR INTERCEPT DETERMINATION (GORID) MK-1.

Finally, during May 1969, a GORID, MK-1A tracking telescope was installed within a 16-foot astrodome on the roof of a 26 foot by 26 foot building referred to as Gregg Site, WSMR (Figure 4). All problems, except the optical system, have been resolved and the instrument was ready for mechanical and electrical integration to the field site. (It had been decided to align the optical system to the best possible performance, mate it to the instrument, and allow the field installation and testing to continue--while simultaneous investigation of the optical problem was being conducted. It was also decided to omit the temperature compensation system installation and calibration at this time in an effort to reduce all possible delays.) The field tests were begun during July 1969 and were successfully completed during January 1970. The field tests were defined in a Test Plan[1] which would provide the data necessary to insure that the performance of the instrument met specifications. The results of the field testing of the GORID, MK-1A instrumentation were documented in a Technical Memorandum[2]. An Operation and Maintenance Manual[3] was also prepared and published.

SYSTEM DESCRIPTION

GENERAL

The GORID, MK-1A (Figures 5 and 6) is nine tons of altazimuth tracking telescope developed to record accurate attitude, event and miss-distance data during high-velocity, high altitude target tracking missions. The "eye" of the instrument is a Newtonian type reflector telescope with selectable 90-, 180-, or 360-inch effective focal length optical paths designed to cover the film format of a 70-mm data recording camera. One operator, seated at the control console, monitors the operating status of the telescope and controls the azimuth and elevation functions by a control stick, while tracking the target through 20-power, 45-degree elbow-type binoculars. The control stick generates command signals which, after processing, are applied to hydraulic motors driving the instrument in azimuth and/or elevation. A hydraulic power supply unit provides the instrument with hydraulic power for operation, while a separate hydraulic system is utilized to drive the astrodome shelter (in which the GORID, MK-1A is housed) in unison with the instrument to maintain alignment of the telescope and the astrodome viewing port.

---

1. Lockheed Electronics Company Publication, "Test Plan for the Ground Optical Recorder for Intercept Determination," GORID, MK-1A, May 1969.

2. Lockheed Electronics Company Technical Memorandum 69-6, "GORID, MK-1A Tracking System Design and Test Report," March 1970.

3. Lockheed Electronics Company Publication, "Description, Theory, Operation, and Maintenance, Ground Optical Recorder for Intercept Determination, GORID, MK-1A, March 1970.

FIGURE 4. GROUND OPTICAL RECORDER FOR INTERCEPT DETERMINATION (GORID) MK-1A INSTALLATION AT GREGG SITE, WSMR.

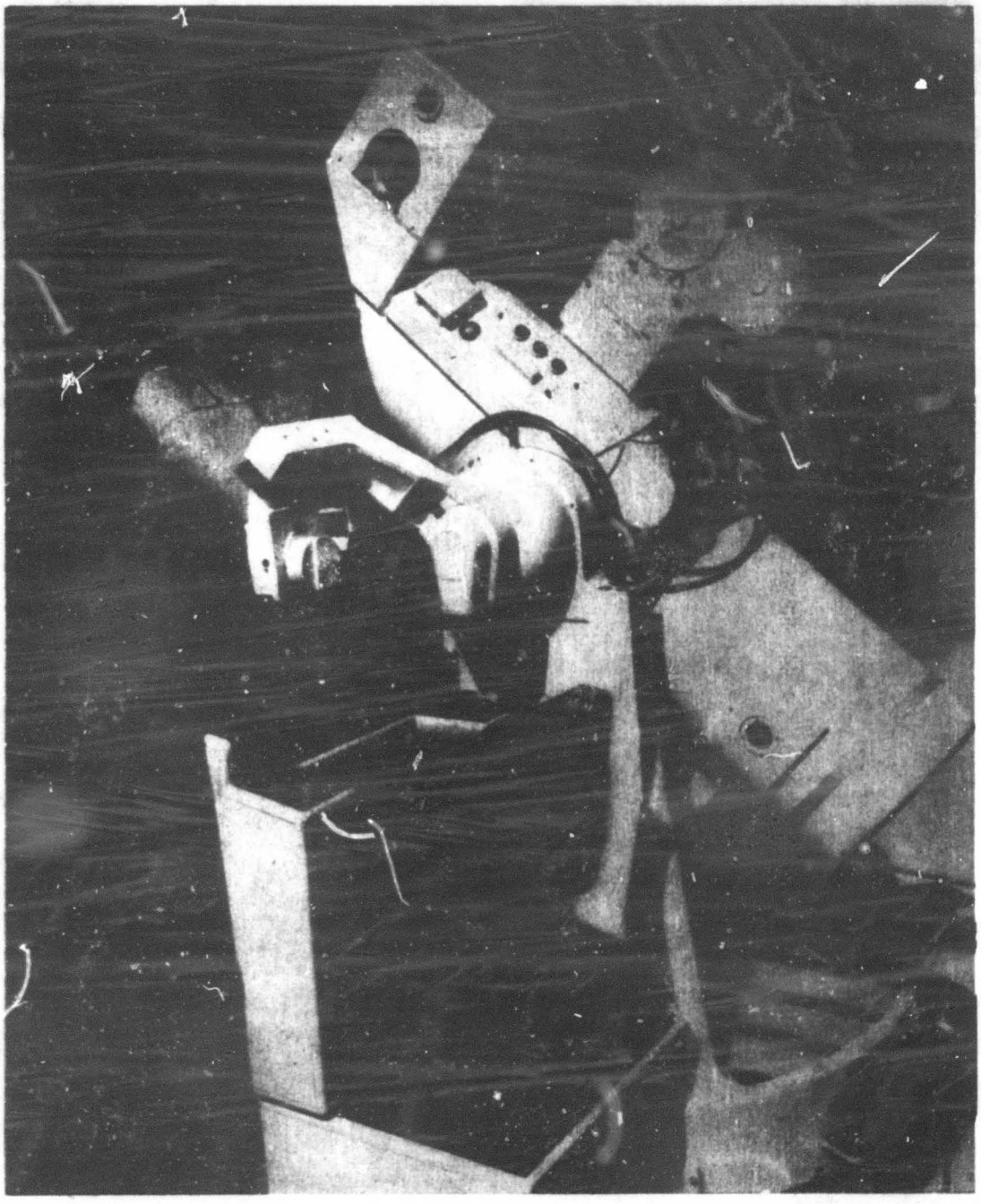

FIGURE 5. GROUND OPTICAL RECORDER FOR INTERCEPT DETERMINATION (GORID) MK-1A, LEFT SIDE.

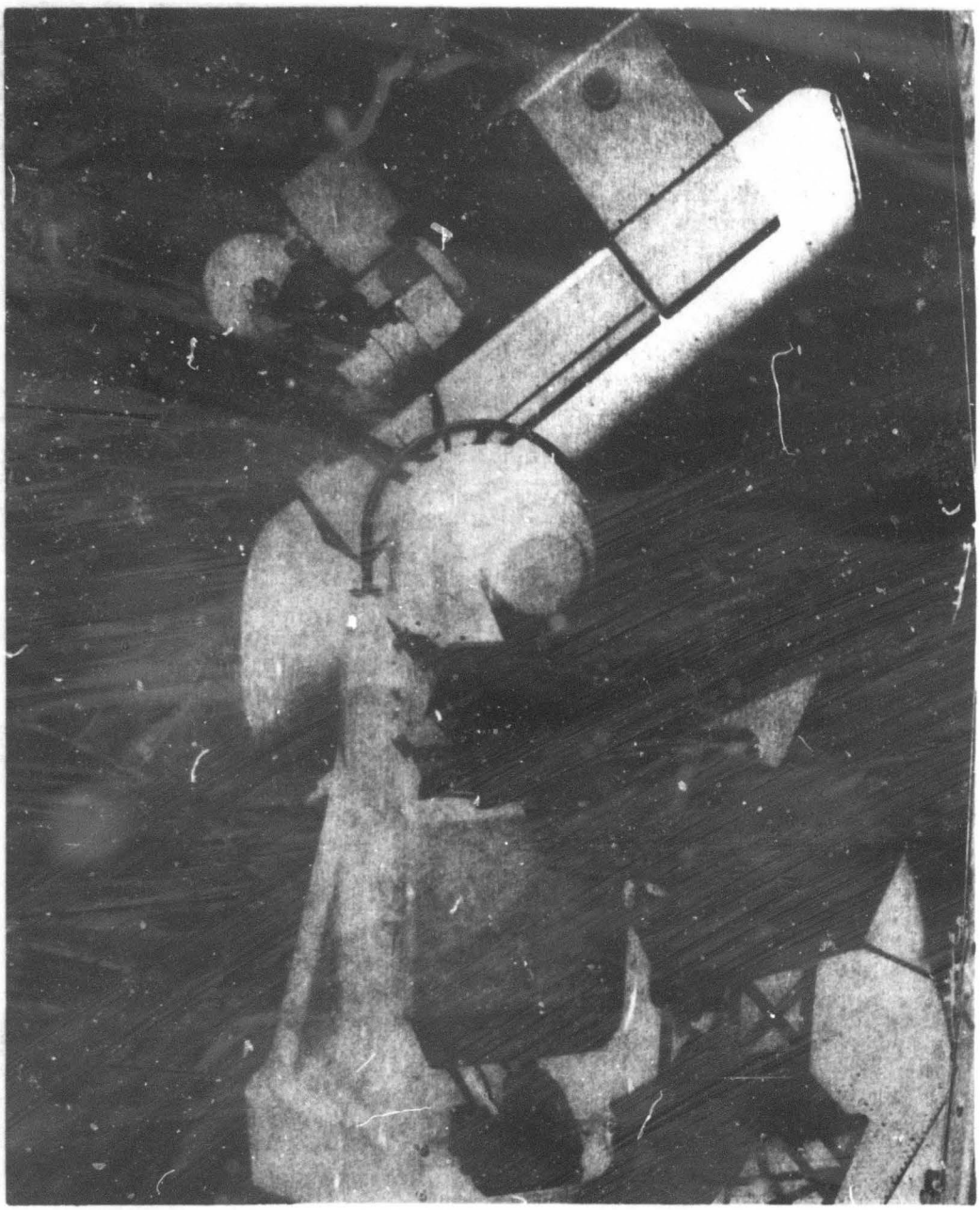

FIGURE 6. GROUND OPTICAL RECORDER FOR INTERCEPT DETERMINATION (GORID) MK-1A, RIGHT SIDE.

OPTICAL SYSTEM

The GORID optical system consists of a basic Newtonian reflector which has been extensively modified to correct off-axis aberrations and field curvature so that the large 70-mm 2-1/4 x 2-1/4-inch film format can be utilized. The system permits selection of three effective focal lengths: 90 inches, 180 inches and 360 inches. Changes in focus of the telescope induced by temperature changes will be automatically monitored and continuously corrected. Changes in focus, due to varying slant ranges, are automatically monitored and continuously reset. The telescope mount is a conventional altazimuth type. The telescope tube is supported on two pillow blocks by the elevation trunnions. An aluminum cover is provided for sealing the tube when it is not in use. A sun shade is also provided.

The GORID, MK-1 optical system supplied by the J. W. Fecker Division of American Optical System was based upon the Baker Reflector-Corrector[4]. The basic system was scaled according to Baker's prescription for converting a 117-inch focal length parabola to a wide-field instrument of 90-inch focal length. The longer focal lengths were achieved by suitably placed Barlow lenses. Because of a requirement for parfocalization of all systems, a 1:1 relay was employed in the 90-inch system.

The GORID, MK-1A optical system is essentially the same except for the changes noted here. The requirement for parfocalization of the shortest focal length system was relaxed so that the 1:1 relay system could be eliminated, thus giving the possibility for substantially improving the imaging performance and the efficiency of the 90-inch focal length system. The six power Barlow system was deleted entirely.

For the MK-1A the Baker Reflector-Corrector design was changed to give better overall performance especially with respect to color correction. Baker[5] states that "...it appears that the most pronounced residual error is that of lateral color....In the case of the Reflector-Corrector the lateral color arises from the so-called secondary spectrum of the achromatic lens." Accordingly, a new corrector lens was designed which consists of four elements and is apochromatic. The resultant 90-inch focal length system is fully apochromatic in the strict sense (corrected for color at 3 wavelengths and for spherical aberration at 2). The design wavefront error for an axial image is given in Figure 7. The lateral color has been brought under good control as is shown in Figure 8, which shows the relative wavefront errors for the extreme off-axis image at three different wavelengths toward the blue end of the spectrum.

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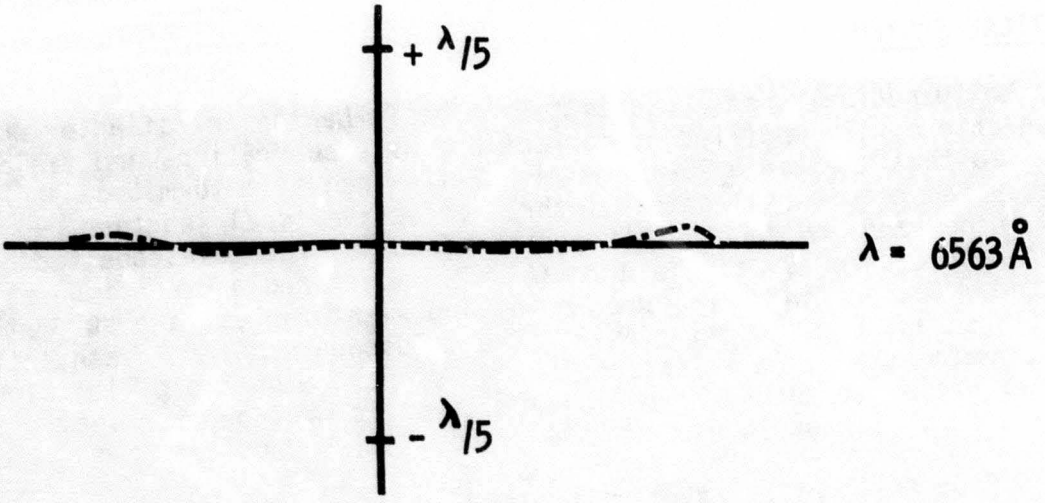
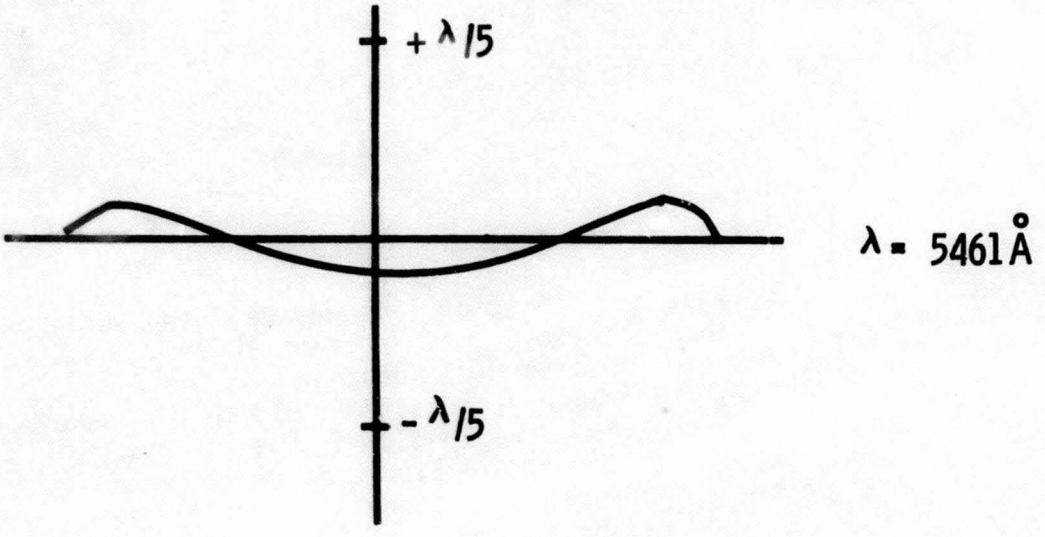
4. Baker, James G., "Optical Systems for Astronomical Photography," in Amateur Telescope Making Book Three, Scientific American, Inc., 1956.

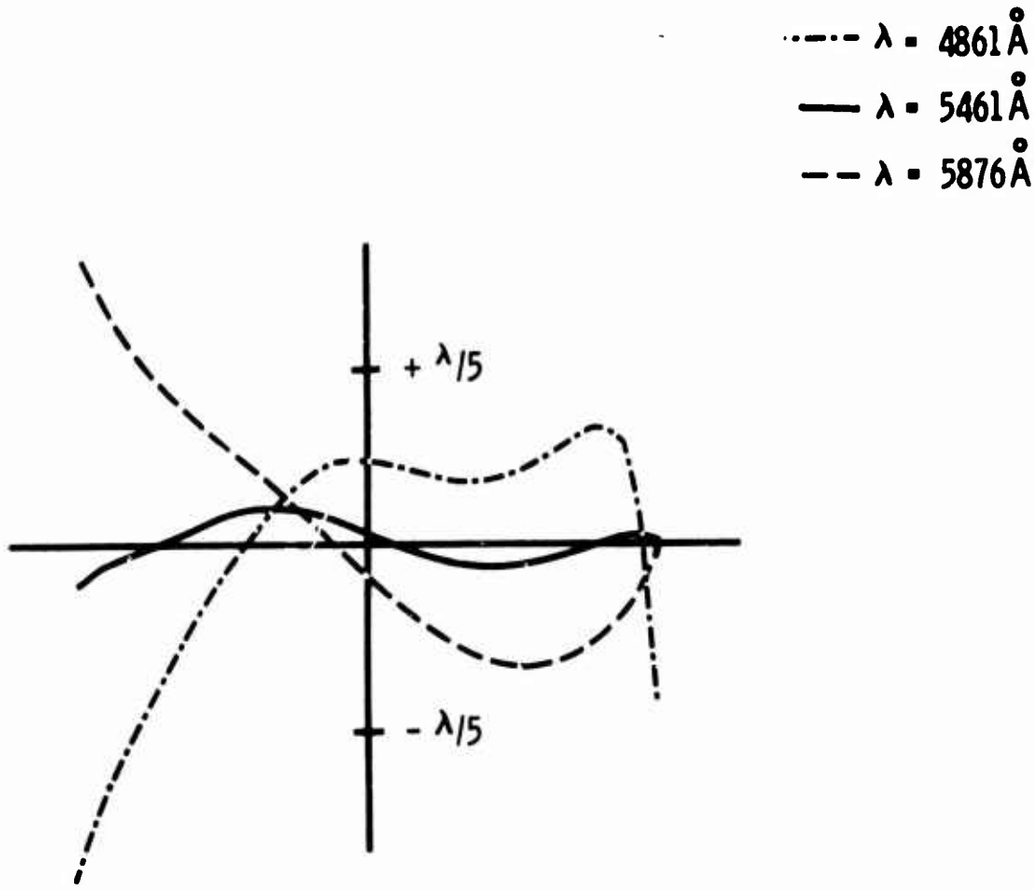
5. Baker, ibid., p. 16.





Wavefront Error for the Axial Image - 90 inch System

Figure 7



Wavefront Error for the off-axis Image - 90 inch System

Figure 8

For the 180-inch and 360-inch systems, Barlow lenses provide the required magnification as they did for the MK-1 design. With these fairly strong negative elements, there was more field curvature than could be tolerated for the 70-mm camera format. Therefore, positive field lenses were included in this design placed as close to the focal plane as the camera construction would permit. Along with the Barlow lenses, some near zero power elements were added to provide extra degrees of freedom for better overall optical system correction.

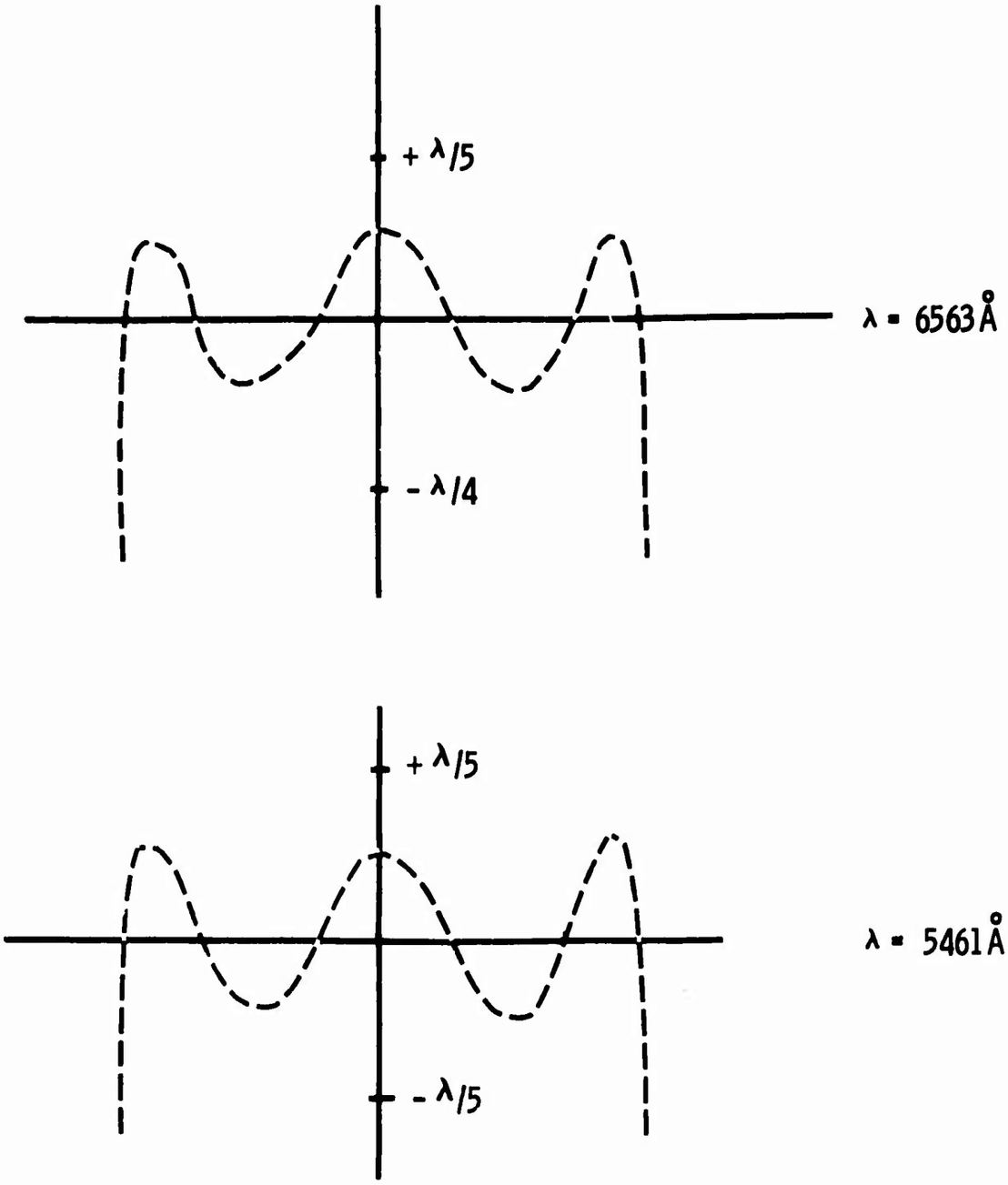
The 180-inch system was also designed as an apochromat. The axial image wavefront error for the final design are given for two wavelengths in Figure 9. This system is within the $\lambda/4$ tolerance, except for the last half inch of the aperture. The off-axis wavefront error rises to slightly more than one-half wavelength.

It was not possible to design the 360-inch system as an apochromat. In fact, it proved difficult to accomplish a completely satisfactory design within the constraints of mechanical placement, etc., which were effective. The wavefront error for the axial image is given in Figure 10. The off-axis wavefront error rises to about one and one-quarter wavelengths.

The design of the GORID MK-1A optics should provide excellent imagery--better than is currently possible by range telescopes at the 90- and 180-inch focal lengths. For much longer focal lengths, it is doubtful if the Barlow arrangement will result in truly high quality imagery. The complete testing of the instrument, to verify the design performance with respect to wavefront error, will not be possible until a planned optical calibration facility has been completed at WSMR. Some preliminary (incomplete) laboratory testing has indicated that more careful consideration of the mechanical mounting of large components for very high performance systems will be necessary.

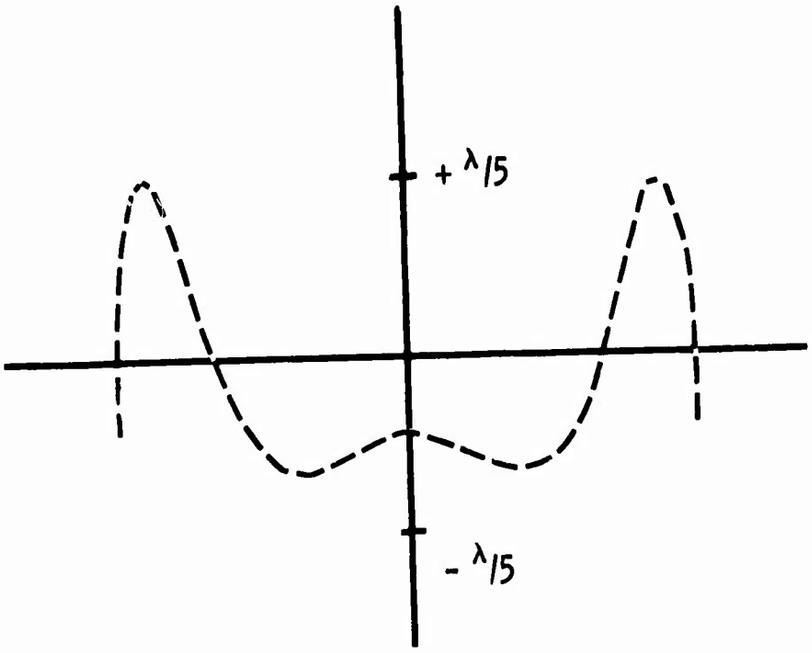
An automatic refocusing system was developed and included in the GORID, MK-1A to maintain the main optics in proper focus during a tracking mission. The slant range distance from the telescope to the target's position during flight is generated by an approximator unit (or furnished by a central control system such as ARTRAC). From this information an error signal is generated to command the refocus servo system. In turn, the servo system drives a torque motor to position the refocusing ring of the main optics. The automatic refocusing system can be manually overridden, and the lens can be focused at various finite distances from 3,000 yards to infinity.

The GORID, MK-1A optical system also includes a temperature compensation system. Telescopic focus changes caused by temperature-induced expansion and contraction are compensated for by a monitoring system. Monitoring is accomplished by means of a special rod extending the length of the telescope tube assembly which serves as an expansion reference gauge. Half the rod



Wavefront Error for the Axial Image - 180 inch System

Figure 9



Wavefront Error for the Axial Image - 360 inch System

Figure 10

length is of Invar metal; the other half of aluminum. This rod approximates the temperature-induced motion of the focal plane relative to the camera position. One rod end is placed against the primary mirror and the other end against an electronic dial indicator which produces an output signal used in a feedback loop to the Ross corrector refocus servo-drive circuit.

Forty-five degree, elbow-type tracking binoculars are attached to a bracket on the telescope evaluation trunnion. The operator's view is down with respect to the line of sight. A circular tracking reticle is in the right-hand optical path and a yellow filter can be inserted by a hand crank. Adjustments are provided for collimation of the binoculars.

TRACKING TELESCOPE MOUNT

This assembly is comprised of the mount base, bearings, transmission and trunnion assemblies.

The base is precision machined from Meehanite casting material. Dimensional stability of the mount was achieved by normalizing the casting, rough machining it to within 0.020-inch of its final dimensions, then processing it for stress relief prior to final machining. This machining, plus use of ultra precise bearings, has provided a highly stable mount.

Bearing design includes a flat-surface thrust bearing, an angular-contact preloaded pintle bearing and two pairs of angular-contact ball bearings. Total eccentricity of the platform about the azimuth axis is within 0.0002-inch. Rotation about the elevation axis is governed by the two pairs of preloaded, duplexed, angular-contact ball bearings. Perpendicularity between the azimuth and elevation axes is within seven seconds of arc.

Power transmission is provided by a dual-gear train mechanized drive transmission coupled to a bull gear at each axis. Precision spur gearing is used exclusively in the system and a mechanical phase adjuster in one train of each dual-gear train system eliminates backlash. The overall gear ratio in each axis is azimuth, 363.03:1 and elevation, 364.2:1. At a tracking rate of 30 degrees per second, the azimuth drive motor shaft rotates at 1815 rpm.

The azimuth carriage provides a support for the GORID major equipment. It also provides an interface between the electronics, optical and operator control system and the GORID mount. The telescope tube assembly, with camera platform and tracking binoculars, is supported on the two elevation trunnion pillow blocks.

ELECTRO-HYDRAULIC CONTROL SYSTEM

The electronically-controlled tracking system consists of a medium pressure (500 to 1000 pounds per square inch) hydraulic system using hydraulic motors, proportional flow servo valves and a hydraulic power supply unit.

This latter unit supplies hydraulic fluid at a variable flow and selectable constant pressure to the elevation and azimuth drive systems. Elevation and azimuth tracking rates are electronically controlled by the servo valve circuits which regulate or meter hydraulic fluid flow to the hydraulic motors. The fluid flow is at a rate and direction dictated by electronic command signals applied to the servo valves.

OPERATOR'S CONSOLE

The GORID, MK-1A features an operator's control station which is a considerable improvement over the original console of the MK-1 instrument (Figure 11). The improved corsole displays dial readouts, switches, meters and other control and monitoring devices, all within comfortable vision of the tracking control stick. The redesign encompasses the latest in human engineering design in conjunction with the control functions of the GORID, MK-1A instrument.

HYDRAULIC SYSTEM

The GORID, MK-1A mount and telescope tube are driven by a hydraulic servo motor at each axis (elevation and azimuth) with a two-way hydraulic solenoid valve in each motor circuit to permit separate control of either axis. Operating at 750 psig, the driving torque at each axis is azimuth, 2000 pound-foot and elevation, 1000 pound-foot. At 30 degrees per second tracking rates, motor fluid requirements are azimuth, 8.4 gpm at 1815 rpm and elevation, 4.2 gpm at 1815 rpm.

A hydraulic power supply unit provides for a 10 gpm flow of temperature-stabilizied and micronically-clean hydraulic fluid at selectable operating pressures between 500 to 1000 psig through a 5/8-inch diameter, high pressure output line and a low pressure, 3/4-inch diameter return line.

DATA RECORDING SYSTEM

GORID, MK-1A's data recording system consists of an instrumentation camera, a digital recorder and two encoders.

The instrumentation camera is a pin registered (accurate to ± 0.001 inch, relative to the optical axis), 70-mm format system with selectable frame rates of 20, 30, 40, 60, and 80 frames per second. It utilizes a rotary disk type shutter with an adjustable opening from 0 to 120 degrees.

The digital recorder is a digital optical system which records the azimuth and elevation encoder output data and range timing information onto each frame of 70-mm film by a 94-bit matrix of ultraminiature arc lamps.

The medium resolution encoders, employed in the GORID, MK-1A, are shaft angle type. The azimuth encoder is located in the trunnion standard and the elevation encoder is installed in the elevation data box. The encoder

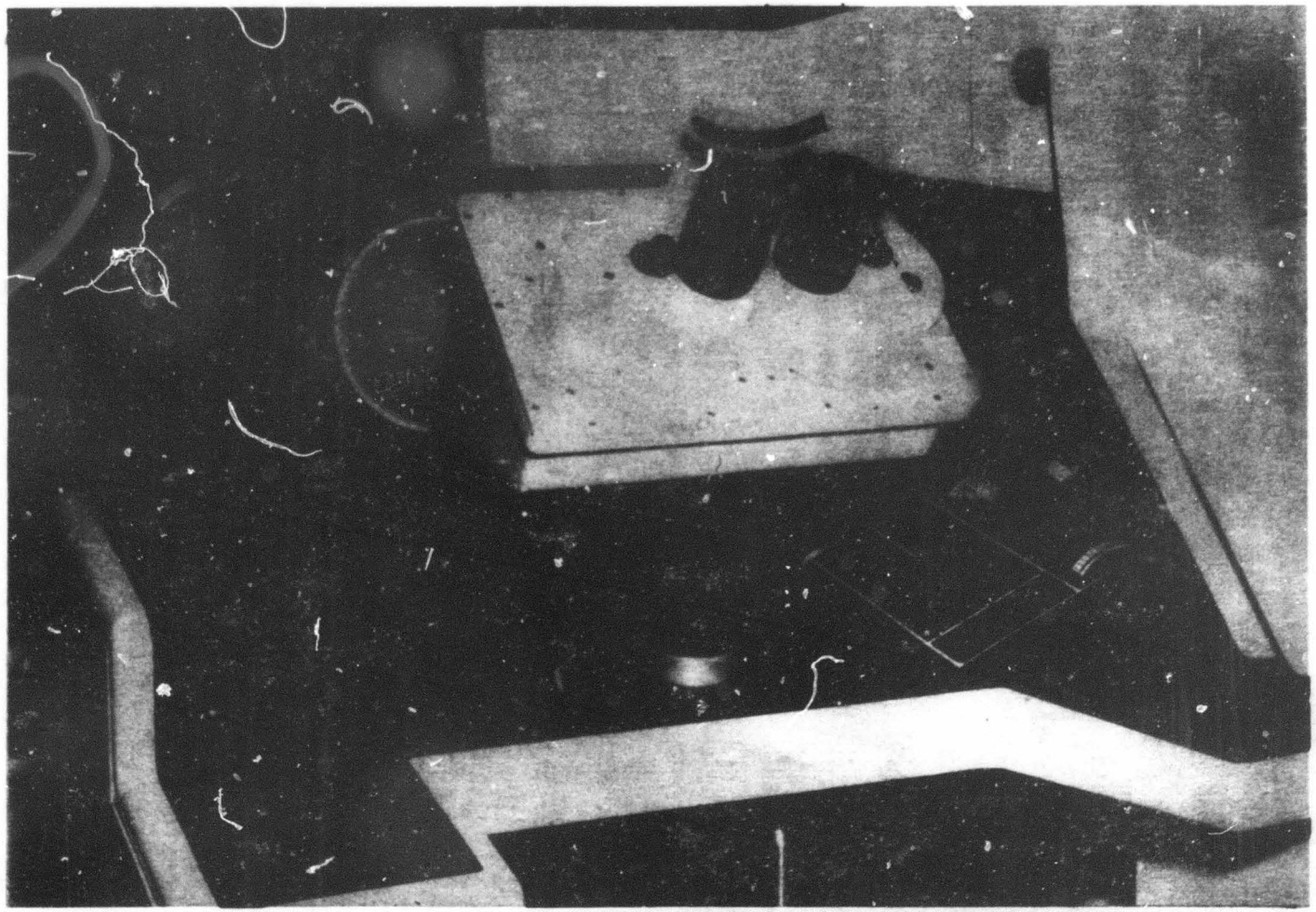


FIGURE 11. OPERATOR CONTROL STATION, GROUND OPTICAL RECORDER FOR INTERCEPT DETERMINATION (GORID) MK-1A.

data, presented in 13-bit Gray Binary Code, is routed to the digital recorder and to the GORID interface equipment for use by ARTRAC or any other facility which has been included for receipt of the information.

TELESCOPE ASTRODOME

The GORID, MK-1A telescope is designed to operate within a type B astrodome. An astrodome of this type, typical of several at WSMR, is mounted on top of a 26 x 26 foot square basic building at Gregg Site where the telescope was field tested. This arrangement affords 676 square feet of instrumentation and work space in the lower area beneath the astrodome. Building height is 19 feet to the top of the fixed cylindrical base on which the prefabricated astrodome revolves in the azimuth plane. The removable dome, 16 feet in diameter, features a viewing port for the telescope with a sliding section which opens to a maximum vertical traverse arc of 95 degrees from the horizontal plane. Minimum width of the port opening is about six feet. A drive control unit is provided to enable the telescope viewing port and astrodome to revolve in azimuth in unison with the telescope tube assembly. Extending from the center of the floor of the lower room to the GORID base mounting plate on the floor of the astrodome is a culvert pipe, or circular well, six and one-half feet in diameter.

SYSTEM TESTS

GENERAL

Following the installation of the GORID, MK-1A instrument in the WSMR field site, the mechanical and electrical interfacing with the site was accomplished. The system tests were then accomplished in two phases: the servo tests and the tracking system tests.

SERVO SYSTEM TESTS

The original design of the servo control system was based on an estimated load, a mechanical model of the actual system, and empirical transfer functions based on velocity loop response of the mechanical model. Servo tests were accomplished to determine the degree of consistency between the laboratory test data for the model and field test data obtained for the actual load.

The servo tests included verification of azimuth and elevation compensation; determination of open-loop frequency response (uncompensated and compensated); azimuth and elevation step response; determination of static sensitivity,

minimum tracking rate and velocity fluctuations; determination of maximum simultaneous slew rates of azimuth and elevation loads; and calibration of tachometers for azimuth and elevation hydraulic motors.

The following servo system performance data was obtained during this series of tests.

Parameter	Azimuth	Elevation
Maximum Velocity	33 deg/sec	33 deg/sec
Maximum Acceleration	34.3 deg/sec^2	34.3 deg/sec^2
Dynamic Range	10,000:1	10,000:1
Rise Time (E_{in} = 0.8 V)	70 ms	70 ms
Settling Time (E_{in} = 0.8 V)	190 ms	310 ms
0/0 Overshoot (E_{in} = 0.8 V)	50 percent	20 percent
Dither	200 Hz at 0.4 volts peak to peak	200 Hz at 0.4 volts peak to peak

TRACKING SYSTEM TESTS

Tracking system tests, designed to define the general quality of the GORID, MK-1A performance, were then accomplished. These tests defined general tracking capabilities of the mount, performance of the automatic refocusing system, pointing accuracy of the mount, and performance of the data recording equipment.

This phase of the test program included such alignments and tests as follows:

Azimuth and elevation encoder-optical system alignment, utilizing a celestial target.

Pointing accuracy determination of the encoders through photography of the celestial target and measurement of the difference between where the target should have appeared and where it actually appeared.

Azimuth and elevation encoder calibrations, utilizing a polygon and an autocollimator, referenced to an initial encoder readout.

Azimuth bearing runout test, utilizing a vertical leveling mirror, placed in the beam path of an autocollimator, affixed to the rotating portion of the base.

Elevation bearing runout test, utilizing an adjustable optical flat target mirror, placed in the beam path of an autocollimator, attached to the telescope finder extension arm.

Orthogonality error determination of the deviation from a true 90 degrees from the elevation axis to the azimuth axis.

Automatic refocusing system performance determination by depth micrometer measurements of the actual Ross lens movements compared to the computed displacement characteristics.

Operational and dynamic tracking tests, performed on targets of opportunities, determined mount capabilities and characteristics.

Detailed discussions of the aforementioned system tests, and the resultant data, are included in a Technical Memorandum[6].

CONCLUSIONS

All of the mechanical, electronic and hydraulic design goals, established for the successful development of the GORID, MK-1A tracking telescope, have been met or exceeded.

The following comparisons of major parameters are presented.

Parameter	Design Goal	Actual Performance
Maximum Velocity	30 deg/sec	33 deg/sec
Minimum Velocity	0.5 deg/sec	0.003 deg/sec
Dynamic Range	600:1	10,000:1
Maximum Acceleration	30 deg/sec^2	34.3 deg/sec^2
Maximum Static Pointing Error	9 arc min	5.64 arc min

The optical design is such that excellent field photographs should be possible. This will be confirmed by extensive field experience over an extended period of time. The GORID, MK-1A program has indicated that a continued investigation of design for very long focal length systems should be carried out, and that studies of the newer optical materials for mirrors and refined mechanical mounting methods should be conducted.

6. LEC Technical Memorandum 69-6, op. cit.

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13. ABSTRACT

The Ground Optical Recorder for Intercept Determination (GORID), MK-1A, is a development model of a tracking telescope with increased capability to provide optical attitude, event, and miss-distance data as compared to tracking telescopes currently in service at WSMR. Through the choice of three long focal lengths (90, 180, and 360 inches), coupled with a precise tracking mount of considerable dynamic range, the GORID offers a very versatile instrument applicable to a variety of optical recording tasks. Through the use of high resolution retro-fitted shaft-angle encoding equipment, it also could provide space position at altitudes exceeding 100,000 feet.

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