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TECHNICAL REPORT

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SPECIFICATION AND TEST PROCEDURE FOR A HIGH PERFORMANCE CINETHEODOLITE

FINAL REPORT

BY

LOWELL D. YATES

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INSTRUMENTATION DEVELOPMENT DIVISION
INSTRUMENTATION DIRECTORATE
WHITE SANDS MISSILE RANGE
NEW MEXICO

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This report specifies the performance of a new state-of-the-art high performance cinetheodolite capable of 2-arc-seconds dynamic pointing accuracy. The feasibility of manufacturing a cinetheodolite to this specification was established by means of static and dynamic testing of a breadboard instrument. The detailed procedure to test instrument performance and determine manufacturer compliance was established.

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INTRODUCTION

The performance specification and test procedure for a high-performance cinetheodolite are the results of an exploratory development that produced a significant breakthrough in the field of theodolite technology.

The conventional mechanical cinetheodolite in current use on U. S. Missile Ranges is the most accurate type (electronic or optical) of instrumentation available for the dynamic measurement of missile space position; yet, the dynamic pointing accuracy of these instruments has never been proven to exceed 20 arc-seconds. The 2-arc-second dynamic pointing accuracy and all other critical performance characteristics specified in this document were proven feasible by the tests of a breadboard instrument during 1967-1970 at WSMR, New Mexico.

The breadboard cinetheodolite achieved the specified dynamic pointing accuracy by utilizing a novel and unique optical compensation technique that rendered the instrument immune to mechanical errors which limit the accuracy of all conventional cinetheodolites.

Only minor portions of the specification can be considered unique to WSMR and can be readily changed to match requirements of the user agency.

The test procedures necessary to determine manufacture compliance with the specification are also a part of this document and are the product of long and difficult testing which required the updating of ultra-precise state-of-the-art measurement techniques. Another result of the test program was the development of a highly sophisticated test complex, Bill Site, located at WSMR which is capable of efficiently determining instrumental static and dynamic pointing accuracy.

A detailed description of the test complex and the test results can be found in the report, "Exploratory Development of the WSMR Cinetheodolite," June 1970, AD No. 713421.

A SPECIFICATION AND TEST PROCEDURE
FOR
A HIGH PERFORMANCE CINETHEODOLITE

1. SCOPE

This Purchase Description (PD) sets forth the minimum requirements for the design, manufacture, and test of a cinetheodolite to achieve a dynamic pointing accuracy of 2 to 4 arc-seconds. The government has demonstrated, in the WSMR Cinetheodolite exploratory development program, the feasibility of the design, fabrication, and test of a cinetheodolite which meets the pointing accuracy requirements of this PD. All data generated by the exploratory development will be furnished the contractor as government-furnished documentation (GFD) for information only. The GFD includes drawings and all technical test data resulting from the development of the breadboard WSMR Cinetheodolite presently installed at WSMR, plus data from an optical redesign contract addressing major optical design deficiencies of the breadboard.

The GFD will also include detailed test procedures which the contractor must follow to test the cinetheodolite at the contractor's plant and at the government-furnished test facility at WSMR.

The primary purpose of the cinetheodolite, as a basic unit of a system of cinetheodolites, is to provide capability for passive determination of missile position with an error of less than 5 feet at a slant range of 200,000 feet.

2. APPLICABLE DOCUMENTS

2.1 The following documents form a part of this PD to the extent specified herein.

SPECIFICATIONS

<u>Military</u>

MIL-A-8625, Anodic Coatings, for Aluminum and Aluminum Alloys

MIL-C-675, Coating of Glass Optical Elements (Anti-Reflection)

MIL-C-13924, Coating, Oxide, Black, for Ferrous Metals

MIL-D-1000, Drawings, Engineering and Associated Lists

MIL-G-174, Glass, Optical

MIL-I-45208, Inspection System Requirements

MIL-O-13830, Optical Components for Fire Control Instruments; General Specification Governing the Manufacture, Assembly, and Inspection of

MIL-P-14538, Plating, Black Chromium (Electro-Deposited)

STANDARDS

Military

MIL-STD-100, Engineering Drawing Practices

MIL-STD-150, Photographic Lenses

MIL-STD-454, Standard General Requirements for Electronic Equipment

MIL-STD-1241, Optical Terms and Definitions

Copies may be obtained from U. S. Naval Publications and Forms Center (ATTN: Code DCI), 5801 Tabor Avenue, (Telephone Randolph 8-1212, Ext. 528 or 530), Phildelphia, Pennsylvania 19120.

PUBLICATIONS

A Briefing on the WSMR Cinetheodolite Development, Optics Division Technical Memorandum 64-1

A Design Study of the WSMR Cinetheodolite Optical System, Final Report prepared by Keuffel and Esser Company under Contract No. DAAD07-69-C-0119

Exploratory Development of the WSMR Cinetheodolite, Final Report STEWS-RE-I-70-2

WSMR Cinetheodolite Main Assembly Drawing List OD-07816E and all drawings included therein

WSMR TDP 731 and Addendum No. 5, Instrument Data Converter Equipment, ARTRAC

WSMR Cinetheodolite Test Facility Drawings

WSMR Drawing No. SK-00201, Test Fixture Assembly

WSMR Drawing No. OD-06443, Control Stick Assembly

WSMR Drawing No. OD-15079, Stiff Stick Schematic

Reliability, Maintainability. and Quality Assurance Guidelines for Purchase Descriptions, WSMR, New Mexico, 4 January 1967

Copies may be obtained from the Contracting Officer, White Sands Missile Range, New Mexico 88002.

American Standards Association Document ASA, PH22.36-1964, Dimensions for 35mm Motion Picture Raw Stock

Copies may be obtained from American Standards Association, Inc., 70 East 45th Street, New York, New York 10017.

Human Engineering Guide to Equipment Design, edited by Clifford T. Morgan, et al, published by McGraw-Hill Book Co., Inc.

3. REQUIREMENTS

The Contract End Item (CEI) shall consist of a high-performance cinetheodolite, including a 50-frame-per-second 35mm camera, and auxiliary equipment, including an operator's console and a remote status and control panel.

3.1 General. The following is given as a synopsis of the principal cinetheodolite requirements. More detailed expressions of these requirements are given elsewhere in this PD.

3.1.1 Pointing accuracy. The total pointing error under severe tracking conditions shall be less than 4.0 seconds of arc.

3.1.2 Stability.

3.1.2.1 Thermal. The cinetheodolite pointing direction shall be stable within 0.5 second of arc during and after a rapid 25° F. temperature change, causing uneven heating of the cinetheodolite structure.

3.1.2.2 Long-term. Instrument calibrations shall not be required more often than every 90 days.

3.1.3 Angular tracking rates. The cinetheodolite shall be capable of the following tracking rates.

3.1.3.1 Azimuth and elevation angular velocities over the entire range from zero to 30 degrees per second.

3.1.3.2 Azimuth and elevation angular accelerations over the entire range from zero to 45 degrees per second per second.

3.1.4 Data sampling.

3.1.4.1 The cinetheodolite system shall be capable of synchronous data sampling rates of 5, 10, 20, and 50 samples per second.

3.1.4.2 A mid-mission change of data sampling rate shall not result in a loss of data for more than 3.0 seconds of time.

3.1.4.3 All parts of the cinetheodolite system shall allow data sampling for a minimum of 7,500 samples in continuous operation at each sampling rate.

3.1.5 Target detection capability. The cinetheodolite shall have a focal length of 3000 millimeters (mm) and an aperture diameter of 410mm.

3.1.6 Cinetheodolite system outputs. All data pertinent to target position determination shall be recorded on each frame of film. This data shall include instrument azimuth and elevation angles; timing data; target, mission, and station identification; and synchronization status.

3.2 Pointing accuracy and stability.

3.2.1 Pointing accuracy. The cinetheodolite shall have an overall instrumental dynamic pointing error, as defined in 6.1.1, of less than 4.0 seconds of arc, with a design goal of 2.0 seconds of arc, under all conditions of the dynamic conditions specified in 3.1.3. The static error increment shall be determined by photogrammetric measurements of star image positions. The dynamic pointing error increment shall be determined by photogrammetric measurements of artificial star (collimated light) image positions.

3.2.2 Stability.

3.2.2.1 Thermal. The cinetheodolite pointing direction shall not vary by more than 0.5 arc-second due to a temperature change from 75 degrees to 100 degrees F. affecting only one side of the cinetheodolite and occurring over a period of 40 minutes.

3.2.2.2 Long-term. The cinetheodolite pointing accuracy, after initial calibration, shall not vary from the requirements of 3.2.1 during a period of at least 90 days due to instrument and site instability.

3.2.3 Tests. The cinetheodolite pointing accuracy and stability shall be tested in accordance with Appendix I, Cinetheodolite Pointing Accuracy Acceptance Test Procedure

3.3 Optics.

3.3.1 Main optical system.

3.3.1.1 The main (target-imaging) optical system shall have an effective focal length of 3000mm plus or minus 100mm.

3.3.1.2 The main optical system shall have a clear entrance aperture diameter of 410mm plus or minus 5mm.

3.3.1.3 The main optical system shall provide, at the image plane, a corrected field of view of at least 20 minute of arc.

3.3.1.4 A focusing system shall be provided for the main optical system and shall be continuously variable to focus on objects from 5000 yards to infinity. Refocusing the main optical system within this range shall not change the angular scale factor in the film plane by more than 0.02 percent.

3.3.1.5 The main optical system shall resolve at least 60 lines per mm as determined photographically at the film plane. This resolution shall be obtained through each filter as required in 3.3.1.9, and all focus positions defined in 3.3.1.4.

3.3.1.6 Radial distortion (defined in MIL-STD-150) shall not exceed 0.6 percent.

3.3.1.7 The transmittance of the main optical system including focusing elements and the clear filter compensation window, shall be at least 63 percent over the spectral range of 400 to 700 nanometers.

3.3.1.8 Image contrast shall be maximized by optimum number and placement of stops, by the use of suitable optical materials and design, and by hard coating all air/glass optical surfaces to give maximum light transmission at approximately 550 nanometers. All such films shall be treated to have the best durability and resistance to physical abrasion and chemical corrosion, in accordance with MIL-C-675. There shall be no "ghost" images recorded on film under daytime illumination. The image-to-object contrast ratio shall be at least 85 percent.

3.3.1.9 A filter assembly shall be included in the instrument and shall allow filtering of the light in the main optical system. The assembly shall include solid glass filters equivalent to the following:

Wratten No. 3 (yellow)

Wratten No. 15 (red-orange)

Wratten No. 25 (red)

Wratten No. 39 (blue)

Clear filter compensation window

The cinetheodolite shall allow changing of filters in less than 15 seconds. This procedure shall not require that the cinetheodolite operator handle the filter itself, but shall be accomplished by actuation of a mechanism. Positive visual indication of which filter is in the optical system shall be given at the operator's console.

3.3.1.10 A screw-on or snap-on dust cover shall be provided for the main optical system front element. The operator's console shall provide indication of the presence or absence of the cover on the cinetheodolite.

3.3.2 Data optical system. Azimuth, elevation, fiducial, and data matrix information shall be optically imaged at the film plane.

3.3.3 Operator's guide telescope.

3.3.3.1 The operator's guide telescope (OGT) shall be a forward-looking mono-objective, binocular-eyepiece, tripower telescope. The OGT objective shall track with the cinetheodolite, while the eyepieces remain stationary in elevation.

3.3.3.2 The OGT shall provide 10-power, 20-power, and 40-power magnification, selectable by the operator. Powers shall be selected by rotation of a lever or knob through 360 degrees or less. The transition from power to power shall be smooth and with detents to maintain alignment at the power selected, so that no image degradation or binocular misalignment shall occur.

3.3.3.3 The OGT shall have optical properties as follows:

Magnification, plus or minus 5 percent	10x	20x	40x
Objective diameter (clear aperture), minimum	120mm	120mm	120mm
Real field, minimum	6°	3°	1-1/2°
Exit pupil, minimum	12mm	6mm	3mm
Eye relief, minimum	22mm	22mm	22mm

3.3.3.4 The OGT shall resolve 3.0 seconds of arc or numerically less on axis, and 4.0 seconds of arc or numerically less at 80 percent field diameter.

3.3.3.5 The OGT shall have no visually discernible chromatic aberration.

3.3.3.6 The optical axes of the OGT at the eyepieces shall be inclined 30 degrees plus or minus 5 degrees above the horizontal (i.e., the cine-theodolite operator shall look downward at 30 degrees below the horizontal).

3.3.3.7 The images shall be upright and sideright with no image rotation when tracked in elevation.

3.3.3.8 Image-viewing contrast shall be maximized by optimum number and placement of stops, by the use of suitable optical materials and design, and by hard coating all air/glass optical surfaces to give maximum light transmission at approximately 550 nanometers. All such films shall be treated to have the best durability and resistance to physical abrasion and chemical corrosion, in accordance with MIL-C-675. There shall be no "ghost" images apparent under daytime illumination. The image-to-object contrast ratio shall be at least 85 percent.

3.3.3.9 The magnification difference between the two eyepiece channels shall be no greater than one percent of the magnification.

3.3.3.10 The eyepieces shall be provided with smoothly operating multi-start-thread focusing means, continuously variable from plus 4.0 diopters to minus 5.0 diopters. Scales calibrated in one-diopter increments shall be provided and shall be set to read zero when focus is at infinity. The scales shall be resettable without drilling, tapping, or otherwise modifying the OGT.

3.3.3.11 The interocular distance shall be adjustable from 56 to 74mm with a reference mark and a scale indicating the distance in 2mm increments.

3.3.3.12 A solid glass filter with transmission and spectral response equivalent to a Wratten No. 8 shall be provided for each optical path. The filters shall be mounted so that they may be introduced into or withdrawn from the optical paths by not more than one revolution of a lever or knob. Detents shall be provided for the "in" and "out" positions.

3.3.3.13 A reticle in the right eyepiece shall consist of four engraved, or etched, and filled orthogonal lines forming a broken cross. The inner ends of the lines shall terminate at points subtending angles of 10.0 plus or minus 0.5 arc-minute from the optical axis in the true field (i.e., the inner ends of the lines shall be separated by 20 minutes). The width of the lines shall be as small as possible consistent with good visibility. The cross lines shall be vertical and horizontal when the interocular scale is set at 64mm. The reticle shall be in the infinity-focus plane of the OGT objective. Variable illumination of the reticle shall be provided. The lamp and controlling rheostat shall be so installed that both may be removed and replaced without disassembly of the OGT.

3.3.3.14 With the two eyepieces set at zero diopters, parallel rays entering the OGT objective shall emerge from the eyepieces parallel to each other within 4 arc-minutes in the vertical plane and within 4 arc-minutes of convergence (i.e., requiring divergence of the eyes) and 5 arc-minutes of divergence (i.e., requiring convergence of the eyes) in the horizontal plane. This binocular collimation shall remain constant within 2.0 arc-minutes over the entire range of interocular settings and over the entire range of diopter settings.

3.3.3.15 The images of a distant vertical line shall be parallel to each other within 5.0 arc-minutes and neither image shall depart from the vertical by more than 5.0 arc-minutes (in the apparent field).

3.3.3.16 With incident white light from a uniformly illuminated field, the emergent light from the two eyepieces shall have the same spectral distribution, and the intensities shall not differ by more than 10 percent.

3.3.3.17 A flexible headrest and eyeshade shall be included.

3.3.3.18 A sun shade for the OGT objective lens shall be included.

3.3.3.19 Screw-on or snap-on dust covers shall be provided for the OGT objective lens and eyepieces.

3.3.4 Tests. The cinetheodolite optical performance shall be tested in accordance with Appendix II, Optical System Test Procedure.

3.4 Data recorder and data recording. The data recorder shall include a camera designed to handle a 1200-foot film load, a camera synchronizer, and a data matrix generator

3.4.1 General. The data recorder shall synchonously record primary or target images, azimuth and elevation pointing data, fiducial images, and binary optical data on 35mm film at synchronous frame rates of 5, 10, 20, and 50 frames per second. The output of the data recorder shall be 35mm film recordings of all of the above data collected during a mission. Recorded image quality shall be as detailed in 3.3.1.5, 3.4.13.3, and 3.4.13.4.

3.4.2 Inputs. The data recorder shall operate as specified herein with the following inputs.

3.4.2.1 Timing. Range timing will be available and will include day of year, seconds of day, milliseconds, and microseconds, all in straight binary format. The characteristics of the timing signals are as follows:

a. Source impedance. 1000 ohms.

b. Logic level. "One," minus 6 volts, plus or minus 0.5 volt. "Zero," zero volts, plus or minus 0.5 volt.

c. Rise and fall times. Not more than 2.0 microseconds.

3.4.2.2 Synchronizing pulse. Pulse rates of 5, 10, 20, and 50 per second will be available for camera synchronization. Dc-level-shift and pulse inputs will be available as follows:

a. Type of input.	Dc-level-shift	Pulse
b. Source impedance.	1000 ohms	1000 ohms
c. Amplitude.	Minus 6 volts, plus or minus 0.5 volt, from a zero-volt plus or minus 0.5 volt baseline	6 volts, plus or minus 1 volt
d. Pulse width.	5.0 microseconds plus or minus 0.5 microseconds	1 or 4 microseconds
e. Rise and fall times.	Each not more than 0 5 microsecond	Rise time not more than 0.5 microsecond

3.4.3 Film characteristics. The camera shall advance and expose 35mm, short-pitch, negative, 4-mil-base film. Dimensions are described in the document ASA, PH22.36-1964.

3.4.4 Film format. The film format shall be chosen by the contractor and shall include a target-imaging area at least 17.5mm in diameter. Azimuth, elevation, fiducial and data matrix information shall be recorded entirely outside the target-imaging area.

3.4.5 Film advance. The contractor shall determine the number of film perforations per frame required by the film format chosen in 3.4.4, but his choice shall be limited to either four or eight perforations per frame. The film advance mechanism shall advance the required number of perforations of 35mm short-pitch negative film (ASA PH22.36-1964) per frame. It shall operate at synchronous rates of 5, 10, 20, and 50 frames per second and shall also operate in a single-frame mode.

3.4.6 Film registration. The film advance mechanism shall provide positive registration of the film in three mutually orthogonal directions for the entire period during which the film is being exposed.

3.4.7 Film exposure duration. The shutter configuration for the camera shall provide the following exposure durations plus or minus 5 percent at the specified frame rates:

FRAMES PER SECOND	EXPOSURE TIME (SECONDS)
50	1/1000, 1/500, 1/250
20	1/1000, 1/500, 1/250
10	1/1000, 1/500, 1/250
5	1/500, 1/250
Single Frame	Variable from 10 milliseconds or less to 10 seconds or more

3.4.8 Film load indicators. A counter shall be provided to indicate the amount of film remaining in the feed side of the film magazine. It shall be visible to the operator and shall read from 0 to 1200 feet with an accuracy of plus or minus 20 feet. In addition, a "camera-loaded" indicator shall be provided at the operator's console to indicate that the camera is loaded and contains at least 400 feet of film in the feed side.

3.4.9 Shutter.

3.4.9.1 Shutter location. It is not required that the shutter mechanism be physically located within the camera housing. The position of the shutter mechanism with respect to the cinetheodolite optical system shall depend upon the type and configuration of the shutter and of the optical system selected by the contractor.

3.4.9.2 Shutter pulse. The camera or camera synchronizer shall provide a shutter pulse, available at a coaxial connector on the status and control panel, as follows: (a) one pulse shall be generated per frame; (b) the leading edge of the pulse shall be coincident with the midpoint in time of the film exposure, plus or minus 20 microseconds; (c) the amplitude of the pulse shall be at least 5.0 volts; (d) the source impedance shall be 1000 ohms or less; and (e) the rise time shall be 1.0 microsecond or less.

3.4.9.3 Single-frame shutter. The single-frame requirement of 3.4.7 may be met by a separate shutter mechanism. Conversion of the shutter from cine mode to single-frame mode and vice versa shall be sufficiently easy to allow changeover in not more than two manhours. Single-frame shutter open and close control lines shall be available at a mil specified connector on the back of the status and control panel and shall have the following characteristics: (a) the required voltage shall be 28 volts dc or less; (b) the required current shall be 5.0 amperes or less; and (c) the opening and closing times shall be 10.0 milliseconds or less. Single-frame shutter open, shutter close, and film advance switches shall be provided at the status and control panel.

3.4.9.4 Shutter indicator. In the single-frame mode of operation visual indication of when the shutter is open and when it is closed shall be provided at the status and control panel.

3.4.10 Camera drive.

3.4.10.1 The camera shall accelerate film from a standstill to 50 frames per second in less than 1.5 seconds, with a full film load.

3.4.10.2 Each frame rate change shall be accomplished within 1.5 seconds after the frame rate change command.

3.4.10.3 A camera power switch shall be provided on or in the camera housing to operate the camera independently of the synchronization system.

3.4.11 Camera housing. The camera housing shall be a light-tight enclosure which permits entrance of light through the film aperture only.

3.4.12 Synchronizer.

3.4.12.1 Exposure synchronization. When synchronized, the leading edge of the shutter pulse shall occur within plus or minus 80 microseconds of the synchronizing pulse being used. The synchronizing pulses will be furnished by the government as detailed in 3.4.2.2.

3.4.12.2 Nonsynchronous frames. The maximum number of nonsynchronous frames when changing frame rates shall be as follows:

FRAMES PER SECOND		NONSYNCHRONOUS FRAMES
From	To	(Maximum)
0	5	10
0	10	10
0	20	20
0	50	60
50	5	60

3.4.12.3 Synchronization signal. The synchronizer shall provide a voltage to the data matrix to indicate the camera synchronization status. The voltage shall also be available at a mil specified connector on the back of the status and control panel.

3.4.12.4 Nonsynchronization alarm. The data recorder shall provide a nominal one-kilohertz alarm, audible to the operator, to indicate non-synchronous operation. The alarm shall sound during nonsynchronous operation and stop whenever the camera is synchronized to the tolerance of 3.4.12.1.

3.4.13 Data matrix and dial data. A matrix of binary bits shall be generated. The matrix images and the dial images, if azimuth and elevation dials are used, shall be recorded on the film.

3.4.13.1 Contents. The data matrix shall include but not be limited to the following:

FUNCTION	BITS REQUIRED	CODE	LEAST SIGNIFICANT BIT
Day of year	9	Binary-Coded Octal	1 day
Seconds of day	17	"	1 second
Milliseconds	10	"	1 millisecond
Microseconds	6	"	less than 25 microseconds
Target identification	3	"	
Station	6	"	
Mission	8	Binary (special)	
Orientation	1	Binary	
Camera synchronization	1	"	
Spares	at least 10		

3.4.13.2 Configuration. The matrix shall be divided into rows and columns in binary-coded octal groupings. At the film plane the bit size shall be at least 200 microns in the smallest dimension, the spacing between individual bits shall be at least 100 microns, the spacing between rows of bits shall be at least 200 microns, and the spacing between triplet groupings of bits shall be at least 200 microns.

3.4.13.3 Density. The recorded image densities of matrix "one" bits, fiducials, and azimuth and elevation dials, if dials are used, shall not be less than 1.0 as defined in MIL-STD-1241. The recorded image densities of matrix "zero" bits shall not be greater than base fog. The optical density of the base fog in the region of the matrix shall not be greater than 0.3.

3.4.13.4 Density gradient. The density gradient at the edge of all recorded images, starting from base fog and going to maximum density, shall be at least 0.7 per 100 microns.

3.4.13.5 Matrix information accuracy. The data recorder shall operate in two cine modes: the synchronous-recording mode and the asynchronous-recording mode. A switch shall be provided at the status and control panel to allow selection between these two modes.

3.4.13.5.1 Synchronous-recording mode. When the data recorder is operated in the synchronous-recording cine mode, the data, including azimuth and elevation data, that is encoded or otherwise present at the time of the leading edge of the synchronizing pulse for a given frame shall be recorded on the film in that frame.

3.4.13.5.2 Asynchronous-recording mode. When the data recorder is operated in the asynchronous-recording cine mode, the data, including azimuth and elevation data, that is encoded or otherwise present at the time of the leading edge of the shutter pulse for a given frame shall be recorded on the film in that frame. The nonsynchronization alarm shall be automatically disabled when the data recorder is operated in this mode.

3.4.13.6 Matrix test. Two test modes, odds and evens, shall be provided. Each test mode shall provide for recording of all fiducials and the azimuth and elevation dials, if such dials are used. The odds test mode shall also provide for recording of all odd matrix bits, and the evens test mode shall also provide for recording of all even matrix bits. A manual matrix trigger switch and an external matrix trigger line shall be provided at the status and control panel. An indicator shall be provided at the operator's console to indicate the status of the test switch.

3.4.13.7 Matrix panel. The matrix panel shall contain all matrix control switches and indicators. These shall include odds and evens test switch; orientation switch; and thumbwheel switches for inputting mission, station and target designation data. Two mission designation switches shall be provided and shall be coded as follows:

SWITCH POSITION	BINARY CODE
A	0001
B	0011
C	0100
D	0101
E	0110
F	0111
G	1000
H	1010
J	1011
K	1100
L	1101
X	1110

Three station designation switches and one target designation switch shall be provided, with switch positions of 0 through 7 and binary-coded octal output.

3.4.14 Reliability of the data recorder. The mean time between failures of the data recorder shall be at least two hours, with a confidence level of 90 percent.

3.4.15 Camera maintainability.

3.4.15.1 Maintenance and repair cycles. The camera shall be designed and constructed so that preventive maintenance shall not exceed one hour for every 20 hours of operation. A preventive maintenance schedule for cleaning and lubrication of the camera shall be provided.

3.4.15.2 Tool kit. A tool kit shall be included and shall contain a complete set of all fixtures, special tools, and lubricants required in the operation and disassembly of the camera. A ten-foot wiring test harness shall be provided to enable the operation of the film advance and related mechanisms when they are removed from the cinetheodolite camera housing.

3.4.15.3 Service and access. The design and construction of the camera shall provide for assembly and disassembly of components without complicated realignment during the reassembly operation. Labeled witness marks or location keys shall be employed for indication of proper alignment. Access panels or covers shall be provided for easy admittance to all parts of the camera for cleaning, adjustment, and maintenance.

3.4.16 Carrying cases. Separate, sturdy, lightweight carrying cases shall be provided for the camera, drive motor (if externally mounted), tool kit, film magazines, and the shutter assembly if such assembly is mounted externally to the cinetheodolite camera housing. The film magazine carrying case shall provide space for two magazines. Carrying handles shall be provided. All cases shall be provided with hinged lids. All cases shall be waterproof and dust tight. All external edges shall be reinforced with metal straps and all corners shall be metal capped. The carrying cases shall be internally fitted to their contents and shall prevent damage of the contents during transit.

3.4.17 Loading and unloading of film. The cinetheodolite and data recorder design shall allow an experienced operator of journeyman level to unload a 1200-foot magazine of exposed film from the camera and properly load a 1200-foot magazine of unexposed film into the camera in 2-1/2 minutes or less. The film path through the film transport mechanism shall be clearly marked, and loading instructions shall be marked on the inside of the camera door.

3.4.18 Microscope. A viewing microscope shall be provided for examination of the camera format area. The microscope shall be a dual-power system. A low power, 3X, shall provide confortable viewing of the entire camera format. A higher power, 10X, shall provide viewing of the target imaging area. An adjustment reticle shall be provided to position an engraved crosshair in the film plane at the center of the target imaging area. In addition, a split image type focusing reticle shall be provided. The focusing reticle shall use two shallow optical wedges cemented side by side on a piece of optical glass with the wedge apexes on opposite sides. The wedge apex angles shall be 2.5 degrees plus or minus 0.25 degrees. Regardless of the cinetheodolite pointing direction, the microscope shall be accessible to and usable by the operator when it is installed in the camera and the camera is installed in the cinetheodolite.

3.4.19 Protective devices. Film transport in the camera shall stop within one-half second after a film jam, a film break, or the end of a film run. The film transport motor shall be inoperative whenever the door is open and whenever the auxiliary microscope is installed.

3.4.20 Mounting configuration and registration. The camera shall be secured to the cinetheodolite by means of quick-release clamps so that the camera may be removed from and remounted to the cinetheodolite by an experienced operator in less than one minute. Removal and remounting of the camera shall not degrade image resolution specified in 3.3.1.5 or the cinetheodolite accuracy specified in 3.2.1.

3.4.21 Power control and indicators. A recorder system On/Off switch and indicator shall be provided at the status and control panel, and indicators shall be provided at the operator's console.

3.4.22 Tests. The data recorder performance shall be tested in accordance with Appendix III, Data Recorder Acceptance Test Procedure.

3.5 Azimuth and elevation servos. The cinetheodolite servos shall drive the cinetheodolite in azimuth and elevation to the accuracies and at the angular rates and accelerations specified herein. Manual and automatic tracking modes shall be provided. Each basic servo shall consist of a rate servo loop, and a constant input signal shall cause a constant rate of change of angular position. Rate feedback shall be utilized and a variable rate feedback control is permissible in manual tracking modes only. Fifteen-bit shaft angle encoders shall be provided in azimuth and elevation for use in automatic tracking modes.

3.5.1 Modes of operation. The azimuth and elevation servos shall operate in the following modes:

a. Manual-tracking rate mode.

b. Manual-tracking aided-rate mode.

c. Automatic-tracking acquisition mode.

d. Automatic-tracking sensor mode.

A switch shall be provided at the operator's console to allow selection of mode. An indicator shall be provided at the status and control panel to indicate the selected mode.

3.5.1.1 Manual tracking. The manual-tracking signal shall be generated when the cinetheodolite operator manipulates the pressure-type control described in 3.15.2. Pressure away from the operator shall cause the instrument pointing axis to rotate toward the zenith. Pressure toward the operator shall cause downward elevation motion. Pressure on the control to the left shall cause cinetheodolite pointing axis rotation in a counter-clockwise direction as viewed from above the cinetheodolite. Conversely, if the control is directed to the right, clockwise rotation shall result. Simultaneous azimuth and elevation control shall be possible. A reversing switch shall be provided at the operator's console for the elevation signal

3.5.1.1.1 In the manual-tracking rate mode, a constant pressure on the control shall cause the cinetheodolite pointing axis to rotate at a constant angular velocity. Upon release of the control, the angular rate shall return to zero. The magnitude of velocity of the pointing axis shall be directly proportional to the pressure applied to the control.

3.5.1.1.2 In the manual-tracking aided-rate mode, a constant pressure on the control shall cause the cinetheodolite pointing axis to change in angular velocity at a constant rate. Upon release of the control, the servo load shall continue to rotate at the last velocity component obtained prior to release of the control.

3.5.1.2 Automatic tracking.

3.5.1.2.1 In the acquisition mode, the tracking error generator unit (TEGU), described in 3.15.1, will determine the analog difference between the pointing data derived from the range computer and the cinetheodolite encoder output data described in 3.5.3. The difference signals shall be used to drive the azimuth and elevation servos.

3.5.1.2.2 In the sensor mode, an auxiliary tracking error sensor will furnish pointing data to drive the azimuth and elevation servos. Provisions shall be made for mounting the sensor on the cinetheodolite in such a way that it shall track with the cinetheodolite. The sensor will not exceed 20 pounds in weight, 8 inches in width, 8 inches in height, and 24 inches in length. A means shall be provided to balance the cinetheodolite elevation tube for all dummy loads from zero to 20 pounds at the sensor location. The azimuth and elevation encoder and tachometer outputs and the servo loop inputs shall be at readily available mil specified connectors mounted on the status and control panel.

3.5.2 Acquisition data. The position servos shall meet all of the requirements of the automatic-tracking modes of operation while using azimuth and elevation acquisition data from the TEGU in the acquisition mode and from the sensor in the sensor mode. The acquisition data will have the following characteristics.

a. Format. Analog.

b. Polarity. Bipolar with provisions for inverting the polarity.

c. Signal level. Continuously adjustable from plus or minus 3.0 volts full scale, to plus and minus 10.0 volts full scale.

d. Stability and drift. Total uncertainty in the signal will be less than plus or minus 1.32 arc-minutes in azimuth and elevation angle components.

e. Noise. Total uncertainty in the signal will be less than plus or minus 1.32 arc-minutes in azimuth and elevation angle components

f. Zero order hold output with closed loop sampling available at 10, 20, 100 or 200 samples per second.

3.5.3 Encoder.

3.5.3.1 Outputs. The cinetheodolite shall provide 15-bit azimuth and elevation encoder outputs to the TEGU in the acquisition mode, and to the auxiliary tracking sensor electronics in the sensor mode. The encoder outputs shall have the following characteristics:

a. Format. Cyclic (gray) binary code or straight binary, parallel.

b. Source impedance. 1000 ohms maximum.

c. Logic true polarity. Positive or negative.

d. Signal level. "One" 3 volts minimum to 20 volts maximum; "zero," zero volts minimum to 0.25 volts maximum.

e. Pulse duration. Five microseconds to dc.

f. Repetition rate. Continuous output or selectable at 20, 40, 50, 100 and 200 pulses per second rate.

3.5.3.2 Inputs. If the encoder output is not contiuous it shall accept external strobe inputs with the following characteristics.

a. Signal level. Six volts, plus or minus 0.5 (logic one); zero volts, plus or minus 0 5 volts (logic zero).

b. Polarity. Selectable, positive or negative.

c. Source impedance. 1000 ohms.

d. Repetition rate. 20, 40, 50, 100 and 200 pulses per second.

3.5.4 Servo performance. The azimuth and elevation servos shall meet all of the following cinetheodolite requirements when a 20-pound auxiliary sensor dummy load is installed at the tracking sensor location.

3.5.4.1 Manual modes.

3.5.4.1.1 In the manual-tracking rate mode, with 10 volts applied to the input of the rate servo loops, the angular velocity shall be 30 plus or minus 0.25 degrees per second. If variable rate feedback is used, this velocity shall be reached with maximum rate feedback applied.

3.5.4.1.2 In the manual-tracking aided-rate mode, with 10 volts applied to the input, the angular acceleration shall be 45 plus or minus 0.5 degrees per second per second. This acceleration shall be maintained throughout the angular velocity range of 0 to 20 degrees per second.

3.5.4.1.3 The minimum angular velocity for each rate servo shall be 0.01 plus or minus 0.0025 degrees per second when approached from an angular velocity of zero degrees per second.

3.5.4.1.4 Each rate servo shall have the following transient response characteristics based on a step input of 0.1 volt with a rise time of 1.0 microsecond or less:

a. Maximum rise time (10 to 90 percent). 80 milliseconds.

b. Maximum settling time to within plus or minus 5 percent of commanded velocity. 250 milliseconds.

c. Maximum overshoot. 10 percent of commanded velocity.

d. Minimum bandwidth (3 decibel point). 5 hertz.

If variable rate feedback is used, this transient response shall apply when minimum rate feedback is utilized.

3.5.4.1.5 Servo drift correction controls shall be provided on the operator's console. The range of the drift correction controls shall be such that all drifting can be corrected over the range of ambient conditions specified in 3.9.1 and over the voltage range specified in 3.8.1. Total time permitted for drift correction adjustments shall not exceed 2 minutes.

3.5.4.1.6 After the operator has made an initial adjustment for zero drift, and as long as the temperature does not change by more than 10 degrees F., the mount shall not drift by more than 0.002 degrees per second. A meter and selector switch shall be provided on the operator's console so that the operator can make adjustments to null the rate loop error signal for each axis while observing the error voltage.

3.5.4.1.7 The torque requirements for both the azimuth and the elevation servo motors shall not vary by more than plus or minus 3.0 percent of average value over the entire azimuth and elevation range of travel.

3.5.4.1.8 Either an elevation balance adjustment or a means to prevent motion caused by minor mechanical unbalance in elevation shall be provided.

3.5.4.1.9 No backlash shall be allowed between the servo drive motors and their respective loads.

3.5.4.1.10 All components of each servo system shall be rated for continuous duty.

3.5.4.2 Automatic-tracking acquisition mode.

3.5.4.2.1 The allowable azimuth and elevation position tracking error shall be plus or minus 4.0 minutes of arc when the simultaneous angular tracking velocity and acceleration are 20 degrees per second and 20 degrees per second per second, respectively.

3.5.4.2.2 Based on a reference step input displacement command of 0.25 degrees, the transient response characteristics for both the azimuth and the elevation internal position servo systems (IPSS) shall be as follows:

a. Maximum rise time (10 to 90 percent). 80 milliseconds.

b. Maximum delay before first motion. 20 milliseconds.

c. Maximum settling time to within plus or minus 5 percent of commanded velocity. 500 milliseconds.

d. Maximum overshoot. 30 percent of commanded velocity.

3.5.4.2.3 When tracking a stationary point, no cinetheodolite pointing axis motion shall be allowed except the drifts specified below.

3.5.4.2.4 Position drift in the acquisition mode shall not be greater than plus or minus 1.0 minute of arc with ambient temperature excursions of plus or minus 10 degrees F. Position loop drift correction controls shall be provided on the operator's console. Each drift correction control shall be capable of correcting position drifts over the range of ambient conditions specified in 3.9.1, and over the voltage range specified in 3.8.1.

3.5.4.3 Automatic-tracking sensor mode. The contractor will not be required to check the closed-loop servo performance in the automatic-tracking sensor mode. However, the following sensor-mode provisions shall be made:

a. The encoder outputs shall be buffered, and short-circuit protection shall be included.

b. The tachometer outputs shall include short-circuit protection.

c. The servo loop analog input lines shall be buffered; shall include switches for selectively inverting signal polarity; shall provide for continuous scaling of gain from 1 to 100; and shall include short-circuit protection.

d. Space shall be reserved for future installation of four active servo compensation networks (two operational amplifiers for azimuth and two for elevation)

e. The drift correction controls of 3.5.4.2.6 shall operate effectively in the sensor mode.

f All signal inputs and outputs shall be made available at one common, easily accessible location on the status and control panel, utilizing suitable mil specified connectors with mates supplied.

3.5.4.4 Input switching. A control shall be provided at the operator's console to switch azimuth and elevation inputs into the system from TEGU velocity, TEGU position, and external sensor. A visual indicator of the input selected shall be provided at the status and control panel.

3.5.4.5 Crossfeed. Crossfeed between the azimuth and elevation servos shall be at least 80 decibels below the maximum commanded output.

3.5.4.6 Interface protection. Overvoltage, short-circuit and saturation protection shall be provided for all operational amplifiers used in the analog/digital interface.

3.5.5 Secant control. A secant control shall be provided which shall increase the azimuth servo input signal directly as a function of the secant of the elevation angle over the elevation angular range of minus 5 degrees to plus 80 degrees. Above 80 degrees it shall increase the azimuth servo input signal directly as the secant of 80 degrees.

3.5.6 Encoder readouts. Continuous five-digit octal readouts of cinetheodolite azimuth and elevation encoders shall be provided at the operator's console and at the status and control panel.

3.5.7 Mount limits and stops The cinetheodolite shall have an unrestricted range of travel in azimuth of at least 720 degrees, and a minimum unrestricted travel in elevation from minus 5 degrees to plus 95 degrees (5 degrees past zenith). A combination of audible alarms, limit switches, shock absorbers, and mechanical stops shall be provided to prevent damage when the mechanical limits are reached. If azimuth rotation is limited, an azimuth location indicator shall be provided at the operator's console The indicator shall indicate zero at the midpoint of azimuth rotational range.

3.5.8 Dome control signal. A 16X synchro transmitter shall be provided in the cinetheodolite to furnish a drive signal to the type HCT control transformer for the dome

3.5.9 Servo power.

3.5.9.1 Separate azimuth and elevation servo power on/off switches and indicators shall be provided at the status and control panel.

3.5.9.2 A servo system operate/standby switch and indicator shall be provided at the operator's console. An indicator thereof shall also be provided at the status and control panel. Standby position shall remove the power amplifier outputs.

3.5.10 Tachometer outputs. The direct azimuth and elevation tachometer outputs shall be available at a suitable mil specified connector at the status and control panel.

3.5.11 Tests. The azimuth and elevation servo performance shall be tested in accordance with Appendix IV, Azimuth and Elevation Servo Acceptance Test Procedure.

3.6 Range servo (focusing). A range servo shall be provided and shall be capable of maintaining the images of all variable-range objects in focus at the film plane. The location and configuration of the focusing system shall be chosen by the contractor. It shall operate in slave and manual modes.

3.6.1 Slave mode. The range servo input shall utilize range output from the TEGU to maintain focus for all objects from 5000 yards to infinity over the velocity range of 0 to 2000 yards per second and the acceleration range of 0 to 2000 yards per second per second. The TEGU range output will have the following characteristics:

a. Format. Analog.

b. Polarity. Unipolar with provisions for inverting the polarity

c. Signal level. Continuously adjustable from plus and minus 3.0 volts full scale, to plus and minus 10.0 volts full scale.

d. Stability and drift. Total uncertainty in the output signal will be less than plus or minus 64 yards.

e. Noise. Output noise level will not exceed 700 microvolts rms.

3.6.2 Manual mode. A manual focusing mechanism, enabling the operator to manually focus to all ranges from 5000 yards to infinity, shall be provided. Manual focusing shall be accomplished by the use of the manual control and a calibrated range indicator. The range indicator error shall not exceed plus or minus 2 percent of the indicated range.

3.6.3 Controls. A control shall be provided at the operator's console which shall enable the operator to select TEGU range and manual range as system input. An indicator of the selected input shall be given at the status and control panel.

3.6.4 Tests. Slave and manual mode range servo tests shall be conducted in accordance with Appendix V, Range Servo Acceptance Test Procedure.

3.7 Controls. The principles given in chapters 6 and 7 of Human Engineering Guide to Equipment Design shall be used for guidance in designing the controls and related equipment.

3.7.1 Operator's station. An operator's station shall be provided and shall be located in the dome, along with the cinetheodolite. It shall include equipment as follows.

3.7.1.1 Controls for tracking. The controls used during the tracking mission shall be minimal in number and identifiable by location or feel as well as by sight. The control stick for controlling the pointing direction of the cinetheodolite will be furnished by the government. The control stick electronics shall be provided by the contractor. Drawing No. OD-15079 (Stiff Stick Schematic) is furnished as a reference. With maximum control stick deflection, the output of the stick electronics shall furnish the control signals required to obtain the angular velocities given in 3.1.3.1. The operator shall be able to operate the following switches while both his hands are on the stick control:

a. Control stick gain (high/low).

b. Tracking mode switch (rate/aided rate).

c. Camera (off/on) control and indicator.

d. Acquire/manual (for automatic signals from TEGU or manual tracking).

The camera control switch shall be a foot switch and the other three switches shall be adjacent to the stick control.

3.7.1.2 Operator's console. The cinetheodolite operator's controls and indicators shall be mounted on a console in functionally related groups. In direct sunlight, the controls and indicators shall be readily visible to and operable by a person seated in the operator's chair. A dimmer control shall be provided for all illuminated indicators. Table I summarizes the console requirements and is given for reference only.

3.7.1.3 Operator's chair. A padded chair shall be provided at the operator's console. It shall be adjustable over a range of at least three inches fore and aft and at least five inches up and down. The chair shall be situated so that the cinetheodolite operator shall be able to view

TABLE I. CONTROL AND INDICATOR REQUIREMENTS

GROUP	FUNCTION	REQUIREMENT	PD PARA
Camera	Exposure control	1/1000, 1/500, 1/250	3.4.7
Camera	Orientation switch	On/off	3.4.13.7
Camera	Focusing switch and indicator	Manual-blue, slave-green	3.6.3
Camera	Manual focusing control and indicator	15,000 feet to infinity	3.6.2
Camera	Film footage counter	0 to 1200 feet	3.4.8
Camera	Nonsynchronization alarm	Aubible 1000 Hz	3.4.12.4
Camera	Camera-loaded indicator	Loaded-green, unloaded-amber	3.4.8
Camera	Data recorder system indicator	On-green, off-amber	3.4.21
Camera	Matrix test indicator	Off-green, on-amber	3.4.13.6
Camera	Lens cap indicator	Off-green, on-amber	3.3.1.10
AZ/EL	Mount limit alarms	Audible 2000 Hz	3.5.7
AZ/EL	Automatic-tracking input switch	TEGU position/TEGU velocity/sensor	3.5.4.4
AZ/EL	Elevation encoder readout	Continuous 5-digit octal display	3.5.6
AZ/EL	Azimuth encoder readout	Continuous 5-digit octal display	3.5.6
AZ/EL	Manual-tracking azimuth drift adjust	Potentiometer	3.5.4.1.5
AZ/EL	Manual-tracking elevation drift adjust	Potentiometer	3.5.4.1.5
AZ/EL	Drift adjust selector switch	AZ/EL/off	3.5.4.1.6
AZ/EL	Drift adjust indicator	Meter	3.5.4.1.6
AZ/EL	Automatic-tracking azimuth drift adjust	Potentiometer	3.5.4.2.6
AZ/EL	Automatic-tracking elevation drift adjust	Potentiometer	3.5.4.2.6
AZ/EL	Azimuth position indicator (if applicable)	-360° to +360°	3.5.7
AZ/EL	Operate/standby switch and indicator	Operate-green, standby-amber	3.5.9.2
AZ/EL	Emergency off switch and indicator	Cherry red	3.7.6
Communications	Countdown net speaker and volume control	4"speaker and potentiometer	3.7.5
Communications	Microphone outlet	U-79/U connector	3.7.5
Communications	Two-station intercom	Slave station	3.7.4
Console	Panel lights dimmer control	Off to full brilliance	3.7.1.2

comfortably through the OGT and operate the controls at the operator's console while seated in the chair. The chair position and console arrangement shall also allow the operator to readily see all console controls and indicators when not viewing through the OGT. There shall not be more than 60 arc-minutes of relative motion between the OGT eyepieces and the operator's chair under all conditions of tracking.

3.7.2 Status and control panel. The contractor shall provide a status and control panel which shall be installed in the equipment room of the government furnished test facility adjacent to the TEGU. Controls shall be mounted on the status and control panel in functionally related groups. Table II summarizes the status and control panel requirements and is given for reference only.

3.7.3 External lines and connectors. External connectors and signal, control, and power lines shall be provided at the status and control panel. All lines shall terminate in suitable mil specified connectors with mates supplied. Table III summarizes requirements given elsewhere in this PD and is included for reference only.

3.7.4 Intercommunications. A two-station intercom system shall be installed to provide communications between the operator's console and the status and control panel. The master station shall be at the status and control panel, and the slave station shall be at the operator's console.

3.7.5 Countdown communications. A four-inch speaker, 3.2 to 8 ohms impedance, complete with volume control, shall be installed in a suitable enclosure at the operator's console for countdown net usage. A suitable cable shall be provided from the status and control panel to the operator's console. The microphone cable shall terminate in a type U-79/U connector at both stations. One end of the speaker cable shall terminate at the operator's console speaker and the other end shall terminate in a suitable two-pin connector at the status and control panel.

3.7.6 Emergency off-switch. At the operator's position and at the status and control panel, an emergency "shut-down" shall be provided by a pushbutton switch. The button shall be bright cherry red in color and approximately one inch in diameter. It shall be labeled "OFF" and shall be positioned to facilitate rapid use in an emergency. Actuating it shall stop azimuth and elevation motion of the instrument by putting the servo systems into standby.

3.7.7 External shut-off. Suitable lines shall be provided at the rear of the status and control panel to allow automatic shut-off of the camera and servo drive systems during acceptance testing.

TABLE II. INDICATOR REQUIREMENTS

GROUP	FUNCTION	REQUIREMENT	PD PARA
Main power	System power switch and indicator	On-green, off-red	3.8.1
AZ/EL	Operate/standby indicator	Operate-green, standby-amber	3.5.9.2
AZ/EL	Azimuth servo power switch and indicator	On-green, off-red	3.5.9.1
AZ/EL	Elevation servo power switch and indicator	On-green, off-red	3.5.9.1
AZ/EL	Emergency off switch	Cherry red	3.7.6
AZ/EL	Tracking indicator	Acquire-green, manual-amber	3.5.1
AZ/EL	Automatic-tracking input indicator	TEGU position-green, sensor-amber, TEGU velocity-blue	3.5.4.4
AZ/EL	Azimuth encoder readout	5-digit octal display	3.5.6
AZ/EL	Elevation encoder readout	5-digit octal display	3.5.6
AZ/EL	Azimuth secant switch and indicator	Secant-green, linear-blue	3.5.5
AZ/EL	Azimuth signal invert switch	Clockwise-positive/clockwise-negative	3.5.4.3
AZ/EL	Elevation signal invert switch	Up-positive/up-negative	3.5.4.3
Data recorder	Recorder system switch and indicator	On-green, off-red	3.4.2
Data recorder	Frame rate selector switch	5/10/20/50 fps and single-frame	3.4.1
Data recorder	Focusing mode indicator	Slave-green, manual-blue	3.6.3
Data recorder	Mission designator	Special code	3.4.13.7
Data recorder	Station designator	Binary-coded octal	3.4.13.7
Data recorder	Target designator	Binary-coded octal	3.4.13.7
Data recorder	Matrix test switch and indicator	Off-green, on-amber	3.4.13.6
Data recorder	Matrix test switch and indicator	Odds-green, evens-blue	3.4.13.6
Data recorder	Single-frame shutter switch	Open/close	3.4.9.3
Data recorder	Single-frame shutter indicator	Open-amber, closed-blue	3.4.9.4
Data recorder	Single-frame advance switch	Momentary	3.4.9.3
Data recorder	Matrix trigger switch	Momentary	3.4.13.6
Communications	Two-station intercom	Master station	3.7.4

TABLE III. EXTERNAL WIRING REQUIREMENTS

GROUP	FUNCTION	REQUIREMENTS (MIN)	PD PARA
Timing	Day, seconds, milliseconds, microseconds	44 lines	3.4.13.1
Timing	Frame rate: 5, 10, 20, 50 pps	4 lines	3.4.2.2
Range	Analog range (TEGU)	2 lines	3.6.1
AZ/EL	Analog azimuth (TEGU velocity)	2 lines	3.5.4.4
AZ/EL	ANalog azimuth (TEGU position)	2 lines	3.5.4.4
AZ/EL	Analog azimuth (sensor input)	2 lines	3.5.4.4
AZ/EL	Analog elevation (TEGU velocity)	2 lines	3.5.4.4
AZ/EL	Analog elevation (TEGU position)	2 lines	3.5.4.4
AZ/EL	Analog elevation (sensor input)	2 lines	3.5.4.4
AZ/EL	Azimuth encoder 17-bit	17 lines plus common and control	3.5.1.2.2
AZ/EL	Elevation encoder 17-bit	17 lines plus common and control	3.5.1.2.2
AZ/EL	External servo compensation net	8 lines, 2 inputs, 2 outputs each axis	3.5.4.3
AZ/EL	External servo kill	2 lines	3.7.7
AZ/EL	Tachometer outputs	4 lines	3.5.10
Dome	16X azimuth synchro transmitter	5 lines	3.5.8
Communications	Countdown circuits speaker, microphone, and switch	6 lines	3.7.5
Camera/data recorder	Shutter pulse	1 line	3.4.9.2
Camera/data recorder	Matrix trigger	1 line	3.4.13.6
Camera/data recorder	Shutter open control, single frame	2 lines	3.4.9.3
Camera/data recorder	Shutter close control, single frame	2 lines	3.4.9.3
Camera/data recorder	Synchronization status	1 line	3.4.12.3
Camera	External camera kill	2 lines	3.7.7
Site power	208 V, 60 Hz, 3-phase	4 lines	3.8.1
Spares	Power lines (operator console to status and control panel)	4 lines	3.8.2
Spares	Signal/control lines	40 lines	3.8.2

3.8 Electrical.

3.8.1 Power. Three-phase, four-wire, 208 plus or minus 20-volts, 60 plus or minus 3-hertz power will be available and shall be used as the power input to the CEI. A system power on/off switch and indicator shall be provided at the status and control panel.

3.8.2 Cables. The signal and power lead configuration shall be chosen by the contractor. Whether slip rings or cables are employed, four square power leads (10-amperes, 120-volts rating) and 40 spare signal leads shall be provided.

3.8.3 Signal lines. All system interconnections and all interface signal lines shall be shielded with grounded shields to insure that all of the performance requirements of this PD are met.

3.9 Environment.

3.9.1 Operational. The CEI shall perform as specified herein under all combinations of the following environmental conditions:

a. Ambient air temperatures between 10 degrees and 120 degrees F.

b. Altitudes between sea level and 10,000 feet above sea level.

c. Relative humidity between 5 percent and 95 percent.

d. Winds between zero and 40 miles per hour, when protected by the dome with the port fully open.

e. Direct solar irradiation for indefinite periods of time.

3.9.2 Storage. The CEI shall perform as specified herein after being subjected to environmental conditions as follows:

a. Ambient air temperatures between minus 20 degrees and plus 130 degrees F.

b. Relative humidity between 5 percent and 100 percent.

3.10. Reliability. The mean time between failures of the CEI, exclusive of camera and shutter failures, shall be at least eight hours, with a confidence level of 90 percent.

3.11 Safety. The CEI shall be designed so as to insure protection from injury to personnel operating and maintaining the equipment. The following paragraphs of MIL-STD-454, Requirement 1, shall apply: paragraphs 6 through 6.5a, 6.7, 6.13, and 9 through 9.6.

3.12 Materials, workmanship, and finishing. The CEI, including all parts and assemblies, shall be constructed and finished in accordance with Requirement 9 of MIL-STD-454, and shall have a uniform appearance in color, type of finish, hardware, and trim.

3.13 Maintainability. Wherever feasible, the design shall use removable and replaceable modular plug-in assemblies in the electronic, electrical, and mechanical parts of the equipment to facilitate operation, maintenance, repair, and adjustment. Labeled input and output test points shall be provided to facilitate circuit evaluation. Labeled witness marks or locations keys shall be employed for indication of proper alignment. Panels or covers shall be provided for easy access to all parts of the equipment for cleaning, adjustment, and maintenance. Cables between units of the system shall have connectors which shall prevent mating of all but the desired units. Number-coded wire shall be used in all cables and interunit wiring. Duplication of number codes shall be avoided. Internal wiring shall be laced or otherwise secured in a safe and orderly manner.

3.14 Technical data. Technical data shall be furnished as set forth in the Contract Data Requirements List (DD Form 1423) and in accordance with the Data Sepcifications (DA Form 3149-R) attached thereto.

3.15 Government-furnished equipment. The following equipment will be furnished by the government to the contractor for use as part of the system.

3.15.1 Tracking error generator unit (TEGU) as described in TDP 731 and its Addendum 5.

3.15.2 Control stick assembly as described in WSMR Drawings OD-06443 and OD-15079.

4. QUALITY ASSURANCE PROVISIONS

4.1 Inspection system. The contractor shall maintain an inspection system in accordance with MIL-I-45208.

4.2 Test procedures. The following test procedures shall be used in testing the CEI for conformance with the requirements of Section 3:

a. Appendix I, Cinetheodolite Pointing Accuracy Acceptance Test Procedure.

b. Appendix II, Optical System Test Procedure.

c. Appendix III, Data Recorder Acceptance Test Procedure.

d. Appendix IV, Azimuth and Elevation Servo Acceptance Test Procedure.

e. Appendix V, Range Servo Acceptance Test Procedure.

If the contractor proposes alternatives to any part of these test procedures, such alternatives shall require approval by the government prior to testing. A test plan for human engineering tests pertaining to the operator's console shall be devised by the contractor and shall be made available to the government in accordance with the attached DD Form 1423 (Data Item 08-006). Conformance to the requirements of 3.8, 3.11, 3.12 and 3.13 shall be determined by inspection. It shall be the government's option to regard satisfactory operation of the CEI during the on-site testing as an adequate demonstration that the requirements of 3.9 have been met. The government reserves the right to perform additional environmental tests on the CEI within the specified limits. The government reserves the right to witness all inspections and tests, and to conduct additional inspections and tests to insure compliance with the requirements of this PD. Complete certified records of all inspections and tests shall be made available to the government in accordance with the attached DD Form 1423 (Data Item 08-009).

4.3 <u>In-plant Tests</u>.

4.3.1 <u>Government responsibility</u>. To facilitate contractor in-plant tests, the government will furnish the following:

a. Servo test unit.

b. Nonsynchronous frames counter.

4.3.2 <u>Contractor's responsibility</u>. The contractor shall conduct inspections and tests to verify that the requirements of Section 3, except 3.2, are met. Advance notice of all inspections and tests shall be given according to the attached DD Form 1423 (Data Item 08-012). The inspections and tests shall be conducted at the contractor's plant or any other facility acceptable to the government. All direct costs associated with the in-plant inspections and tests shall be the responsibility of the contractor.

4.4 <u>On-site tests</u>. Following successful in-plant testing, the CEI shall be tested at the test facility at WSMR. These tests shall be conducted to verify that the requirements of 3.2 are met, and to reverify the performance of the camera and servo systems.

4.4.1 <u>Government responsibility</u>. During the on-site testing period, the government will furnish the following:

a. The existing test facility.

b. Star position (azimuth, elevation, and time) data for conducting static pointing accuracy tests.

c. Film and film processing.

d. Film-reading services.

e. Computer data-processing services.

4.4.2 Contractor responsibility. All direct costs associated with the on-site tests, other than those specified in 4.4.1, shall be the responsibility of the contractor. The contractor's responsibility shall include the following:

a. The interface between the CEI and the test facility.

b. A mathematical analysis for the conversion of the static and dynamic error increments to angular pointing error. This shall include an error model of the CEI.

c. A working computer program of the mathematical analysis, written in FORTRAN V.

d. Performance of all tests described in Appendices I through V.

e. Compilation and preservation of all test data required to determine the performance of the CEI.

f. A written report on the tests, giving all pertinent information from raw data to final conclusions.

5. PREPARATION FOR DELIVERY

Preservation, packaging, packing, and marking shall be as specified elsewhere in the procurement document.

6. NOTES:

6.1 Definitions.

6.1.1 Dynamic pointing error. The dynamic pointing error is defined as the square root of the sum of the variance of the static error and the square of the dynamic error increment, i.e.,

$$\epsilon^2 = \sigma_s^2 + \epsilon_d^2 \quad .$$

6.1.2 Variance of static error. The variance of the static error is defined as the summation of the squares of a number of individual static residuals or discrepancies divided by the number of degrees of freedom, i.e.,

$$\sigma_s^2 = \frac{\Sigma \delta_{si}}{D.F.} \quad .$$

6.1.3 Dynamic pointing error increment. If the statistical procedures, designed to test the hypothesis that dynamic error and static error are the same, fail to confirm the specified hypothesis, then the procedures give a best estimate of the magnitude of the difference between dynamic error and static error. This best estimate of the difference between dynamic and static error is termed the dynamic pointing error increment.

APPENDIX I

CINETHEODOLITE POINTING ACCURACY ACCEPTANCE TEST PROCEDURE

The pointing accuracy acceptance test procedure is divided into the following general areas:

a. Tests to establish basic variances.

b. Static pointing accuracy.

c. Dynamic error increment.

d. Thermal stability error increment.

e. Dynamic pointing accuracy.

TESTS TO ESTABLISH BASIC VARIANCES

The following tests are to be performed to establish certain basic variance estimates which will be used to compute various statistics, required sample sizes, etc. The sample sizes of 60 specified for determining the variances immediately in question are such that the variances will be estimated within ±20 percent with 90 percent confidence (approximately and given the appropriate assumptions). All of these tests will be conducted using the test fixture within the astrodome at the prototype evaluation facility. The target produced on the film by the collimator which is part of this test is a small star-image-like point.

In conducting these field tests, near ideal conditions must be obtained. The tests will be conducted in the closed dome. There shall be no operator or observer present in the dome while the exposures are being made. A sufficient period of time shall be allowed for the air within the dome to reach an equilibrium condition after the last disturbance of the air by operating personnel.

All of the tests described in this section will be repeated three times, at elevation angles of 30°, 45°, and 60°. The final reported variance shall be the lumped variance for the three separate tests.

FILM MEASUREMENT VARIANCE

A single photograph will be taken of the target at each of the aformentioned elevation angles. The same frame of film shall be measured repeatedly sixty times, and the azimuth and elevation angles computed. That portion of the

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measurement process accomplished by a human operator shall be done in a sequence from start to finish on the selected frame and then repeated, after the frame has been removed from the reader and then repositioned. The measuring machine used is not being tested, so the accuracy of this machine must be sufficiently good that the error attributable to the machine itself is well below the best accuracy required of the cinetheodolite, i.e., well below 2 arc seconds. In accumulating the sample of sixty azimuth and elevation angles estimates at least three different operators will be used. The variance of these data will be computed and referred to as $S^2_{AM_i}$ and $S^2_{EM_i}$ (A and E refer to azimuth and elevation angles, respectively, and $i = 1, 2, 3$). The lumped variance shall be computed, averaged, in the horizontal case, over the cosine of the elevation angle:

$$S^2_{hM} = \frac{1}{3}(S^2_{AM_i} \cos^2 30° + S^2_{AM_2} \cos^2 45° + S^2_{AM_3} \cos^2 60°)$$

$$S^2_{vM} = \frac{1}{3}(S^2_{EM_1} + S^2_{EM_2} + S^2_{EM_3}) \quad ,$$

assuming that each component variance has the same number of degrees of freedom (the required 59).

If either S^2_{hM} or S^2_{vM}, or both, exceeds 16 (arc-seconds)^2 the instrument will be considered as not conforming to the accuracy specification.

STATIC INSTRUMENT VARIANCE

For this determination a series of sixty different exposures will be measured from which azimuth and elevation angles will be calculated. The first series will be taken with the camera operating in the single frame mode, and the camera motor will be turned off during the actual exposure. The cinetheodolite will be locked at fixed azimuth and elevation angles and the drive servos turned off. The variances for this series of observations shall be computed, and referred to as $S^2_{AS_i}$ and $S^2_{ES_i}$. The $\cos^2 E_i$ weighted variances will be computed, as above, and the following F-statistics then computed:

$$F_A = \frac{S^2_{hS}}{S^2_{hM}} \qquad F_E = \frac{S^2_{vS}}{S^2_{vM}}$$

If

$$F_A \quad 1.53 \text{ or } F_E \quad 1.53 \quad ,$$

it will be considered that no statistically significant (5 percent significance level) error can be attributed to relative motion of the cinetheodolite and the test fixture supporting the collimator, and variance due to this motion will be considered equal to zero If

$$F_A > 1.53 \text{ or } F_E > 1.53 \quad ,$$

a significant contribution to the variances will be considered as due to test fixture motion, and a variance due to fixture motion computed by the formulas:

$$S^2_{hF} = \langle S^2_{hS} \rangle - \langle S^2_{hM} \rangle$$

$$S^2_{vF} = \langle S^2_{vS} \rangle - \langle S^2_{vM} \rangle \quad .$$

If the shaft angle information is recorded in digital form the azimuth and elevation shaft angle positions will be separately analyzed. The shaft angle variances, $S^2_{AA_i}$ and $S^2_{EA_i}$, shall be computed and averaged with $\cos^2 E_i$ weighting, as above. These variances shall be subtracted in computing the variance due to test fixture motion. If the variances computed for test fixture motion turn out negative, they will be set equal to zero.

If the fixture motion variances are found to be zero according to the prescription given, and if $\langle S^2_{hS} \rangle$ or $\langle S^2_{vS} \rangle$, or both, is greater than 16 (arc-seconds)^2 the instrument shall be considered as not conforming with the accuracy specification.

The next series of exposures will be taken with the camera operating at 50 frames per second, with the shutter set so as to give the longest possible exposure at this frame rate. The collimator shall be operated with a constant, rather than a pulsed, source of illumination. The film shall be measured and computations of the angles and variances thereof made. The lumped variance, averaged over $\cos^2 E$ as above, will be computed. These variances shall be adjusted as follows to produce the static instrument variances.

$$\langle S^2_{hC} \rangle = \langle S^2_{h\cdot} \rangle - \langle S^2_{hF} \rangle$$

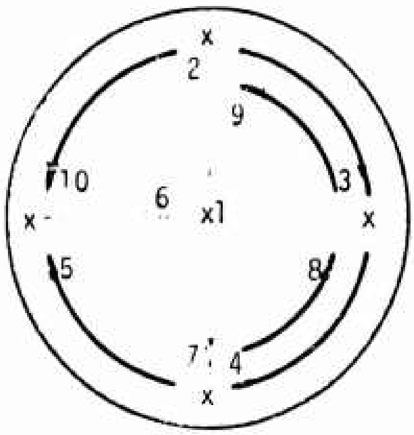
$$\langle S^2_{vC} \rangle = \langle S^2_{v\cdot} \rangle - S^2_{vF} \quad ,$$

where $\langle S^2_{h\cdot} \rangle$, $\langle S^2_{v\cdot} \rangle$ represent the newly computed variances.

If $\langle S^2_{hC} \rangle$ or S^2_{vC}, or both, exceed 16 (arc-seconds)^2, the instrument will be considered nonconforming.

SMALL DISPLACEMENT VARIANCE

For this determination a series of exposures shall be analyzed between which the instrument has been very slightly displaced in azimuth and elevation under very modest dynamic conditions. The displacements shall be such as to locate the collimator target in the field of view as is illustrated in the sketch below.



This sequence shall be repeated six times to give the desired sixty member sample. In moving from point to point, the servos shall be operated at the minimum gain which will produce satisfactory position error in final instrument location and at very low velocity. The camera shall be operated in the single-frame mode. From the angular data computed from these observations, the instrument small displacement variances, designated as S^2_{hP} and S^2_{vP}, shall be computed as follows:

$$S^2_{hP} = S^2_{h} - S^2_{hF}$$

$$S^2_{vP} = S^2_{v} - S^2_{vF}$$

If S^2_{hP} or S^2_{vP}, or both, is greater than 16 (arc-seconds)^2, the instrument shall be considered nonconforming.

STATIC POINTING ACCURACY

The static pointing accuracy shall be determined by a series of photographs of stars. The testing of static accuracy will be designed to be substantially free of refraction error uncertainty, and film measurement error. The testing will be designed to emphasize the inherent geometrical integrity of the instrument, the angle metrology, and the stability under nonsevere climatic environmental conditions.

The star photographs will be taken at night. It will normally be true that the temperature inside the dome is cooler than the outside air temperature at sunset. At sunset the dome will be opened, and the air temperature inside the dome allowed to become the same as the outside temperature. At the start of the test one operator will occupy the tracking operator's seat and will remain there for the duration of the test. Prior to the commencement of the test the operator shall make whatever adjustments to the cinetheodolite as are required and shall make no others for the duration of the test. The long term tilt stability of the pedestal cannot be guaranteed to be below any level.

A list of 140 stars that are to be used as targets in the accuracy evaluation of the CEI are listed in the star list data sheet.

The contractor shall calibrate the cinetheodolite using the North Star (Polaris) as a reference. The coordinate information shall be obtained from the government-furnished star position listing The calibration shall be performed as follows:

a. Set the TEGU target position thumbwheel switches to register the azimuth coordinates of the North Star.

b. Set the TEGU selector switch to saturate the D to A converter at 22.5 degrees.

c. Position the cinetheodolite so that the North Star is in the center of the field of view of the main optical system to ±1 arc minute.

d. Set the calibrate on/off switch to on.

e. Set the azimuth/elevation switch to azimuth.

f. Set the mode enter/verify switch to enter.

g. Set the selector position/velocity switch to position.

h. Depress the calibrate execute switch. The azimuth angle of the North Star relative to the cinetheodolite is now entered into the TEGU.

i. Repeat Step a except enter in the elevation coordinates of the North Star.

j. Verify that the North Star is still centered in the field of view to ±1 arc minute.

k. Repeat Step d

l. Set the azimuth/elevation switch to elevation.

m. Repeat Steps f, g, and h. The elevation angle of the North Star relative to the cinetheodolite is now entered into the TEGU.

Each nights test will consist of the observation of at least 20 stars. The stars to be observed shall be selected by the contractor. A sequence of N_s photographs of each star will be taken. N_s will be determined by the magnitude of certain variances. The interval between photographs, [illegible], shall be such that $N_s \cdot$ [illegible] = 5 minutes of time, approximately. N_s shall be an odd integer. Each star shall be photographed with the camera operating in the single frame mode. The theodolite will be repositioned to the new star position between each photograph.

To accomplish each night's testing, the following procedure will be followed:

a. Select a star from the government-furnished listing.

b. Log the barometric pressure, ambient temperature, star number and time as per Star Test Data (sample form attached).

c. Set the star number into the station switches of the data matrix unit.

d. Set the selected time, T_0, into the ARTRAC Modular IRIG Timing Terminal (MITT). T_0 establishes the time of exposure of the first photograph; it also establishes the time sequence for the remaining $N_s - 1$ photographs.

e. Set the target position thumbwheel switches of the TEGU to register the azimuth coordinate of the selected star. This will be the azimuth coordinate for the time $T_0 + (N_s - 1)$

f. Set the TEGU select azimuth elevation switch to azimuth.

g. Set the TEGU mode switch to verify.

h. Set the TEGU calibrate on/off switch to off.

i. Depress the TEGU execute switch. This will drive the instrument in azimuth to the direction of the star.

j. Verify that the cinetheodolite azimuth direction is within 5 arc-minutes of the star azimuth direction by checking the encoder readouts.

k. Repeat Steps e through j for elevation.

l. Initiate the camera shutter sequence. The shutter shall open 1/8 second before time $T_0 + (N - 1)$.

m. At time $T_0 + (N - 1)$ the system shall strobe on all position and matrix data.

n. At time $T_0 + (N - 1)$ the camera shutter will close.

o. Advance the film one frame.

p. Repeat Steps e through o $N_s - 1$ times.

q. Repeat Steps a through p until a minimum of 20 stars have been photographed N_s times each.

An azimuth and elevation angle shall be computed for each star photograph from the film measurements. The elevation angle shall be corrected for refraction error based upon ground observations of temperature and pressure. This set of $2N_s$ data, the refraction error corrected azimuth and elevation angles, shall be used in an optimal way to produce 2 data, a horizontal pointing error and a vertical pointing error (these are errors in the two direction cosines normal to the light of sight). For each observation a difference in azimuth and a difference in elevation between the position of the pointing axis of the theodolite and the position of the star shall be computed:

$$\Delta A_j = A_j^s - A_j^t$$

$$\Delta E_j = E_j^s - E_j^t \quad .$$

The means and variances of the azimuth and elevation angle differences, $\overline{\Delta A}$ and $\overline{\Delta E}$, $S^2_{\Delta A}$ and $S^2_{\Delta E}$ shall be calculated. The sample size N_s shall be chosen so that the contribution of refraction error uncertainty and theodolite small displacement variance to the variance of the estimates of $\overline{\Delta A}$ and $\overline{\Delta E}$ is small, i.e., that

$$\frac{1}{N_s} S^2_{\Delta A} < 2 \quad S^2_{hP} + 1$$

$$\frac{1}{N_s} S^2_{\Delta E} \qquad S^2_{vP} + 1 \quad .$$

in units of (arc-seconds)^2. N_s shall be chosen so that the left sides of these inequalities shall be one-tenth as large as the right sides.

There will be a $\bar{A}$ and a $\bar{E}$ for each star observed during the course of a test. The duration of each test shall be at least four hours. No observation shall be made at a zenith angle greater than 65°. The observations for each test shall be well distributed over the cap of the hemisphere permitted for observing. Each test shall consist of the observation of at least 20 stars. At least six different tests shall be conducted at intervals of approximately two weeks. The entire set of tests shall last for no less than 10 weeks.

From the entire static testing program there will be at least 120 estimates, $(\Delta A)_i$ and $(\Delta E)_i$, more or less evenly distributed over the hemisphere above 25° elevation angle. These are the ingredients of the data adjustment made to compute the static pointing error of the instrument. These differences shall be fit to whatever error model is appropriate to the instrument. All of the data must be used to determine a single set of parameters for the model with the following exception. A different origin for azimuth angle measurement may be used for each different night's results. From the parameters of the error model and the observations residual errors for:

$$(\Delta h)_i = (\Delta A)_i \cos E_i$$

$$(\Delta v)_i = (\Delta E)_i$$

shall be determined. The standard deviation of these residuals, using the appropriate number of degrees of freedom, shall be called the horizontal and vertical static pointing accuracy, S_{sh} and S_{sv}, respectively.

If S_{sh} or S_{sv} is greater than 4 arc-seconds, the instrument shall be considered nonconforming with the accuracy requirements.

DYNAMIC ERROR INCREMENT

The dynamic error increment shall be determined by a series of photographs of a collimator target supported by a test fixture inside the astrodome. The testing of the dynamic error increment will be free of any errors of the geometry of the instrument or of angle metrology. The testing will be designed to emphasize those aspects of pointing error performance which depend upon tracking motion. The data extraction error will be included in the dynamic error increment in the overall assessment of dynamic pointing accuracy.

The collimator photographs may be taken at any convenient time. The dome will remain closed. At the start of a test one operator will occupy the tracking operator's seat and will remain there for the duration of the test.

The dynamics of each axis will be tested separately, i.e., only one axis will be in motion at any given time. The testing will be accomplished by making a series of sequences of five photographs according to the prescription to be described below.

The first photograph will be made with the instrument pointing in the direction of the collimator and completely motionless. This will be referred to as the static photograph for each sequence. The instrument will then be slowly moved away from the collimator by at least 30°, and then slowly returned to the direction of the collimator. The second photograph will then be made and will be referred to as the displacement photograph. The instrument will then be given a maximum acceleration command. After about 50 ms, before the collimator target has left the field of view, the third photograph will be taken. This will be referred to as the low-velocity photograph. The instrument shall then be slowly positioned to the position from which a 45°/sec² acceleration, 20°/sec velocity condition at the collimator must start. The instrument will then be given the appropriate command and the fourth photograph taken as the instrument direction passes the collimator direction under the specified dynamic conditions. This photograph will be referred to as the dynamic photograph The instrument will be allowed to coast to a stop and will then be returned from a position at least 30° away from the collimator direction under closed-loop position servo control at maximum servo gain and bandwidth. After the instrument is at the commanded position the fifth photograph will be taken with the instrument motionless This will be referred to as the acquisition photograph. The field testing will then continue with a second sequence of five photographs which will be conducted in the same manner as the first except that all displacements, velocities, and accelerations will be in the opposite sense. The third sequence will be identical to the first, the fourth identical to the second, etc. During all testing for dynamic error increment a record of the angular velocity of each axis will be kept (servo tachometer output, for example) so that velocity and acceleration can be established.

The photographs necessary for determining the dynamic error increment will be taken in the following sequence.

1. The target shall be positioned so that when the cinetheodolite is pointed at the target, the cinetheodolite pointing axis will make a 30 angle with the horizon

2. The camera shall be loaded with the film type specified in 3 4 3 of this PD.

3. Set the TEGU target position thumbwheel switches to 444444

4. Set the TEGU selector to saturate the D to A converter at 22 5°

5 The cinetheodolite will then be positioned so that the target is in the center of the field of view of the main optical system. This will be observed through the microscope specified in 3.4.18 of this PD. A laser beam emitted from a small laser mounted on the side of the target collimator will be directed to strike a photodiode mounted on the side of the cinetheodolite main telescope tube.

6. Record the azimuth and elevation encoder outputs for reference The following switches are located on the remote control box of the TEGU.

7. Set the calibrate on/off switch to on

8. Set the azimuth/elevation selector switch to azimuth.

9 Set the enter/verify mode switch to enter.

10. Set the position/velocity selector switch to position.

11. Depress the calibrate execute switch. The azimuth angle of the artificial star relative to the cinetheodolite is now entered into the TEGU as the octal number 444444

12. Repeat Step 7.

13 Set the azimuth/elevation selector switch to elevation.

14 Repeat Steps 9 through 11 The elevation angle of the artificial star relative to the cinetheodolite is now entered into the TEGU as the octal number 444444

15 Verify encoder outputs of Step 6 to be within 5 arc-minutes of the recorded reference outputs

16. Set the camera to operate in the single frame mode

17 Set the target strobe switch to manual

18 Depress the camera shutter open switch.

19 Depress the target strobe switch.

20. Depress the shutter close switch

21 Depress the frame advance switch The photograph taken will be referred to as the static photograph.

22 The servo drive acquisition/manual switch will be set to manual.

23 Repeat Step 17.

24. Using the tracking central stick the operator will slowly drive the instrument downward, about the elevation axis, by at least 30°. The operator will then slowly drive the instrument upward about the elevation axis until it is aligned with the target.

25. Repeat Steps 18 through 21 The photograph taken will be referred to as the displacement photograph.

26. Set the target strobe switch to the 50 ms delay position.

27. Set the servo drive acquisition/manual switch to acquisition

28. Set the target position thumbwheel switches to 44444

29. Set the calibrate on/off switch to off.

30. Set the enter/verify switch to verify

31. Depress the shutter open switch.

32. Depress calibrate execute switch.

33. Depress shutter close switch (wait for audible signal from strobe). The photograph taken will be referred to as the low velocity photograph.

34. Set the target strobe switch to laser.

35. Repeat Step 27.

36. Change the target position thumbwheel switches 472710

37. Set the calibrate on/off switch to off.

38. Set the enter/verify switch to verify.

39. Depress the calibrate execute switch. The cinetheodolite pointing axis moves upward about the elevation by approximately 44°. This is the starting point of the elevation down dynamic run.

40. Change the target position thumbewheel switch to 144444.

41. Turn on laser.

42. Repeat Steps 31 through 33. The photograph taken will be referred to as the dynamic photograph

43. Repeat Step 17.

44. Set the thumbwheel switches to 444444

45. Repeat Steps 37 and 38.

46. Repeat Steps 18 through 21. The photograph taken will be referred to as the acquisition photograph.

47 Repeat Steps 16 through 23.

48. Repeat Step 24 except drive the instrument upward 30°.

49. Repeat Steps 25 through 27.

50. Set target position thumbwheel switches to 744444.

51. Repeat Steps 29 through 35.

52 Change the target position thumbwheel switches to 436200

53. Repeat Steps 37 through 39. This will be the starting point of the elevation upward dynamic run.

54 Change the target position thumbwheel switches to 744444

55. Repeat Steps 41 through 46.

56. Steps 15 through 55 shall be repeated until 60 sequence of elevation data are recorded. This will result in 600 useful photographs.

57 To obtain the required azimuth data, set the azimuth/elevation selector switch to azimuth.

58. Repeat Steps 15 through 23.

59 Using the tracking control stick, the operator will slowly drive the instrument counterclockwise, about the azimuth axis, by at least 30°. The operator will then slowly drive the instrument clockwise until it is aligned with the target.

60. Repeat Steps 25 through 38.

61. Depress the calibrate switch. The cinetheodolite pointing axis moves clockwise about the azimuth axis by approximately 4 4° This will be the starting point of the azimuth converter clockwise dynamic run.

62. Repeat Steps 49 through 53. The end of Step 53 will now be the starting point of the azimuth converter clockwise dynamic run.

63 Repeat Steps 54 through 56 for the 60 sequences of recorded azimuth data.

64. The entire test shall be repeated with the target positioned so that the cinetheodolite is pointing up at a 45° and again at 60° angle in elevation.

In addition to the above tests the contractor shall record test results utilizing the Dynamic Test Data (sample form attached).

In analyzing the data, the azimuth and elevation angles to the collimator target shall be computed from the data extracted from the useful photographs. For each sequence of five observations eight differences shall be computed:

D_{A1} = displacement azimuth - static azimuth,

D_{A2} = low velocity azimuth - static azimuth,

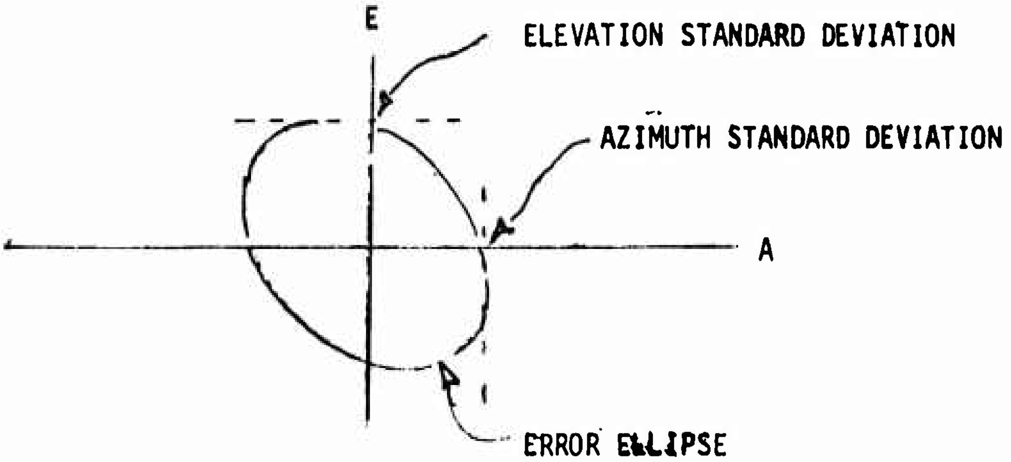
D_{A3} = dynamic azimuth - static azimuth,

D_{A4} = acquisition azimuth - static azimuth;

and correspondly for the elevation angle, D_{E1}, D_{E2}, etc. Each of the sets of differences corresponding to the dynamics of a particular axis for a particular test will be analyzed separately, as follows. The means and variances for each sense of direction for each axis will be computed. These quantities will not be used in defining the dynamic error increment, but do provide interesting information. The matrix,

$$\frac{1}{120}\begin{pmatrix} \Sigma(D_{A}.)_i^2 & \Sigma(D_{A}.)_i(D_{E}.)_i \\ \Sigma(D_{A}.)_i(D_{E}.)_i & \Sigma(D_{E}.)_i^2 \end{pmatrix}$$

shall be computed. The tangents, to the error ellipse corresponding to this matrix, which are parallel to the coordinate axes will define the azimuth and elevation variances attributable to the particular dynamic situation in question. The sketch below illustrates this definition.



For each test, and each set of differences, there will be two such ellipses and two sets of variances corresponding to the dynamics of the two axes. Net azimuth and elevation angle variances for each test shall be defined as follows:

$$S^2(Az) = S_A^2(Az) + S_E^2(Az) - S_{AM}^2 \quad ,$$

$$S^2(El) = S_A^2(El) + S_E^2(El) - S_{EM}^2 \quad ,$$

where the subscript refers to the axis which is in motion and the index in parentheses refers to the angular coordinate whose variance is represented. The net pointing variances, horizontal and vertical, shall be defined as follows:

$$S^2(h) = S^2(Az) \cos^2 E \quad ,$$

$$S^2(v) = S^2(El) \quad .$$

There will be a total of 12 of the quantities $S^2(h)$ and $S^2(v)$, 4 from each test and 3 tests. From the 12 $S^2(h)$ quantities, the largest will be selected and designated S_{Dh}^2. From the 12 $S^2(v)$ quantities, the largest will be selected and designated S_{Dv}^2. The dynamic error increments are defined as S_{Dh} and S_{Dv}.

If S_{Dh} or S_{Dv} is greater than 4 arc-seconds the instrument will be considered as not conforming with the accuracy specification. Further, if

$$\sqrt{S_{Dh}^2 + S_{Sh}^2}$$

or

$$\sqrt{S_{Dv}^2 + S_{Sv}^2}$$

or both, is greater than 4 arc-seconds, the instrument will be considered as not conforming with the accuracy specification.

THERMAL STABILITY ERROR INCREMENT

The thermal stability error increment shall be determined by a series of photographs of the same collimator used in the dynamic error increment testing. The testing will be designed to emphasize those aspects of pointing error performance which depend upon the instrument stability under severe climatic environmental conditions.

Prior to making a test the instrument shall have been enclosed in the air-conditioned astrodome for at least 24 hours. At the time of the test it shall be assured that the dome temperature is at least 15° cooler than the outside temperature. The instrument, dome and collimator shall be oriented so that when the dome is oriented the sun shines on the side of the instrument. The dome shall be opened, exposing only the instrument to the sun, for 30 minutes. During this time single photographs of the collimator target shall be taken at 1/2 minute intervals of time.

The azimuth and elevation angles to the collimator target shall be computed. A smooth (in some sense) curve shall be fit to the azimuth angle versus time and elevation angle versus time data. The thermal stability error increment in azimuth angle for a test shall be defined as the greatest slope of this smoothed curve (in units of arc-seconds per time-minute) times ten minutes. The thermal stability error increment for elevation angle, for a particular test, is similarly defined.

Six such tests shall be conducted. Two tests shall be conducted at 30°, 45° and 60° elevation angles. The instrumental thermal stability error increments shall be defined as the greatest error increments within the sample of six and will be designated as S_{TA} and S_{TE} for azimuth and elevation angles, respectively. From these largest quantities the horizontal and vertical thermal stability error increments shall be calculated as follows:

$$S_{Th} = S_{TA} \cos E$$

$$S_{Tv} = S_{TE} \quad .$$

If S_{Th} or S_{Tv} exceeds 4 arc-seconds the instrument shall be considered as not conforming to the accuracy requirements.

DYNAMIC POINTING ACCURACY

The dynamic pointing accuracy horizontal and vertical shall be defined as

$$S_h = \sqrt{S_{Sh}^2 + S_{Dh}^2 + S_{Th}^2 + S_{hC}^2}$$

$$S_v = \sqrt{S_{Sv}^2 + S_{Dv}^2 + S_{Tv}^2 + S_{vC}^2} \quad .$$

If S_h 4 arc-seconds or if S_v 4 arc-seconds, the instrument does not meet the accuracy requirement.

STAR TEST DATA (Sample Form)

EXPOSURE NO.	STAR NO.	UNIVERSAL MEANTIME OCTAL SECONDS	BAROMETRIC PRESSURE INCHES OF MERCURY	TEMPERATURE DEGREES F.

DYNAMIC TEST DATA (Sample Form)

DATE_______________________

AXIS_______________________

SEQUENCE___________________

EXPOSURE NO.	STATIC DISPLACEMENT LOW VELOCITY DYNAMIC ACQUISITION	DIRECTION	ANGULAR VELOCITY	ANGULAR ACCELERATION
EXPOSURE NO	STATIC DISPLACEMENT LOW VELOCITY DYNAMIC ACQUISITION	DIRECTION	ANGULAR VELOCITY	ANGULAR ACCELERATION

APPENDIX II

OPTICAL SYSTEM TEST PROCEDURE

1. MAIN OPTICS

1.1 Scale factor and radial distortion. Conformance to the requirements of 3.3.1.4 and 3.3.1.6 shall be determined from the specifications for the final design. A computer ray-tracking program shall be used to examine the design at various focus positions in green light. The requirements will be satisfied if the total range of angular scale factor in the image plane does not exceed 0.02 percent, and if the radial distortion does not exceed 0.6 percent.

1.2 Resolution. Conformance to the requirements of 3 3.1.5 shall be tested as follows:

a. Set up a 1952 National Bureau of Standards resolution target having a contrast ratio of 1000:1 and illuminate it with light.

b. Place the target at the focus of a collimator to produce an image of the target at infinity.

c. Load the cinetheodolite data recorder with Eastman Linagraph Shellburst Pan (Estar, gray base) instrumentation film.

d. Set up the cinetheodolite to photograph the target image. The cinetheodolite optical system should be focused at infinity, and no special modifications shall be made to any part of the system.

e. Turn on the azimuth, elevation, and range servo power and allow them to run in the operate mode during the entire period of photographing the resolution target.

f. Run the data recorder at 50 frames per second in the cine mode.

g. Move the cinetheodolite or the target to shift the target image to a different part of the image plane. Repeat Step f, then move the image again, and so on until five widely spaced parts of the image plane have been tested.

h. Rotate the target by 45 degrees and repeat Step g

i. Change the cinetheodolite optical system filter (reference paragraph 3.3.1.9) and photograph the target at one position only Repeat with each filter.

j. Develop the film in accordance with the manufacturer's recommendation for a gamma of 2.0 $\pm$0.1.

k A set of bars of the resolution target shall be considered to be resolved when the density difference between bars and spaces of the image of the target is greater than 0.1, as measured with a microdensitometer having a slit width of 5 microns.

l An attached Resolution Data Sheet (sample form) is provided as a guide for the resolution test.

1.3 Transmittance. Conformance to the requirements of 3.3.1.7 shall be tested in accordance with Methods 5 and 7 of MIL-STD-150, to measure transmittance at the center and at the edge of the field of view.

1 4 Veiling glare. Conformance to the requirements of 3.3.1.8 shall be tested in accordance with Method 34 of MIL-STD-150. The same target shall also be used to test for ghost images by strongly exposing an image and visually examining the developed film for ghost images.

2 DATA SYSTEM

2 1 Density and density gradient Conformance to the requirements of 3 4 13 3 and 3 4 13.4 shall be tested as follows:

a. Load the cinetheodolite data recorder with Eastman Linagraph Shellburst Pan (Estar, gray base) instrumentation film.

b. Operate the cinetheodolite in the matrix test mode for odd bits. Run the data recorder at 40 frames per second in the cine mode.

c Repeat Step b in the matrix test mode for even bits.

d Develop the film in accordance with the manufacturer's recommendation for a gamma of 2.0 ±0.1.

e. Measure the recorded matrix image densities with a microdensitometer having a nominal slit width of 25 microns

f. The matrix images shall be considered satisfactory with regard to density if the density of each measured image is at least 1 0 and the density gradient is at least 0 7 per 100 microns

3. OPERATOR'S GUIDE TELESCOPE (OGT)

3 1 Resolution Conformance to the requirements of 3.3 3 4 shall be tested in accordance with Method 13 of MIL-STD-150.

3 2 Chromatic aberration Conformance to the requirements of 3 3 3 5 shall be tested by placing a matte card, half white and half black, at the focus of a collimator to produce a collimated beam of the same approximate

size as the OGT aperture. The target shall be illuminated with white light. The collimated beam shall be viewed with the OGT to determine the presence or absence of apparent colors other than white or black at the line between the two halves of the field. The test shall be repeated with the collimator beam defocused to produce an apparent target at the near focus point of the OGT.

3.3 Binocular collimation. Conformance to the requirements of 3.3.3.14 shall be tested by setting up a collimator to produce an image of a set of crosshairs at infinity, and directing this beam into the OGT objective. A high-quality telescope objective lens shall be used to focus the beams emerging from the eyepieces. This lens shall be at least one inch larger in aperture than the total of the interocular distance and the eyepiece aperture diameter. A traveling microscope shall be set up nominally parallel to the eyepiece optical axes and positioned to focus on the real images produced at the focus of the telescope objective lens. The lateral separation of the two images shall be measured with the microscope in two axes and shall be converted mathematically to angular decollimation at the eyepieces. The requirements of 3.3.3.14 will be satisfied if the two beams are parallel to each other within 4.0 arc-minutes in the vertical plane and within 3.0 arc-minutes of convergence and 5.0 arc-minutes of divergence in the horizontal plane.

3.4 Image parallelism. Conformance to the requirements of 3.3.3.15 shall be tested by the same test setup described for binocular collimation. Two or more points on each of the vertical crosshair images will be measured, and their angular separation shall be mathematically determined.

3.5 Diopter correction. Conformance to the requirements of 3.3.3.10 shall be tested with a Lyle Model L112 dioptometer or equivalent.

RESOLUTION DATA SHEET (Sample Form)

TARGET POSITION	TARGET ORIENTATION N-S	E-W	NW-SE	NE-SW
Center				
North				
East		(Resolution)		
South				
West				

FILTER	TARGET ORIENTATION N-S	E-W
Clear		
Yellow		
Red-orange	(Resolution)	
Red		
Blue		

APPENDIX III

DATA RECORDER ACCEPTANCE TEST PROCEDURE

The data recorder shall be acceptance tested by the contractor per the following procedures.

PD PARAGRAPHS 3.4.1 AND 3.4.12.1 CAMERA FRAME RATE AND SYNCHRONIZATION ACCURACY

a. Load camera magazine with 1200 feet of film in the supply side.

b. View shutter pulses and camera synchronizing pulses on a dual beam calibrated time-base oscillsocope, such as Tektronix 543.

c. Switch data recorder to synchronous recording mode.

d. Operate camera at 4 frames per second for 20 seconds.

e. Observe oscilloscope, determine maximum time difference between pulses after synchronization is achieved and log this value.

f. Operate camera at 50 frames per second and repeat Step d.

g. Operate camera at 10 frames per second for 20 seconds and repeat Step d.

h. Operate camera at 20 frames per second for 20 seconds and repeat Step d.

i. Run camera until 600 feet of film has transferred to the take-up side of the magazine.

j. Repeat Steps d through h.

k. Run camera until 900 feet of film has transferred to the take-up side of the magazine.

l. Repeat Steps d through h.

The leading edge of the shutter pulses shall be coincident with the leading edge of the frame rate synchronizing pulses within plus or minus 80 microseconds. There shall be one shutter pulse for each frame rate synchronizing pulse.

PD PARAGRAPHS 3 4 7 AND 3 4 9 2 EXPOSURE DURATION AND SHUTTER PULSE RELATIVE TO EXPOSURE MIDPOINT

a. Load camera with unexposed film

b. Intensity modulate a televsion monitor with the camera shutter pulse.

c. Set exposure duration to one millisecond.

d Switch data recorder to synchronous recording mode.

e. Operate camera at 5 frames per second

f Approximately 5 seconds after synchronization is achieved, change to 10 frames per second

g. Repeat Step f, except change to 20 frames per second.

h Repeat Step f, except change to 50 frames per second.

i. Change exposure duration to 2 milliseconds and repeat Steps e through h

j. Change exposure duration to 4 milliseconds and repeat Steps e through h

k. Process film.

l. Measure the exposure duration by counting the raster lines on the processed film and multiplying the result by the line duration of 63 5 microseconds

Exposure durations shall be 1, 2 and 4 milliseconds plus or minus 5 percent. The start of the shutter pulse brightened spot shall be at midpoint of the total raster lines counted ±1/3 line (20 microseconds).

m Log the results.

PD PARAGRAPH 3 4 8 AND 3.4 17 FOOTAGE COUNTER, CAMERA LOADED INDICATOR AND CAMERA LOADING TIME

a Load the supply side of the film magazine with an empty reel

b. Log the footage counter, camera loaded indicator reading and time used to load the camera.

c. Load the supply side of the film magazine with 350 feet of film and repeat Step b.

d. Load the supply side of the film magazine with 400 feet of film and repeat Step b.

e. Load the supply side of the film magazine with 1200 feet of film and repeat Step b.

The footage counter shall indicate 0, 350, 400, and 1200 $\pm$20 feet, respectively. The camera loaded indicator shall indicate unloaded with $\overline{0}$ and with 350 feet of film supply and shall indicate loaded with 400 and with 1200 feet of film supply. Camera loading time, including removal of previous film load, shall be less than 2-1/2 minutes.

PD PARAGRAPH 3.4.9.3 SINGLE FRAME SHUTTER REQUIREMENTS

a. Connect shutter open control line to the external trigger input of a calibrated time base oscilloscope such as Tektronix 543.

b. Connect one end of the shutter open switch to the oscilloscope vertical input and connect the other end of the shutter open switch to a suitable source of voltage.

c. Apply the required voltage to the shutter open control line.

d. Measure the total time between control voltage application and switch transfer by viewing the oscilloscope and log the result.

e. Repeat Steps a through d except use the shutter close control line and the shutter closed switch contacts.

The total time between application of the control voltage and switch transfer shall be less than 10 milliseconds in each case.

PD PARAGRAPHS 3.4.12.2 AND 3.4.12.3 NONSYNCHONOUS FRAMES AND MATRIX SYNCHRONIZATION BIT

a. Load the camera with a 1200 feet supply of unexposed film.

b. Connect camera synchronization pulse and camera shutter pulse lines to the government-furnished nonsynchronous frames counter.

c. Zero the nonsynchronous frames counter and switch the data recorder to the synchronous-recording mode.

d. Switch the camera from 0 to 5 frames per second.

e. Approximately 1 second after synchronization is achieved, note the counter reading, switch the camera back to 0 and log the noted counter reading

f Note and log the counter reading, switch the camera from zero to 10 frames per second and repeat Step 3.

g. Note and log the counter reading, switch the camera from 0 to 20 frames per second and repeat Step 3

h. Note and log the counter reading, switch the camera from 0 to 50 frames per second

i. Approximately 1 second after synchronization is achieved, note and log the counter reading and switch the camera from 50 to 5 frames per second

j Repeat Step e

k. Note and log the counter reading and switch the camera from 0 to 5 frames per second.

l Run the camera until 700 feet of film remains in the supply side of the camera magazine, switch the camera back to 0 and note and log the counter reading.

m Repeat Steps d through j

n. Note and log the counter reading and switch the camera from 0 to 50 frames per second

o. Run the camera until 300 feet of film remains in the supply side of the camera magazine, switch the camera back to 0, and note and log the counter reading

p. Repeat Steps d through j

q Process the film.

r. Count the number of frames where the synchronization status bit indicates nonsynchronous operation The number shall be equal to or greater than the total nonsynchronous frames count of the counter.

s The maximum number of nonsynchronous frames allowed when changing frame rates shall be as follows:

FRAMES PER SECOND		NONSYNCHRONOUS FRAMES
FROM	TO	MAXIMUM
0	5	10
0	10	10
0	20	20
0	50	60
50	5	60

t. The maximum number of nonsynchronous frames while operating at any fixed frame rate, i.e., after synchronization is achieved and before a change in frame rate is made, shall not exceed one percent of the frames

PD PARAGRAPHS 3.4.13.2.3, 4.6.7 AND 3.4 20 MATRIX CONFIGURATION BIT DENSITY AND DENSITY GRADIENT, MATRIX TEST, MATRIX PANEL, AND MOUNTING AND REGISTRATION

a. Remove and remount the camera and record the time taken.

b. Load the camera with a supply of unexposed film.

c. Switch the data recorder to the synchronous recording mode.

d. Switch the matrix test switch to On and the Odds Evens switch to Odds.

e. Operate the camera at 40 frames per second.

f. After 5 seconds or greater, switch the Odds-Evens switch to Evens

g. After 5 seconds or greater, switch the camera back to 5 frames per second and shut off the matrix test switch.

h. Advance the Target, Mission, Station and Orientation switches one position each in time increments of 2 seconds or greater until all switch positions have been recorded. During this test all timing signals shall also be recorded.

i. Process the film and examine the processed film for accuracy

j. In the matrix Odds portion of the film, all odd number bits only shall appear in the matrix.

k. In the matrix Evens portion of the film, all even number bits only shall appear in the matrix.

l The target, mission, station and orientation bits shall appear in the matrix in the order in which the test was conducted. All timing data shall also appear in the matrix.

m A microdensitometer shall be used to determine matrix bit spacing, density and density gradients. The spacing between bits, rows of bits and triplet grouping of bits shall be at least 100, 200 and 200 microns, respectively. The matrix image density of "zero" bits shall be no greater than base fog and base fog shall be no greater than 0.3. The density gradient at the edge of all matrix "one" bit images shall be at least 0.7 per 100 microns

PD PARAGRAPHS 3.4.14 AND 3.4.15.1 RELIABILITY OF THE DATA RECORDER AND CAMERA MAINTAINABILITY

Reliability of the data recorder shall be verified by the contractor at WSMR by means of a reliability verification test specified in WSMR Regulation 715-6, Appendix II. The government reserves the right to witness these tests.

Reliability will be verified according to the sequential test plan shown in the graph. If the plot moves across the accept line, then the reliability test is satisfactorily completed. For example, if the system is tested for 10.5 hours with no failure, then the specified reliability and confidence level is acceptable. However, if the 6 failures occur, then the system must be tested for a total of 24 hours to satisfactorily complete the test. If the plot moves across the reject line, the system reliability is unacceptable. The contractor shall have the opportunity to take corrective action and conduct a test rerun

During the reliability test, the contractor shall perform only that preventive maintenance specified by the contractor's recommended maintenance procedures.

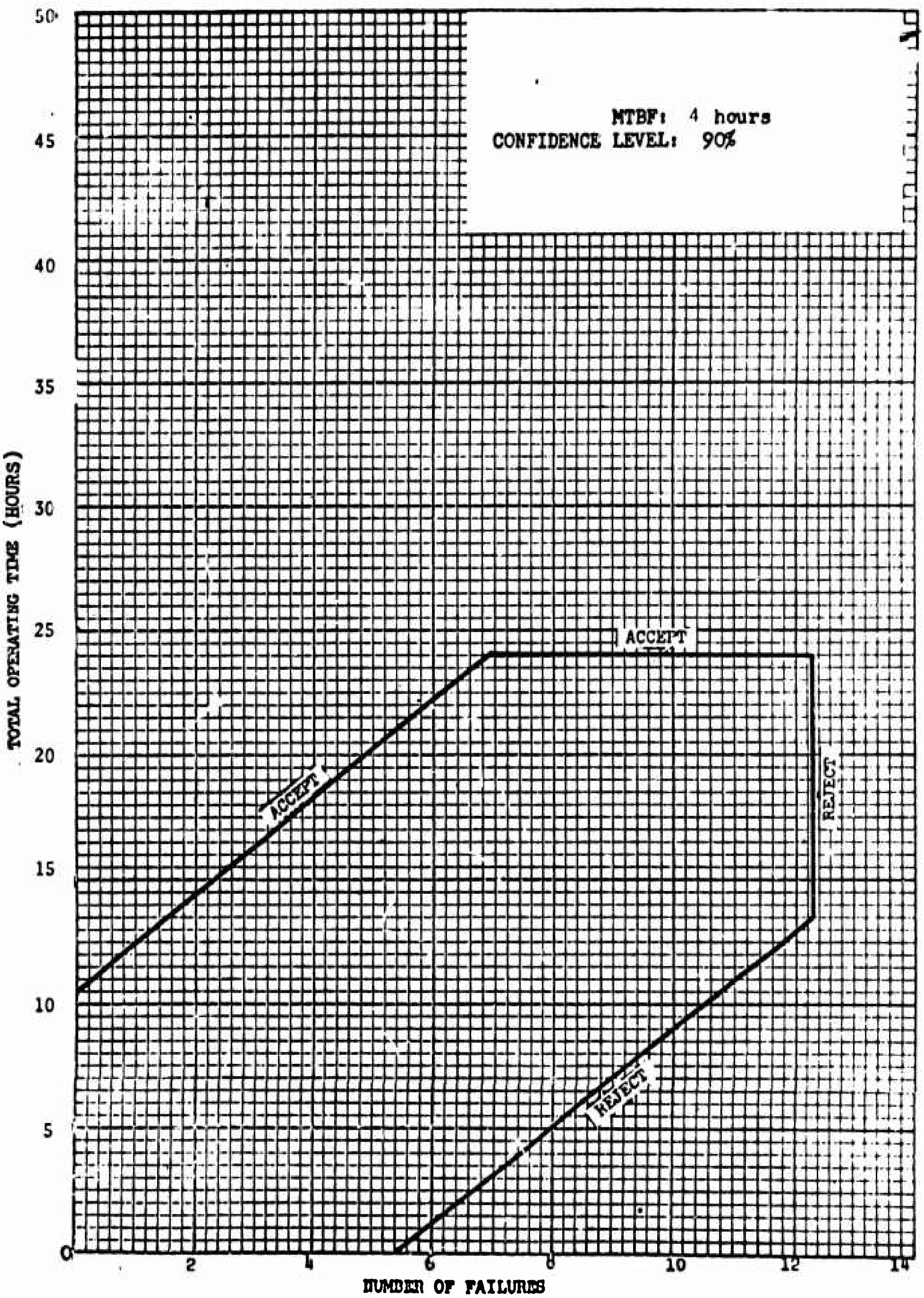
Operating time is defined as time expended while power is applied to the film transport drive motor and the camera is recording target and binary data on film at a 50 per second frame rate.

PD PARAGRAPH 3.4.18 MICROSCOPES

The viewing microscopes shall be installed in the CEI and will be visually tested by the government for conformance with the requirements.

PD PARAGRAPH 3.4.19 PROTECTIVE DEVICES

The protective devices will be tested by the government. This includes the film jam switch, end of film switch and camera door interlock.


MTBF: 4 hours
CONFIDENCE LEVEL: 90%
ACCEPT
ACCEPT
REJECT
REJECT
TOTAL OPERATING TIME (HOURS)
0
5
10
15
20
25
30
35
40
45
50
2
4
6
8
10
12
14
NUMBER OF FAILURES

Other data recorder paragraphs of the PD will be visually inspected by the government for compliance or will automatically be covered by the resolution and contrast requirements of the optics section (PD paragraphs 3.3.15 and 3.3.18)

DATA RECORDER ACCEPTANCE TEST DATA (Sample Form)

REQUIREMENTS	CONDITION	SPECIFIED	MEASURED	PD PARA
Sync accuracy (majority of film in supply side)	5 frames/sec	≤ ±80 μs	______	3.4.12.1
	10 frames/sec	≤ ±80 μs	______	3.4.12.1
	20 frames/sec	≤ ±80 μs	______	3.4.12.1
	50 frames/sec	≤ ±80 μs	______	3.4.12.1
Sync accuracy (half of film in supply side)	5 frames/sec	≤ ±80 μs	______	3.4.12.1
	10 frames/sec	≤ ±80 μs	______	3.4.12.1
	20 frames/sec	≤ ±80 μs	______	3.4.12.1
	50 frames/sec	≤ ±80 μs	______	3.4.12.1
Sync accuracy (majority of film in take-up side)	5 frames/sec	≤ ±80 μs	______	3.4.12.1
	10 frames/sec	≤ ±80 μs	______	3.4.12.1
	20 frames/sec	≤ ±80 μs	______	3.4.12.1
	50 frames/sec	≤ ±80 μs	______	3.4.12.1
Exposure duration	minimum	1 ms ±5%	______	3.4.7
	medium	2 ms ±5%	______	3.4.7
	maximum	4 ms ±5%	______	3.4.7
Shutter pulse/exposure midpoint	minimum	±20 μs	______	3.4.9.2
	medium	±20 μs	______	3.4.9.2
	maximum	±20 μs	______	3.4.9.2
Film footage counter	no film supply	0 ±20 feet	______	3.4.8
	350 feet supply	350 ±20 feet	______	3.4.8
	400 feet supply	400 ±20 feet	______	3.4.8
	1200 feet supply	1200 ±20 feet	______	3.4.8

DATA RECORDER ACCEPTANCE TEST DATA (Cont'd)

REQUIREMENTS	CONDITION	SPECIFIED	MEASURED	PD PARA
Camera loaded indicator	no film supply	unloaded	______	3.4.8
	350 feet supply	unloaded	______	3.4.8
	400 feet supply	loaded	______	3.4.8
	1200 feet supply	loaded	______	3.4.8
Camera loading time	1200 feet load change	2-1/2 min.	______	3.4.17
Single frame shutter	opening time	10 milliseconds	______	3.4.9.3
Single frame shutter	closing time	10 milliseconds	______	3.4.9.3
Nonsync frames when changing frame rate--most of film in supply side of magazine	from 0 to 5 frames/sec	10 maximum	______	3.4.12.2
	0 to 10 frames/sec	10 maximum	______	3.4.12.2
	0 to 20 frames/sec	20 maximum	______	3.4.12.2
	0 to 50 frames/sec	60 maximum	______	3.4.12.2
	50 to 5 frames/sec	60 maximum	______	3.4.12.2
Nonsync frames when changing frame rate--half of film in supply side of magazine	from 0 to 5 frames/sec	10 maximum	______	3.4.12.2
	0 to 10 frames/sec	10 maximum	______	3.4.12.2
	0 to 20 frames/sec	20 maximum	______	3.4.12.2
	0 to 50 frames/sec	60 maximum	______	3.4.12.2
	50 to 5 frames/sec	60 maximum	______	3.4.12.2
Nonsync frames when changing frame rate--most of film in take-up side of magazine	from 0 to 5 frames/sec	10 maximum	______	3.4.12.2
	0 to 10 frames/sec	10 maximum	______	3.4.12.2
	0 to 20 frames/sec	20 maximum	______	3.4.12.2
	0 to 50 frames/sec	60 maximum	______	3.4.12.2
	50 to 5 frames/sec	60 maximum	______	3.4.12.2

DATA RECORDER ACCEPTANCE TEST DATA (Cont'd)

REQUIREMENTS	CONDITION	SPECIFIED	MEASURED	PD PARA
Maximum nonsync frames at fixed frame rates	5 fps	1%	______	3.4.12.2
	50 fps	1%	______	3.4.12.2
Matrix spacing	between bits	100 microns	______	3.4.13.2
	between rows of bits	200 microns	______	3.4.13.2
	between triplet groupings	200 microns	______	3.4.13.2
Matrix density	zero bits	base fog	______	3.4.13.3
Matrix base fog	density	0.3	______	3.4.13.3
Matrix density gradient	one bit	0.7/100 microns	______	3.4.13.4

APPENDIX IV

AZIMUTH AND ELEVATION SERVO ACCEPTANCE TEST PROCEDURE

All servo acceptance tests shall be conducted with the servo loop adjustments set. If adjustments are made in tachometer gain or any other sensitive parameter during the tests, all portions of the acceptance test conducted prior to such change is invalidated and shall be rerun under the new condition.

PD PARAGRAPH 3.7.1.1 STIFF STICK TESTS

The azimuth and elevation servos shall be acceptance tested by the contractor as follows in the manual tracking rate mode, using the stiff stick signals as inputs.

a. With full force applied to the stiff stick away from the operator, the cinetheodolite shall drive up in elevation at a minimum velocity of 30 degrees per second.

b. With full force applied to the stiff stick towards the operator, the cinetheodolite shall drive down in elevation at a minimum velocity of 30 degrees per second.

c. With full force applied to the stiff stick towards the operator's left, the cinetheodolite shall drive counterclockwise in azimuth as viewed from above at a minimum velocity of 30 degrees per second.

d. With full force applied to the stiff stick to the operator's right, the cinetheodolite shall drive clockwise in azimuth as viewed from above at a minimum velocity of 30 degrees per second.

e. The tachometer signals shall be recorded during all of the preceding tests, and the velocity shall be determined and logged.

PD PARAGRAPH 3.5.4.1.1 MANUAL TRACKING VELOCITY TESTS

The azimuth and elevation servos shall be acceptance tested by the contractor as follows in the manual tracking rate mode (velocity) by disconnecting the stiff stick inputs and applying test signals.

a. With a positive 10.000 plus or minus 0.005 volts input signal to the azimuth servo, the cinetheodolite shall drive in azimuth at 30 plus or minus 0.25 degrees per second.

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b With a negative 10.000 plus or minus 0 005 volt input signal to the azimuth servo, the cinetheodolite shall drive in the opposite direction in azimuth at 30 plus or minus 0.25 degrees per second

c With a positive 10 000 plus or minus 0.005 volts input signal to the elevation servo, the cinetheodolite shall drive in elevation at 30 plus or minus 0.25 degrees per second.

d With a negative 10 000 plus or minus 0.005 volt input signal to the elevation servo, the cinetheodolite shall drive in the opposite direction in elevation at 30 plus or minus 0.25 degrees per second

e The tachometer signals and a suitable time base shall be recorded during all of the preceding tests and the velocity shall be determined and logged

PD PARAGRAPH 3 5 4 1 2 MANUAL TRACKING ACCELERATION TESTS

The azimuth and elevation servos shall be acceptance tested by the contractor as follows in the manual tracking aided rate mode (acceleration) by applying test signals

a With a positive 10.000 plus or minus 0 005 volt gate input signal with a duration of 0 50 second applied to the azimuth servo, the cinetheodolite shall drive in azimuth at 45 plus or minus 0 5 degrees per second per second acceleration from zero through 20 degrees per second velocity. The velocity decrease (droop) 20 seconds after the end of the gate input signal shall not exceed one degree per second

b With a negative 10.000 plus or minus 0.005 volt gate input signal with a duration of 0 50 second applied to the azimuth servo, the cinetheodolite shall drive in the opposite direction in azimuth at 45 plus or minus 0.5 degrees per second per second acceleration from zero through 20 degrees per second velocity The velocity decrease 20 seconds after the end of the gate input signal shall not exceed one degree per second.

c With a positive 10.000 plus or minus 0.005 volt gate input signal with a duration of 0 50 second applied to the elevation servo, the cinetheodolite shall drive in elevation at 45 plus or minus 0 5 degrees per second per second acceleration from zero through 20 degrees per second velocity. The velocity decrease 3 seconds after the end of the gate input signal shall not exceed 0 15 degree per second

d. With a negative 10.000 plus or minus 0.005 volt gate input signal with a duration of 0 50 second applied to the elevation servo, the cinetheodolite shall drive in the opposite direction in elevation at 45 plus or minus 0.5 degree per second per second acceleration from zero through 20 degrees per second velocity. The velocity decrease 3 seconds after the end of the gate input signal shall not exceed 0 15 degree per second.

e. The tachometer signal, input signals and a suitable time base shall be recorded during all of the preceding tests. The acceleration and velocities shall be determined from the recordings and logged.

PD PARAGRAPH 3.5.4.1.3 MINIMUM ANGULAR VELOCITY TESTS

The minimum angular velocity of the azimuth and elevation servos shall be acceptance tested by the contractor in the manual tracking rate mode as follows.

a. Connect an adjustable positive low voltage source to the azimuth input.

b. Adjust voltage to zero and verify that the cinetheodolite does not move in azimuth by observing that the azimuth encoder readout does not change more than one least significant bit (LSB) in a 40 second time period.

c. Increase input voltage in small increments, pausing after each increase until motion is obtained as determined by encoder readout changes.

d. When motion is attained, count the encoder changes occurring over a minimum time period of 2 minutes. The readout shall change at a constant rate of 9 LSB's or less per 40 seconds of time.

e. Record the encoder readout change rate.

f. Repeat the above Steps a through e using a negative low voltage source to determine the minimum angular velocity for reverse drive direction.

g. Repeat the above Steps a through f but apply the voltage to the elevation input and obtain minimum angular velocity in elevation in each direction.

h. Log all test results.

PD PARAGRAPH 3.5.4.1.4 MANUAL TRACKING TRANSIENT RESPONSE TESTS

Transient response of the azimuth and elevation servos shall be acceptance tested by the contractor as follows in the manual tracking rate mode by applying a 0.1 volt step input having a rise time of 1.0 microsecond or less.

a. Apply the step input to the azimuth servo.

b. Record the step input, timing and the azimuth tachometer output.

c. Apply the step input to the elevation servo.

d. Record the step input, timing and the elevation tachometer output

e. From the recordings, measure and log the rise time, the settling time and the overshoot.

The rise time from 10 to 90 percent of final velocity shall be less than 80 milliseconds; the settling time, i.e., the time from signal application until the cinetheodolite has settled to within 5 percent of the final velocity shall be less than 250 milliseconds; and the velocity overshoot shall not exceed 10 percent of the final velocity.

PD PARAGRAPH 3 5.4.1.4 SERVO BANDWIDTH TEST

The small signal servo bandwidth of the azimuth and elevation servos shall be acceptance tested by the contractor as follows by applying a 0 1 volt peak to peak constant amplitude sine wave input signal.

a. Apply the input to the azimuth servo

b Record the input, timing and the azimuth tachometer output.

c. Slowly increase the frequency of the input signal from 0.1 to 15.0 hertz.

d. Apply the input to the elevation servo

e Record the input, timing and the elevation tachometer output

f Repeat Step c.

g Determine and log the 3 dB bandwidth of each axis from the recordings. The frequency at which the tachometer output is down to 0.707 of its 0 1 hertz amplitude is defined as the 3 dB bandwidth frequency. The bandwidth shall be at least 5 hertz.

PD PARAGRAPHS 3 5 4 1 5 AND 3.5.4 1 6 MANUAL TRACKING MODE DRIFT CORRECTION

A log shall be kept of all manual tracking mode drift corrections made during the entire acceptance testing time period of 90 days or greater. The log shall include the date, time of day, ambient temperature, frequency and voltage of site power, the drift rate prior to and after adjustment, the cinetheodolite axis and the time required to make the adjustment. The drift rates may be logged as encoder octal readout changes per 80 seconds of time The drift rate shall not exceed 4 LSB's of encoder readout per 20 seconds of time over any ambient temperature change of plus or minus 10 degrees F. This log will be used by the government to determine compliance with the manual tracking mode drift correction requirements of the PD paragraphs 3 5.4.1.5 and 3.5.4.1.6. A suggested log format follows.

DRIFT CORRECTION LOG - MANUAL TRACKING (Sample Form)

DATE	TIME	TEMP (°F)	SITE POWER VOLT	SITE POWER FREQ	DRIFT RATE - LSB/20 SEC BEFORE ADJ	DRIFT RATE - LSB/20 SEC AFTER ADJ	CINE AXIS	ADJUSTMENT TIME

PD PARAGRAPH 3.5.4.1.7 LOAD VARIATION TESTS

Load variation of the azimuth and elevation servo shall be acceptance tested by the contractor over the entire range of travel in both azimuth and elevation in the manual rate mode by applying a fixed amplitude signal commanding a 5 degrees per second velocity.

a. Apply the signal to the azimuth servo.

b. Record the azimuth load current.

c. Apply a signal of the same amplitude but opposite polarity to the azimuth servo

d. Repeat Step b.

e. Apply the signal to the elevation servo.

f. Record the elevation load current

g. Apply a signal of the same amplitude but opposite polarity to the elevation servo.

h. Repeat Step f.

j. Determine the load current variations from the recordings and log the results. Load current variations shall be less than 3 percent of the average load current value.

PD PARAGRAPH 3.5.4.2.1 AUTOMATIC TRACKING ERROR TESTS

Tracking error of the azimuth and elevation servos shall be acceptance tested by the contractor in the automatic tracking acquisition mode by using command data furnished to the TEGU from the government furnished test box. The test set will furnish 20 degree per second per second acceleration commands as follows:

Elevation Up - 2 seconds.

Elevation Down - 2 seconds

Azimuth Clockwise - 2 seconds.

Azimuth Counterclockwise - 2 seconds.

The test shall be conducted per the following step by step procedure.

a. Record the command inputs, the servo error at the servo input and the encoder and tachometer outputs on the same time base.

b. Drive the cinetheodolite from the test box program.

c. Convert the servo error signal to angular measure (tracking error).

The tracking error shall be less than 4.0 minutes of arc in each axis and each direction at 20 degrees per second per second acceleration and 20 degrees per second velocity. Log the tracking error

PD PARAGRAPH 3.5.4.2.2 AUTOMATIC TRACKING TRANSIENT RESPONSE TEST

Transient response of the azimuth and elevation servos shall be acceptance tested by the contractor as follows in the automatic tracking acquisition mode by applying a displacement command of 0.25 degree to the TEGU.

a. Apply the azimuth 0.25 degree step input.

b. Record the step input, timing and the azimuth tachometer output.

c. Apply the elevation 0.25 degree step input.

d. Record the step input, timing and the elevation tachometer output.

e. From the recordings, measure and log the rise time, delay time, the settling time and the overshoot.

Rise time from 10 to 90 percent of the position change shall be less than 80 milliseconds; delay time before first motion shall be less than 20 milliseconds; settling time, i.e., the time from signal application until the cinetheodolite has settled at the commanded position within 5 percent of the total position change, shall be less than 500 milliseconds; and the position overshoot shall not exceed 30 percent of the commanded position change.

PD PARAGRAPH 3.5.4.2.2 AUTOMATIC TRACKING MODE DRIFT CORRECTION

A log shall be kept of all automatic tracking mode drift corrections made during the star tests. The log shall include the date, time of day, ambient temperature, the commanded azimuth and elevation, the encoder readout azimuth and elevation and the difference between commands and readouts. Drift shall not exceed one arc-minute over any ambient temperature change of plus or minus 10 degrees F. A suggested log format follows:

DRIFT CORRECTION LOG - AUTOMATIC TRACKING (Sample Form)

DATE	TIME	TEMP (°F)	AZIMUTH & ELEVATION COMMANDED POSITION	AZIMUTH & ELEVATION ENCODER READOUT	DIFFERENCE

AZ AND EL ACCEPTANCE TEST DATA - MANUAL TRACKING MODES

(Sample Form)

REQUIREMENT	CONDITIONS	SPECIFIED	MEASURED	PD PARA
Stiff stick	Full force, left, AZ, CW	>30°/sec	______	3.7.1.1
Stiff stick	Full force, right, AZ, CCW	>30°/sec	______	3.7.1.1
Stiff stick	Full force, away, EL, up	>30°/sec	______	3.7.1.1
Stiff stick	Full force, toward, EL, down	>30°/sec	______	3.7.1.1
Manual tracking	Rate mode, AZ, CW	30±0.25°/sec	______	3.5.4.1.1
Manual tracking	Rate mode, AZ, CCW	30 ±0.25°/sec	______	3.5.4.1.1
Manual tracking	Rate mode, EL, up	30 ±0.25°/sec	______	3.5.4.1.1
Manual tracking	Rate mode, EL, down	30 ±0.25°/sec	______	3.5.4.1.1
Manual tracking	Aided rate, AZ, CW, accel	45 ±0.3°/sec^2	______	3.5.4.1.2
Manual tracking	Aided rate, AZ, CW, droop	1°/sec	______	3.5.1.1.2
Manual tracking	Aided rate, AZ, CCW, accel	45 ±0.5°/sec^2	______	3.5.4.1.2
Manual tracking	Aided rate, AZ, CCW, droop	1°/sec	______	3.5.1.1.2
Manual tracking	Aided rate, EL, up, accel	45 ±0.5°/sec^2	______	3.5.4.1.2
Manual tracking	Aided rate, EL, up, droop	0.5°/sec	______	3.5.1.1.2
Manual tracking	Aided rate, EL, down, accel	45 ±0.5°/sec^2	______	3.5.4.1.2
Manual tracking	Aided rate, EL, down, droop	0.15°/sec	______	3.5.1.1.2
Minimum angular velocity	AZ, CW	(0025°/sec max) 9 LSB/40 sec	______	3.5.4.1.3
Minimum angular velocity	AZ, CCW	(0025°/sec max) 9 LSB/40 sec	______	3.5.4.1.3
Minimum angular velocity	EL, up	(0025°/sec max) 9 LSB/40 sec	______	3.5.4.1.3
Minimum angular velocity	EL, down	(0025°/sec max) 9 LSB/40 sec	______	3.5.4.1.3

AZ AND EL ACCEPTANCE TEST DATA - MANUAL TRACKING MODES (Cont'd)

REQUIREMENT	CONDITIONS	SPECIFIED	MEASURED	PD PARA
Manual tracking transient response	AZ, rise time	80 ms	______	3.5.4.1.4
Manual tracking transient response	AZ, settling time	250 ms	______	3.5.4.1.4
Manual tracking transient response	AZ, overshoot	10%	______	3.5.4.1.4
Manual tracking transient response	AZ, bandwidth	5 hertz	______	3.5.4.1.4
Manual tracking transient response	EL, rise time	80 ms	______	3.5.4.1.4
Manual tracking transient response	EL, settling time	250 ms	______	3.5.4.1.4
Manual tracking transient response	EL, overshoot	10%	______	3.5.4.1.4
Manual tracking transient response	EL, bandwidth	5 hertz	______	3.5.4.1.4
Load variation	AZ, CW	3%	______	3.5.4.1.7
Load variation	AZ, CCW	<3%	______	3.5.4.1.7
Load variation	EL, up	3%	______	3.5.4.1.7
Load variation	EL, down	<3%	______	3.5.4.1.7
Drift rate	Manual tracking, AZ	<4 LSB/20 sec	______	3.5.4.1.5
Drift rate	Manual tracking, EL	<4 LSB/20 sec	______	3.5.4.1.5

AZ AND EL ACCEPTANCE TEST DATA - AUTOMATIC TRACKING MODES (Sample Form)

REQUIREMENT	CONDITIONS	SPECIFIED	MEASURED	PD PARA
Tracking Error	AZ, CW	<4.0 arc-min.	______	3.5.4.2.1
Tracking Error	AZ, CCW	<4.0 arc-min.	______	3.5.4.2.1
Tracking Error	EL, up	<4.0 arc-min.	______	3.5.4.2.1
Tracking Error	EL, down	<4.0 arc-min.	______	3.5.4.2.1
Automatic tracking transient response	AZ, rise time	<80 ms	______	3.5.4.2.2
Automatic tracking transient response	AZ, delay time	<20 ms	______	3.5.4.2.2
Automatic tracking transient response	AZ, settling time	<500 ms	______	3.5.4.2.2
Automatic tracking transient response	Overshoot	<30%	______	3.5.4.2.2
Automatic tracking transient response	Rise time	<80 ms	______	3.5.4.2.2
Automatic tracking transient response	Delay time	<20 ms	______	3.5.4.2.2
Automatic tracking transient response	Settling time	<500 ms	______	3.5.4.2.2
Automatic tracking transient response	Overshoot	<30%	______	3.5.4.2.2
Drift rate	Automatic tracking, AZ	<1 arc-min.	______	3.5.4.2.4
Drift rate	Automatic tracking, EL	<1 arc-min.	______	3.5.4.2.4

APPENDIX V

RANGE SERVO ACCEPTANCE TEST PROCEDURE

PD PARAGRAPH 3.6.2 MANUAL MODE

The contractor shall acceptance test the range (focusing) servo in the manual mode at WSMR by sighting objects of known range and adjusting the manual focus control for best focus. When best focus is obtained, the range indicator shall read within plus or minus 1 percent of the known range. This test shall be conducted using objects at near, intermediate and far range.

PD PARAGRAPH 3.6.1 SLAVE MODE

The contractor shall test the range servo in slave mode by using the government furnished test unit. The test unit will furnish range signals simulating a missile at ranges from 5000 yards to infinity, at missile velocities from zero to 2000 yards per second and at missile accelerations from zero to 2000 yards per second per second. The test shall be conducted per the following procedure:

a. Record the commanded input, the servo error signal at the servo input and the tachometer output on the same time base.

b. Drive the range servo from the above test unit signals.

c. From the recordings determine the range servo error.

d. Convert the range servo error into percentage of depth of field. The resulting depth of field change shall be less than plus or minus 50 percent of the depth of field.

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ACCEPTANCE TEST DATA - RANGE SERVO

(Sample Form)

REQUIREMENT	CONDITIONS	SPECIFIED	MEASURED	PD PARA
Manual mode	Near object	$\pm 1\%$	______	3.6.2
Manual mode	Intermediate object	$\pm 1\%$	______	3.6.2
Manual mode	Far object	$\pm 1\%$	______	3.6.2
Slave mode	Near object	50% depth of field	______	3.6.1
Slave mode	Intermediate	50% depth of field	______	3.6.1
Slave mode	Far object	50% depth of field	______	3.6.1