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REAL-TIME CINETHEODOLITE DATA SYSTEM (RTCDS) FOR YUMA PROVING GROUND

Kenneth B. Bellinger

White Sands Missile Range
New Mexico

June 1974

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This report covers the systems analysis, design, procurement, installation, checkout, testing, and operator training of the Real-Time Cinetheodolite Data System (RTCDS) for Yuma Proving Ground (YPG), Yuma, Arizona. Related material is included as appendices.

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PREFACE

This report covers the systems analysis, design, procurement, installation, checkout, testing, and operator training of the Real-Time Cinetheodolite Data System (RTCDS) for Yuma Proving Ground (YPG), Yuma, Arizona. Related material is included as appendices.

WSMR was charged by TECOM to analyze YPG capabilities in terms of existing equipment, personnel, and facilities and implement a solution to a problem of vectoring helicopters to a predetermined location. WSMR personnel performed a system analysis, including a review of project requirements, and designed a real-time data system which would encourage growth to a greater capability as the requirements for real-time data increased. Following TECOM and YPG approvals of the system design, a WSMR team prepared a complete set of specifications, in thirteen separate purchase descriptions, for the RTCDS. A contract was awarded and monitored by WSMR personnel. In addition to assisting the technical efforts of the contractor during the development of the RTCDS, WSMR personnel designed and, with YPG assistance, prepared Government facilities at YPG for the installation and acceptance phase of the contract. WSMR personnel monitored the installation of the RTCDS at YPG and, following the contractor's successful demonstration of the system's dynamic tracking accuracy, completed the Government's test and acceptance of the instrumentation system.

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SYSTEM DESCRIPTION

The RTCDS is a real-time cinetheodolite space position measurement system. (See Appendix A, Real-Time Cinetheodolite Data System.) Three cinetheodolites provide angle data to a central processor for space position computation. Position data necessary for flight vector control is displayed on numeric and plotting board displays. The RTCDS consists of three modified Contraves EOTS-C cinetheodolites, hardware to provide serial data messages (angle data) to a central location, timing equipment, communication modems, special interface equipment (I/O) for connection to the YPG EMR 6130 computer, tape recorders, plotting boards, numeric displays, control consoles and system software. A semiautomatic film reader is included to read the modified digital film data format and boresight correction.

BACKGROUND

On 31 March 1971, TECOM charged WSMR to "provide, in support of YPG, the necessary Government effort for system analysis and design, procurement, installation, checkout, testing and operator training of a real-time cinetheodolite space position system" (see Appendix B, Letter dated 31 March 1971, from TECOM to CG, WSMR, Subject "WSMR Support to YPG for Procurement of Cinetheodolite Modification and Real-Time Data System).

A WSMR Task Team was formed and in May 1971 they had completed the Analysis and Design of a Real-Time Cinetheodolite Data System for YPG (see Appendix C). Following a review by TECOM, preparation of procurement specifications and related documentation was begun. The solicitation document, including a system purchase description and twelve separate equipment/software purchase descriptions, was released on 8 February 1972. On 31 August 1972, Contract No. DAAD07-73-C-0023 in the amount of $868,700 was awarded to Goerz/Inland Systems Division, Kollmorgan Corporation, for a RTCDS meeting the Government's minimum requirements for a dynamic tracking accuracy of five meters. An incentive payment schedule was included which provided for additional payment for a RTCDS with dynamic tracking accuracy greater than five meters; priced in one-quarter meter increments, to a ceiling of $913,600 for a RTCDS with an accuracy of three meters or less.

CONTRACT SYNOPSIS

31 August 1972	Contract Award, with delivery schedule of 26 August 1973.
3 January 1973	Amendment P00001, Redesignated optical coating requirements, reducing total amount of contract by $1200.00.
7 February 1973	Amendment P00002, Replacement of motors, generators and transformers in GFE cinetheodolites with EOTS-F solid state components, increasing the total amount of contract by $17,467.00. Also, extended delivery schedule from 26 August 1973 to 26 October 1973.
20 March 1973	Amendment P00003, Furnishing of astrodome drive gear boxes and synchro transmitters for the GFE cinetheodolites, increasing the total amount of the contract by $7,950.00.
20 June 1973	Amendment P00004, Clarification and definition of technical requirements.
15 October 1973	Amendment P00005, Extension of delivery schedule from 26 October 1973 to 30 January 1974.
25 April 1974	Amendment A00002 (DCAS, Pittsburgh, PA) Spare parts, increasing the total amount of the contract by $43,024.24. Schedule for delivery of complete spare parts package extended to August 1974.
19 June 1974	Amendment P00006, Extension of delivery schedule to allow the contractor to begin his RTCDS dynamic accuracy demonstration by 14 March 1974 or face forfeiture of the incentive portion of the contract.

GENERAL HISTORY

In preparation for the contractor's installation of equipment at YPG, the Government updated the various facilities at Cibola and Kofa Range areas which would be utilized by the RTCDS. The following major items were accomplished to fulfill these requirements:

1. Establishment of physical space for the RTCDS mission control, computer room and cinetheodolite film reader consoles and equipment in Building 3523, Kofa Range Area. Provided for the termination of necessary power and communication circuits within these areas. A special exhaust duct was required to accommodate the installation of the cinetheodolite film reader.

2. Preparation of a 4 ft. by 4 ft. by 4 ft. concrete foundation for installation of the 40 ft. Rohn antenna tower.

3. Installation of WSMR supplied and modified 10 ft. tracking astrodomes, with hydraulic power supplies and environmentally controlled electronic enclosures, at cinetheodolite Sites 8, 10 and 12 in the Cibola Range Area. Termination of the 25 pair aerial cable at each of the cinetheodolite sites and termination of 11 pairs of these cables within the astrodome electronic enclosures. Removal of the existing orientation and calibration targets, for the three cinetheodolite sites, and the erection of a new calibration system, firmly implaced in concrete and securely guyed. A complete first order resurvey of each cinetheodolite and their dedicated orientation and calibration targets was completed (see Appendix D, Survey Data, Horizontal and Vertical Control).

4. Installation of an atmospheric calibration target close to the center of the 2.75 in. Baseline Accuracy Target Array and a static test target at Fran Site. (The 2.75 in. calibration target was the one used for the static accuracy test defined by the contract.) First order surveys of their positions were completed (see Appendix D).

The prime contractor, due mostly to internal problems, did not exert any significant effort under this contract until approximately June 1973. This delayed beginning was the basic reason for the contract delivery schedule extensions. The real-time software portion of this contract was subcontracted to Duane Brown Associates. The delivery and installation at YPG of the first equipment began in October 1973 and completion of the installation phase was on 13 March 1974 with the delivery and installation of the cinetheodolite film reader. Following the installation and checkout of the RTCDS, the contractor was to demonstrate the RTCDS dynamic tracking accuracy to qualify for the incentive portion of the contract.

The contract required that test flight data would be produced by the RTCDS on at least three separate days. The maximum number of flight tests for the incentive tests should not exceed 30. The minimum number of flight tests should be 20. The requirement for additional flight tests above the minimum 20 would be based on the Government's need for film data from at least 16 successful flight tests and the contractor's need for 80 percent success rate of the RTCDS to produce a real-time data report in order to qualify for any incentive payment.

The RTCDS was to produce test trajectory data on film, and in real time, of a helicopter aircraft flying at an altitude of 100 feet (nominal), at an airspeed of 100 knots, along the prescribed 2.75 in. "Baseline Accuracy" line of flight (see Appendix E, Map, RTCDS Complex). The Government would use the trajectory data derived from film reading and subsequent YPG standard data reduction process as the standard for accuracy evaluation.

A comprehensive test plan for testing the RTCDS to demonstrate conformance with the requirements of the system specifications was prepared by the contractor and approved, with changes, by the Government (see Appendix F, Report, System Engineering Test Plans and Procedures, With Changes).

The contractor's demonstration of the dynamic tracking accuracy of the RTCDS, or incentive test flights, was conducted on 14, 18 and 20 March 1974 through the 2.75 in. target array rectangle identified in the contract. A total of 30 flights comprised the incentive testing. Ten test flights were conducted on 14 March 1974, with the second flight of the series of 10 being aborted due to a film break. Three flights were conducted on 18 March 1974, with the first flight of this series being aborted due to a film break. Eighteen flights were conducted on 20 March 1974. All flights were recorded on black and white film (linograph shellburst), with the exception of the final flight of the series which was recorded on color film (Ektachrome EF). The Government provided for the processing of all RTCDS film through a film processing contractor in Yuma, Arizona, who was under contract for normal instrumentation film processing services for YPG. An operation log of the 3 days is included (see Appendix G, Incentive Test Operations Log).

The contractor selected the flights, as well as the 50 point data bracket, to be used for the incentive test post-flight data reduction comparison from the post test, real-time data report (post test data reports were produced within 5 to 6 minutes of flight completion). Film data of the selected flights, from the three cinetheodolite stations, was read on the cinetheodolite film reader and computer tapes were generated for input to the YPG post-flight cinetheodolite data reduction program. A detailed summary of the comparison between real-time data and post-flight data is inclosed (see Appendix H, Incentive Test Summary). Review of this data indicates that the dynamic tracking accuracy of the RTCDS is well within the required five meter accuracy and was consistently within one meter for all but one flight: flight number "DF." (For that flight, the software computed a two-station solution due to problems with film data received from one cinetheodolite. The resulting dynamic tracking accuracy of the RTCDS for that particular flight was just over one meter).

Operation and maintenance training of YPG personnel, on all portions of the RTCDS equipment and software, was conducted by contractor personnel (see Appendix I, Summary of RTCDS Training Received by YPG Personnel).

Following the delivery of all required documentation (see Appendix J, Summary of RTCDS Documentation Delivered to YPG), WSMR personnel conducted the test and acceptance phase of the contract. All deficiencies noted in the RTCDS hardware and software have been corrected. The RTCDS has been accepted and turned over to YPG for utilization as range support instrumentation. (Actual contract completion will not occur until sometime in August 1974 when the final RTCDS spare parts are scheduled for delivery.)

CONCLUSIONS

The development of a RTCDS for YPG was a successful venture. YPG now has a real-time space measurement system capability with a dynamic tracking accuracy of one meter, or less, and a static pointing accuracy of one-half meter.

The system that was visualized and cost estimated in May 1971 by the WSMR Task Team (see Appendix B) was born in May 1974 almost exactly as described and for a cost extremely close to the original estimate.

Government's Estimate of Contract Cost, May 1971	$962,119
Actual Contract Cost, May 1974	$980,841*

RECOMMENDATIONS

YPG should immediately incorporate the fully-operational RTCDS into their arsenal of range instrumentation.

YPG should immediately begin a program of software development to expand the capabilities of the Cinetheodolite Film Reader. This software development should include the following:

1. Modification of the software to allow the operator to delete, change or accept the data when an error is detected.

2. Modification of the software to allow the operator to instruct the computer that a particular bit in the data matrix is faulty and allow the software to correct the problem.

3. Modification of the software to include an option, at the beginning of a data run, for the operator to set in a particular time code and allow the reader to transport until the required time code is reached.

4. A software program should be included so that the data tape could be corrected before it is sent to the computer for reduction.

*For an accurate comparison, this figure includes $24,217 for additions to the basic contract not included in the original design. Therefore, $980,841 less $24,217 should be the cost for comparison; $956,624 actual versus $962,119 estimated--$5,495 below the original Government's estimate of costs.

5. Modify assembler to use the magnetic tape unit to decrease assembly time; a boot strap program for magnetic tape would be required to use the binary tape created by the modified assembler.

6. A core dump program should be included to allow minor changes to the program from the mini-computer operator's panel and a new binary program tape could then be prepared without going through the assembler.

It is recommended that YPG study the possibility of reprogramming their batch processing data reduction programs to operate on the 7044/7094 DCS computer system and acquire the necessary hardware and software to accomplish the reduction of cinetheodolite film data. This would speed up batch processing due to the increased capability of the DCS and the system's high speed printers, and free the EMR 6130 for dedication to real-time operation on a full-time basis.

It is further recommended that YPG study the feasibility of updating their remaining Contraves EOTS-C cinetheodolites to an EOTS-CF configuration. In addition to providing an updated, modern cinetheodolite system, this modification of additional cinetheodolites would also reduce data reduction manhours and more fully utilize the Cinetheodolite Film Reader procured with the RTCDS. Also, Contraves AG, Zurich, Switzerland, has notified its U. S. distributor that orders for spare parts for the EOTS-C instruments will be accepted only until the end of 1976; from 31 December 1974 to 31 December 1976, the supply of spare parts will be on a special order basis; after 31 December 1976, availability of EOTS-C spare parts is not guaranteed by Contraves unless the same parts are being utilized on the EOTS-F cinetheodolites. If it is not economically feasible to YPG to update their remaining EOTS-C cinetheodolites, a sufficient stock of spare parts for these instruments should be procured, prior to the deadline, to provide for future maintenance.

Minor modifications to the real-time software would allow data from the Laser Tracker, located at Site 7, to be accepted by the RTCDS in combination with the data from the three modified cinetheodolites. By simply establishing the communication circuits from the Laser site, using the spare modem provided with the RTCDS, the Laser Tracker could be used in lieu of one modified cinetheodolite for real-time space point computation.

Further, if another modified cinetheodolite were to be included, or the Laser Tracker used, and telemetry data were to be eliminated from the real-time process, the RTCDS as implemented on the EMR 6130 computer could be modified to support two independent tracking missions--both in real time. The display and control equipment, as provided with the RTCDS, is adequate to support this type of expansion.

APPENDIX A

REAL-TIME CINETHEODOLITE DATA SYSTEM

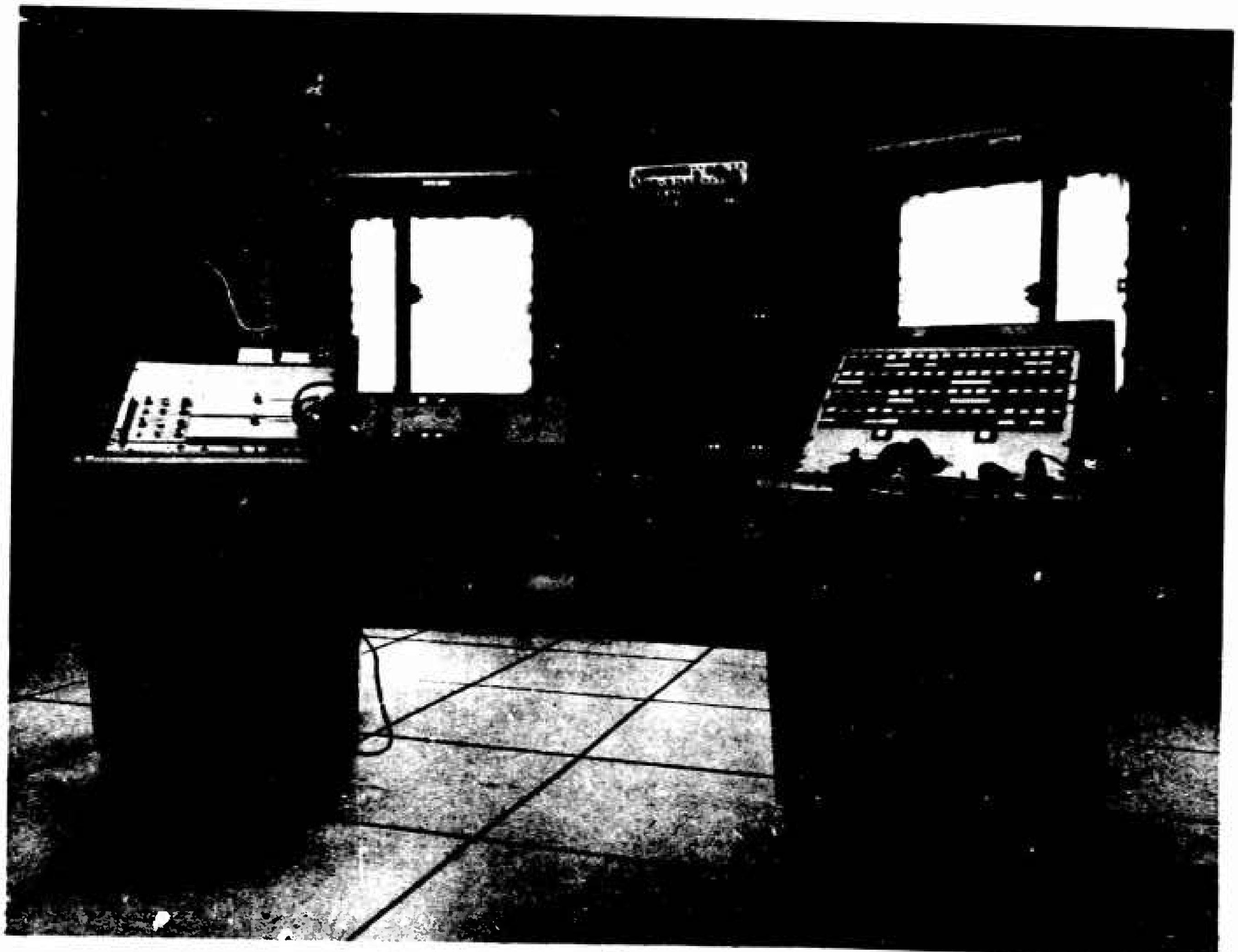

FIGURE 1. REAL-TIME CINETHEODOLITE DATA SYSTEM MISSION CONTROL ROOM

From left to right: RTCDS Mission Control Console, EAI Plotter, DAC's and Display Console, Discrete Events Input Unit, and another EAI Plotter.

DESCRIPTION, RTCDS REAL-TIME SOFTWARE

The real-time software for the RTCDS provides the capability to perform many complex functions. The software provides a diagnostic capability to verify that the decimal and binary displays, the plotting boards, and the discrete events input unit are functioning normally for premission checkout. Assignments of parameters to be displayed or plotted can be assigned by the software during premission setup. Various control functions are assigned to the discrete events input unit during premission setup. The software provides a premission calibration capability for the cinetheodolites and determines calibration corrections for tilt, mislevel, and collimation for each cinetheodolite to be applied to the space point solution. The software will accept data from four cinetheodolite subbuffers at 20 samples per second, while also accepting telemetry data at the rate of 144,000 bits per second. It will use data from up to three cinetheodolites to produce smoothed space position of an aircraft, derived velocity, acceleration and related parameters at 5 samples per second. It will also block, store and output telemetry data concurrently. The software causes selected parameters to be displayed on decimal and binary displays and plotting boards at the rate of 5 samples per second in real time. The software provides the capability to vector an aircraft to a point in space, detect the time of firing of a missile at a ground target and produce a refined estimate of the space position of the aircraft and related parameters at time of fire, in non-real time, on the line printer. The software also allows real-time inputs at 20 samples per second to be recorded in digital form along with 5 samples per second space position and related data on a 9 track digital log tape.

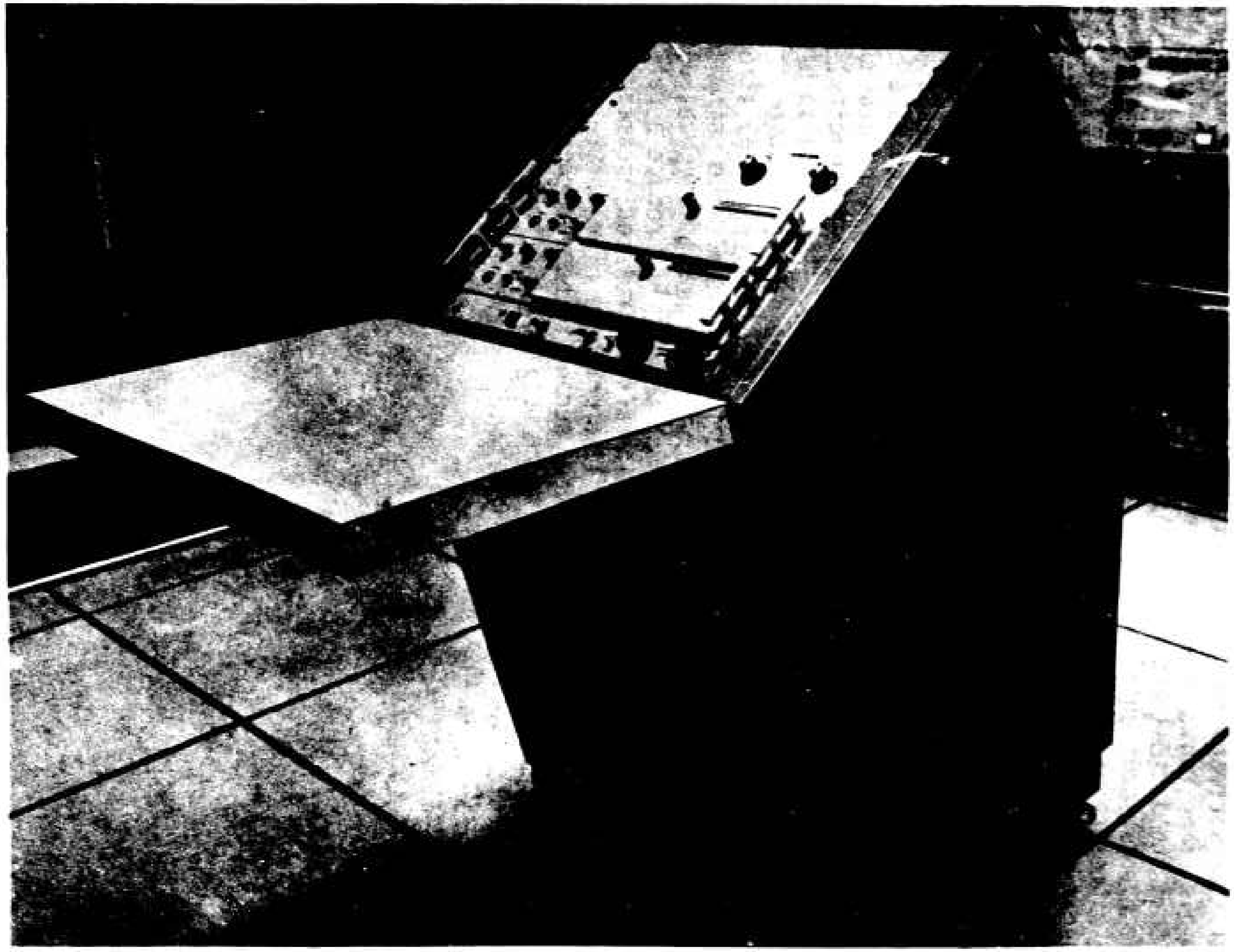

FIGURE 2. RTCDS MISSION CONTROL CONSOLE

The RTCDS mission controller directs each mission operation from this console. The console contains four radio receivers and a remote transmitter link for ground to air communications.

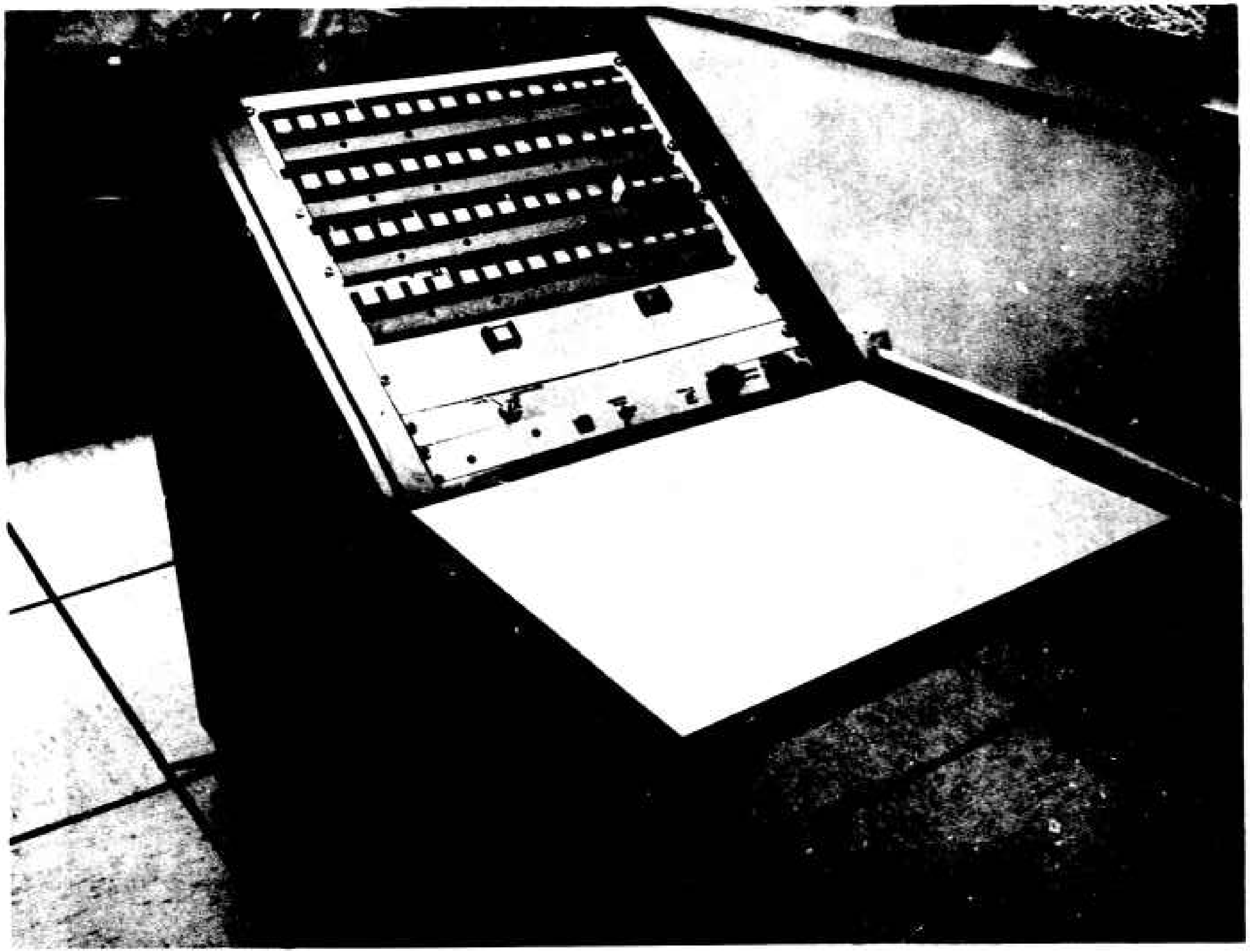

FIGURE 3. DISCRETE EVENTS INPUT UNIT (DEIU)

The DEIU is a peripheral operator interface to the RTCDS. The DEIU provides the control functions necessary for the systems controller to initiate events during a test. The system interfaces directly with the EMR Telemetry Data Channel, 2761.

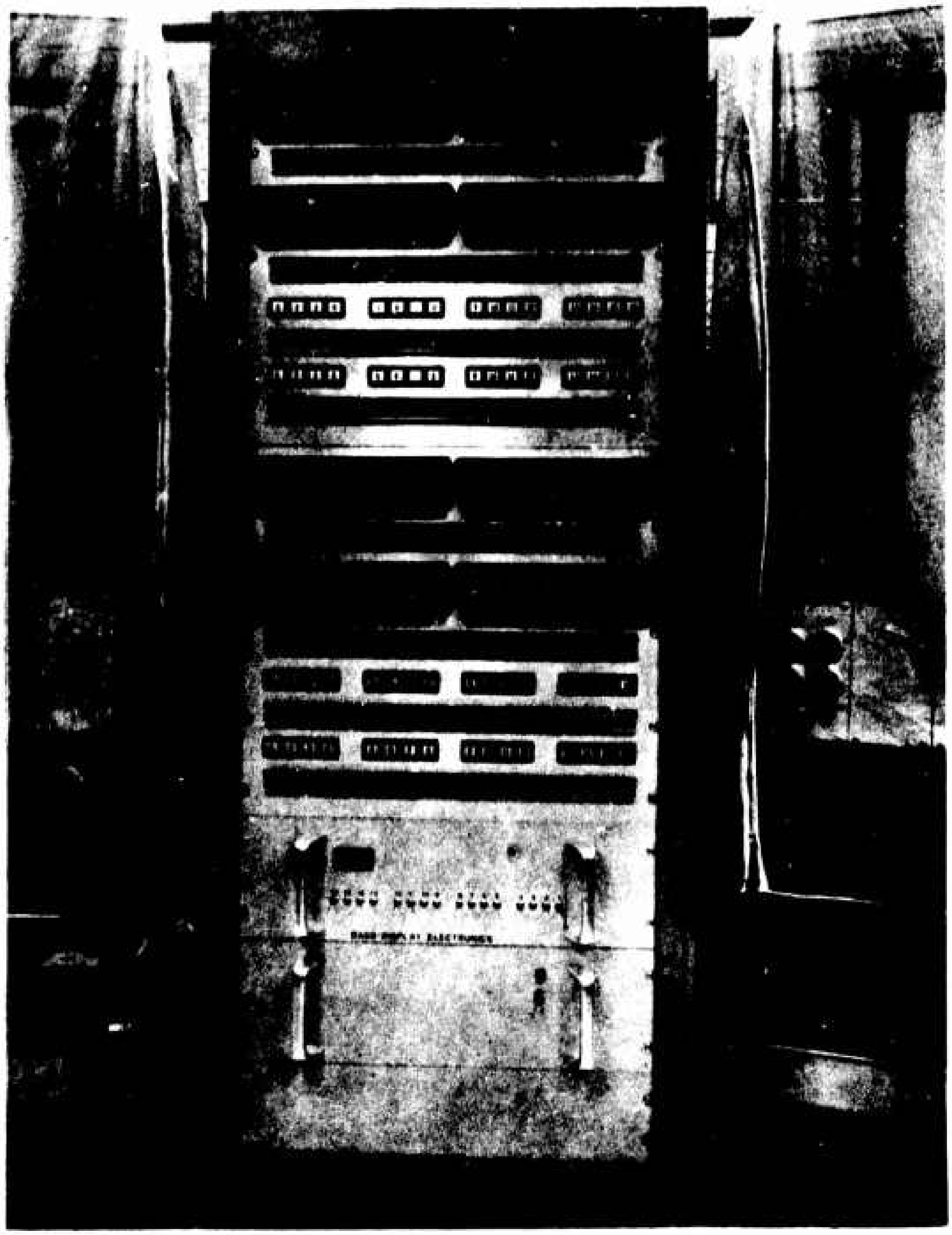

FIGURE 4. DAC's AND DISPLAY CONSOLE

This unit is the major interface from the EMR Telemetry Data Channel and the mission controller. The system consists of two identical display panels, each containing four 5-digit BCD displays with sign and floating decimal point and two 16-bit binary displays. In addition the Console contains eight DAC's to drive two dual channel X-Y plotters. The decimal display will communicate to the mission controller the positioned and dynamic progress of the test while the binary display will primarily indicate data status vital to the mission. A capability of self test is provided through seventeen front panel test switches, which may be made to represent data from the Telemetry Data Channel.

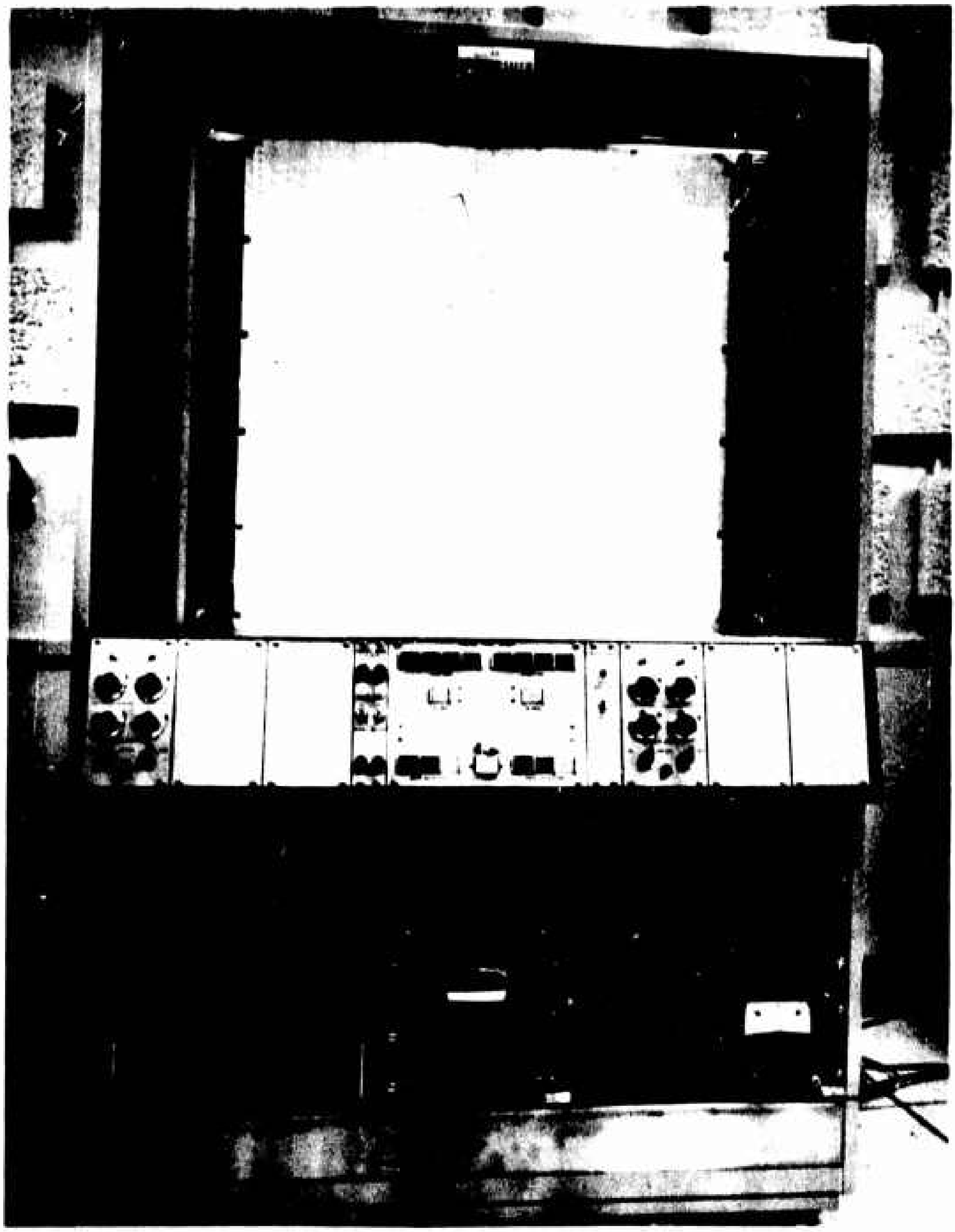

FIGURE 5. RANGE PLOTTER (TWO IN RTCDS)

This is a 30 in. by 30 in. EAI vertical plotter capable of producing two simultaneous plots. The X-Y plotter allows the mission controller to exercise a real-time quality control of the mission.

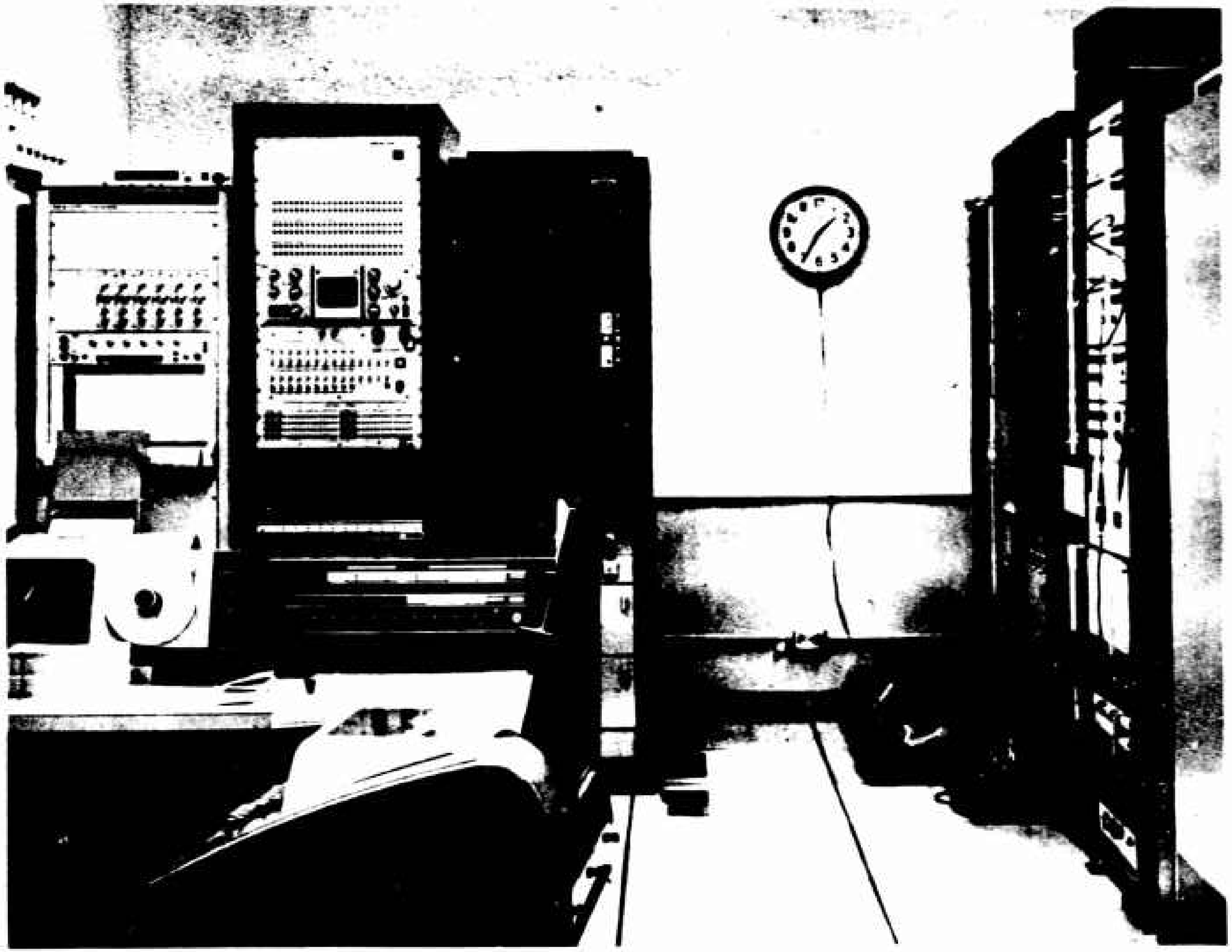

FIGURE 6. RTCDS COMPUTER ROOM

An overall view showing RTCDS equipment interfaced with the EMR 6130 Computer.

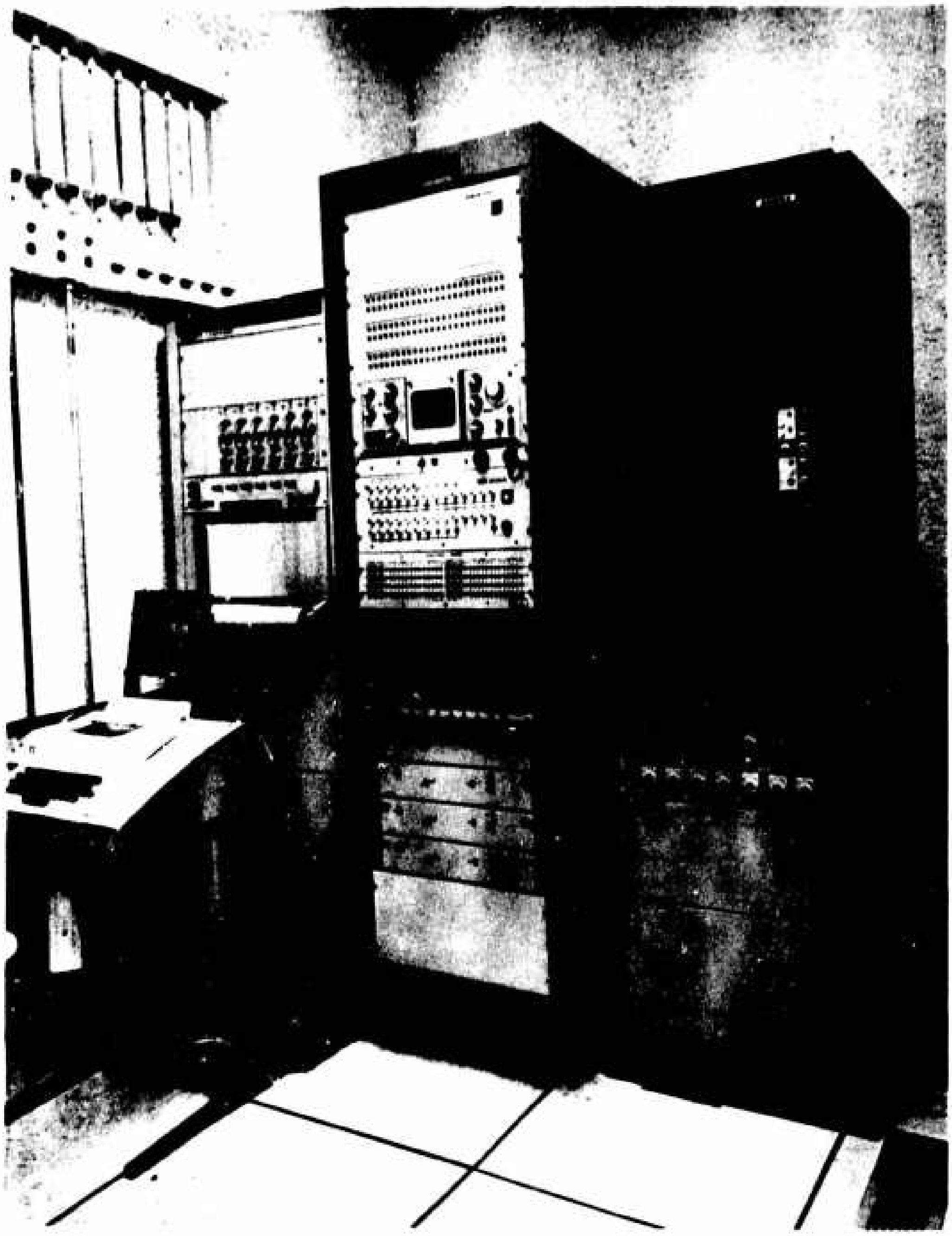

FIGURE 7. RTCDS COMPUTER ROOM CONSOLE

This console (center unit) serves as the interface between the cinetheodolites and the rest of the RTCDS. The incoming modem signals are routed through the Patch Bay Chassis, Audio Switcher Chassis to the receiving modems. The Multi-Channel Data Interface Unit (MDIU) Chassis accepts eight independent channels of input data from modems and formats these data for input to the EMR 6130 Computer via the Telemetry Data Channel. Intercom and communications signals are all amplified in the Intercom Chassis. A Siemens Line Tester Chassis is included to enable premission checks of incoming data lines for quality transmission. The unit on the right is the Ampex FR 2000 Recorder/Reproducer which is utilized to record all data input to communications line receive modems as well as all voice communications on RTCDS network.

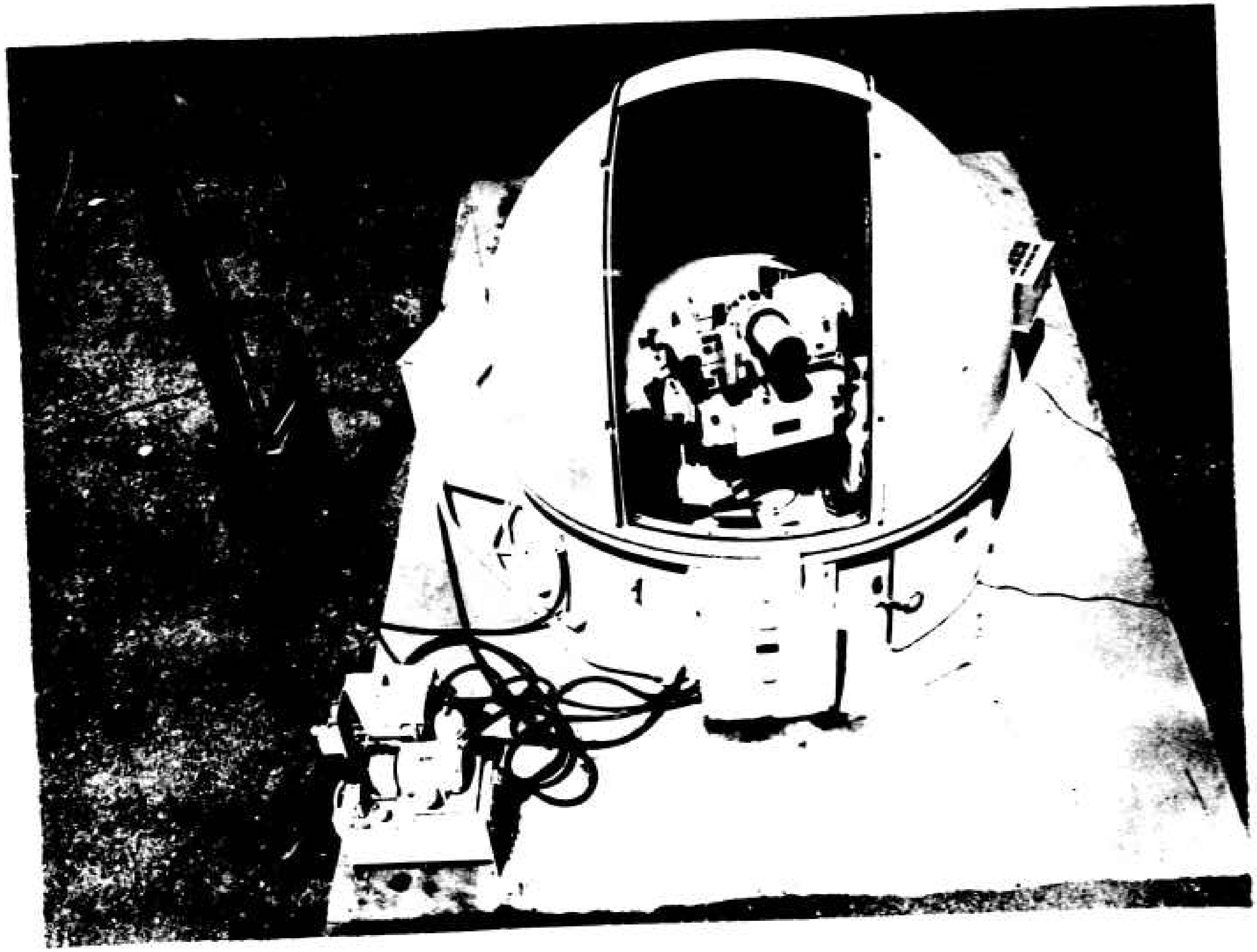

FIGURE 8. A RTCDS CINETHEODOLITE FACILITY

A Contraves EOTS-FC Cinetheodolite installed in the 10 ft. tracking astrodome at RTCDS Site No. 12.

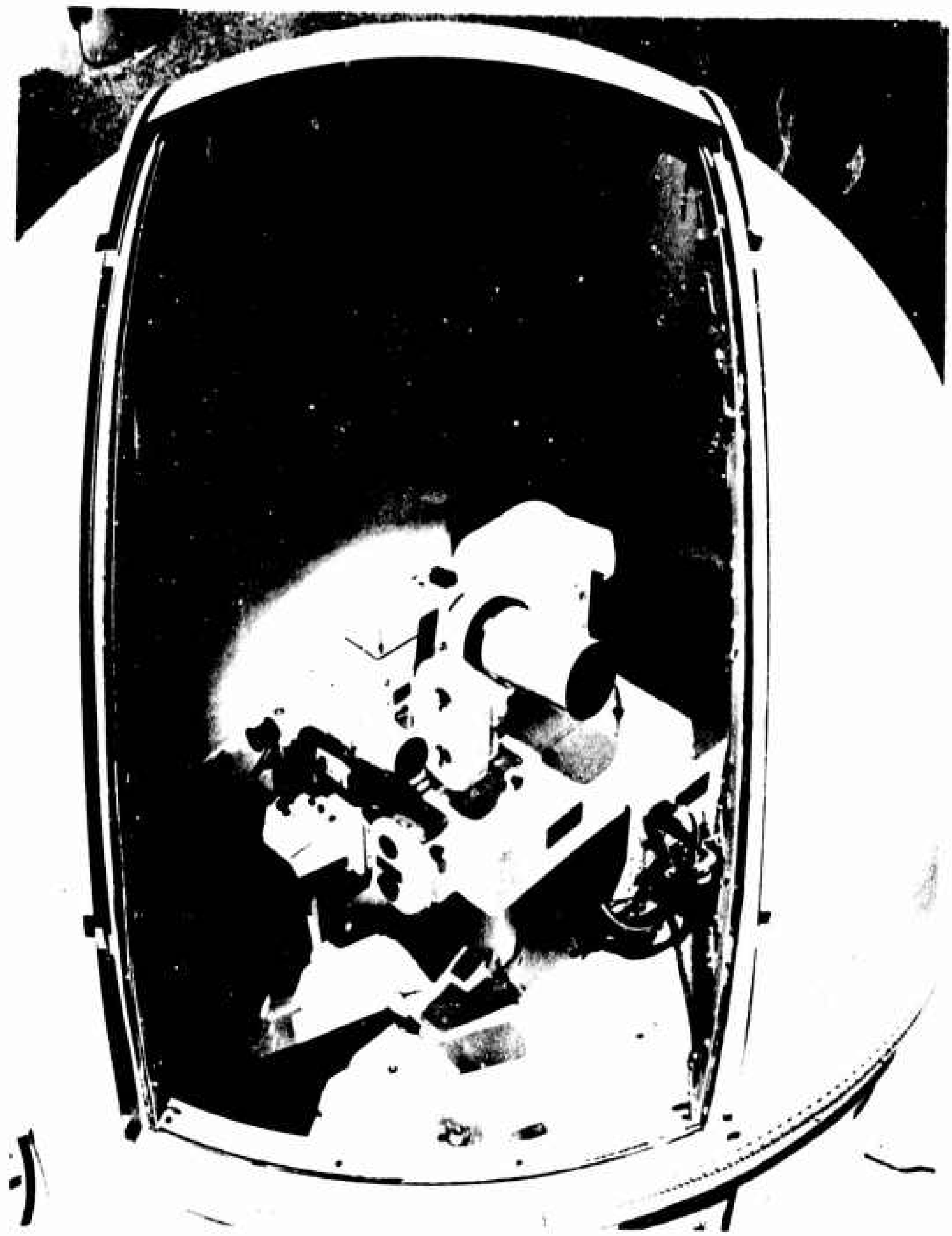

FIGURE 9. CONTRAVES EOTS-FC CINETHEODOLITE

The EOTS-FC is a digitized verison of the EOTS-C instrument with the angle data being electronically encoded for machine processing. The new angle measuring system consists of a time code generator, Inductosyn-resolver shaft angle transducers, angle readout chassis, real-time output chassis, operator control station and film recording system. The modification further includes a one-man tracking conversion, replacement of all standard EOTS-C motors, motor generators and transformers with EOTS-F solid state components, and replacement of the standard slip-ring assembly with a larger capacity assembly.

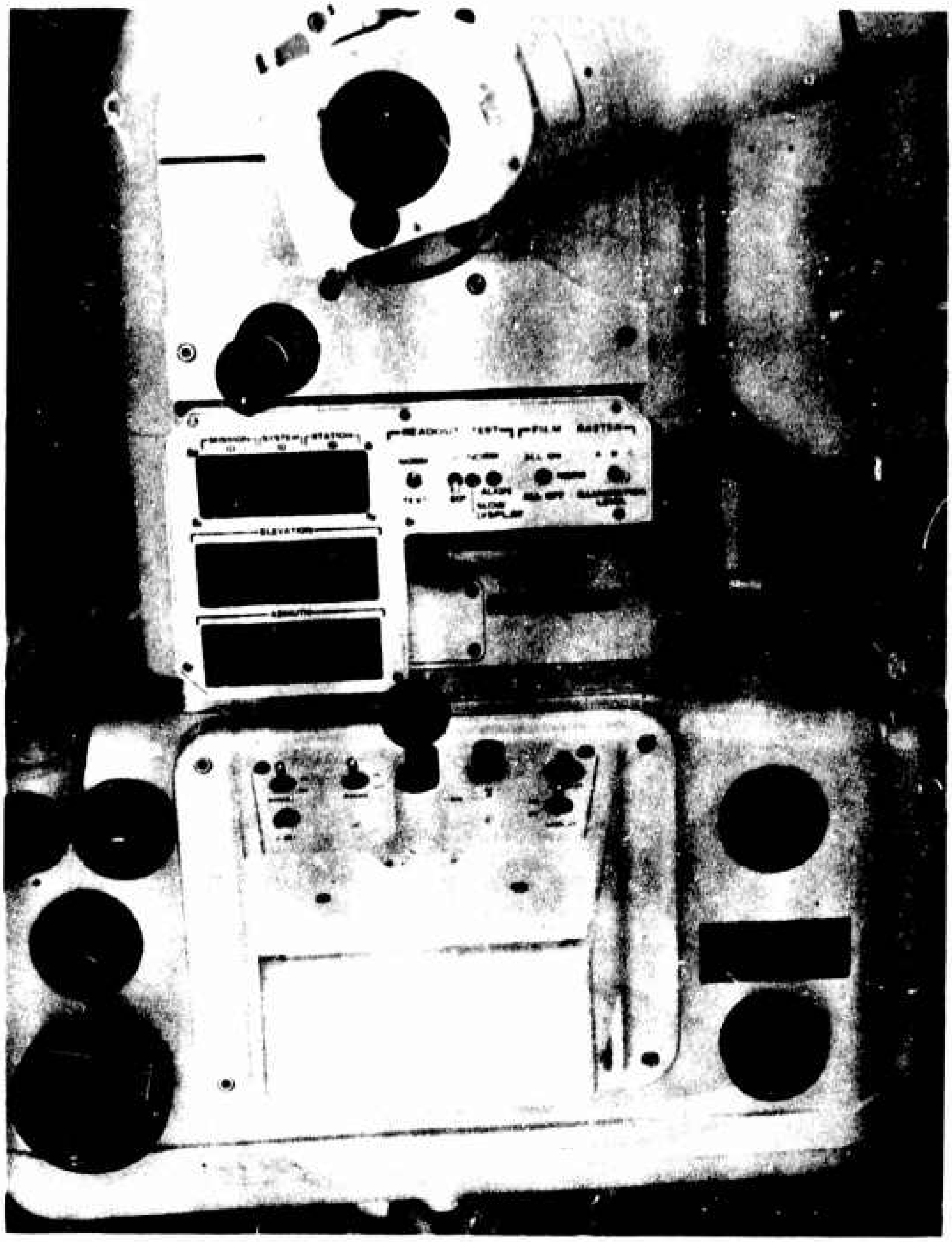

FIGURE 10. CONTRAVES EOTS-FC CINETHEODOLITE, OPERATOR'S CONTROL STATION AND STIFF-STICK CONTROL

The Operator's Control Station provides a visual numeric display of the digitized theodolite angles, a switch input for station and mission data to be recorded on the film and the self-test switching required to check the operation of the angle encoding and data recording subsystems. The Stiff-Stick is a force transducer which resolves the force applied by the operator into azimuth and elevation components and produces an electrical signal proportional to the resolved component.

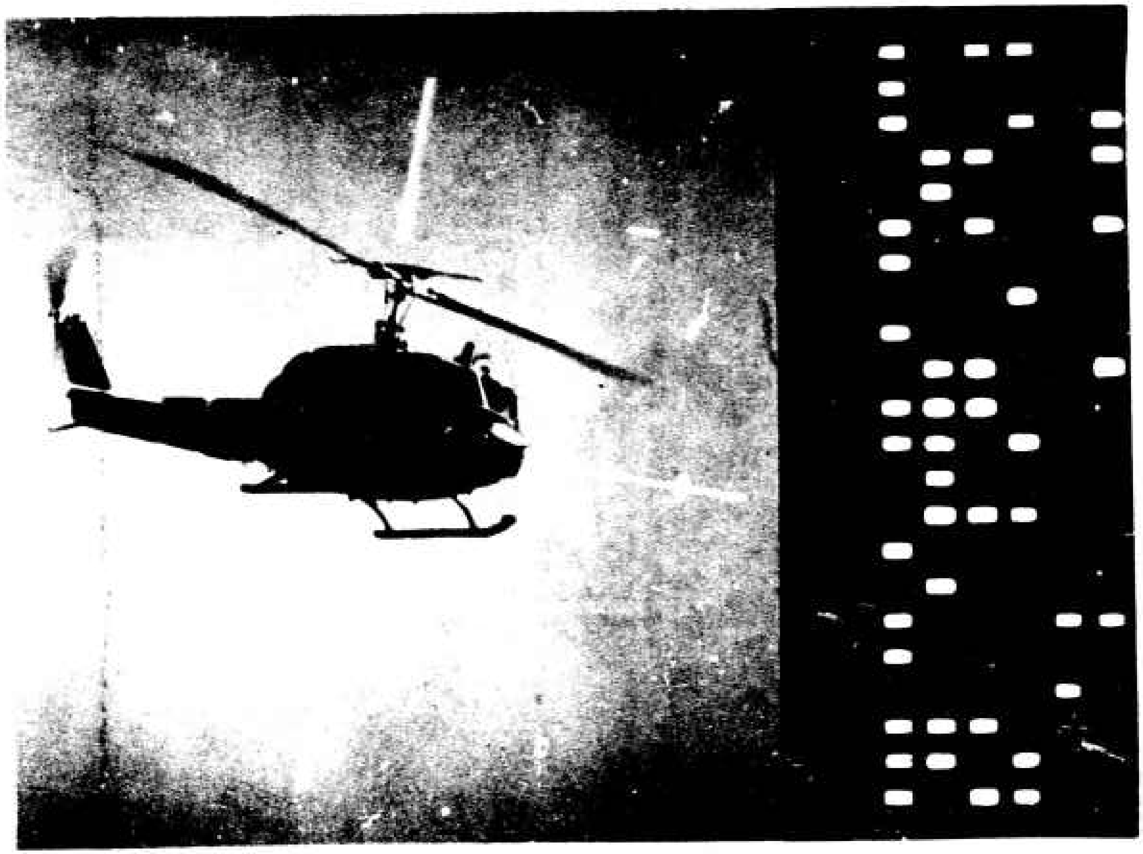

FIGURE 11. ENLARGEMENT OF A FRAME OF 35MM FILM FROM THE CONTRAVES EOTS-FC CINETHEODOLITE

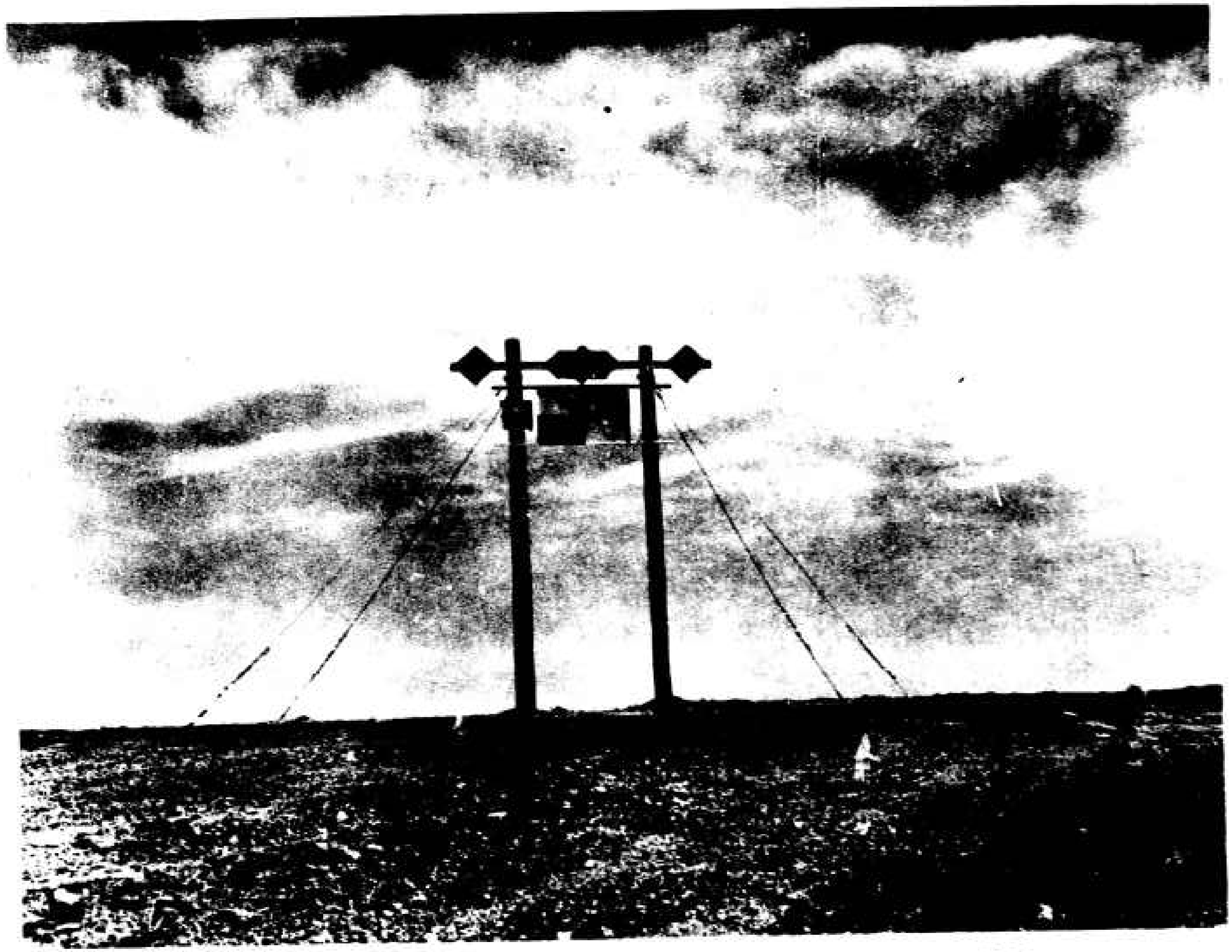

FIGURE 12. CINETHEODOLITE SITE CALIBRATION TARGET BOARD

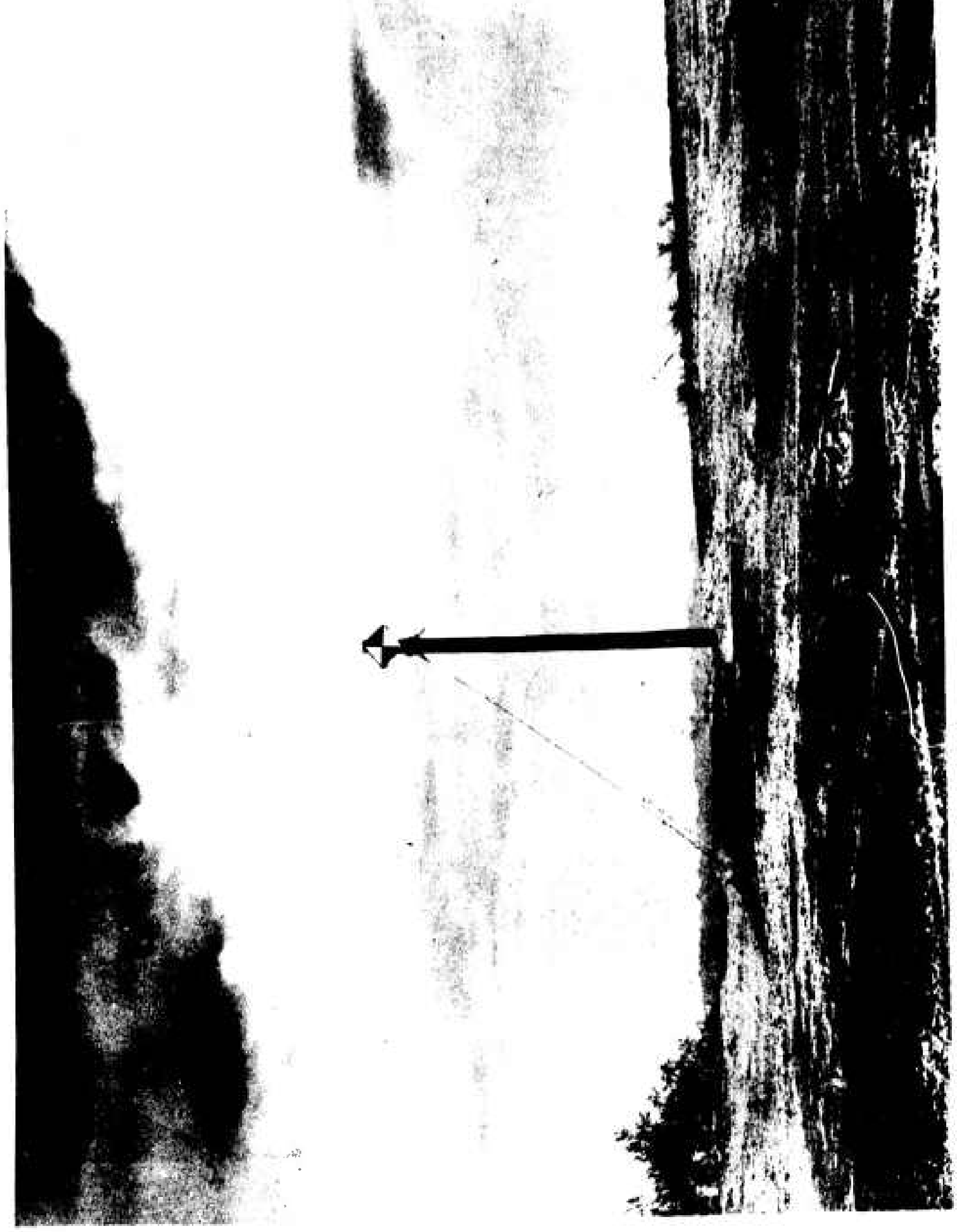

FIGURE 13. CINETHEODOLITE SITE TARGET BOARD

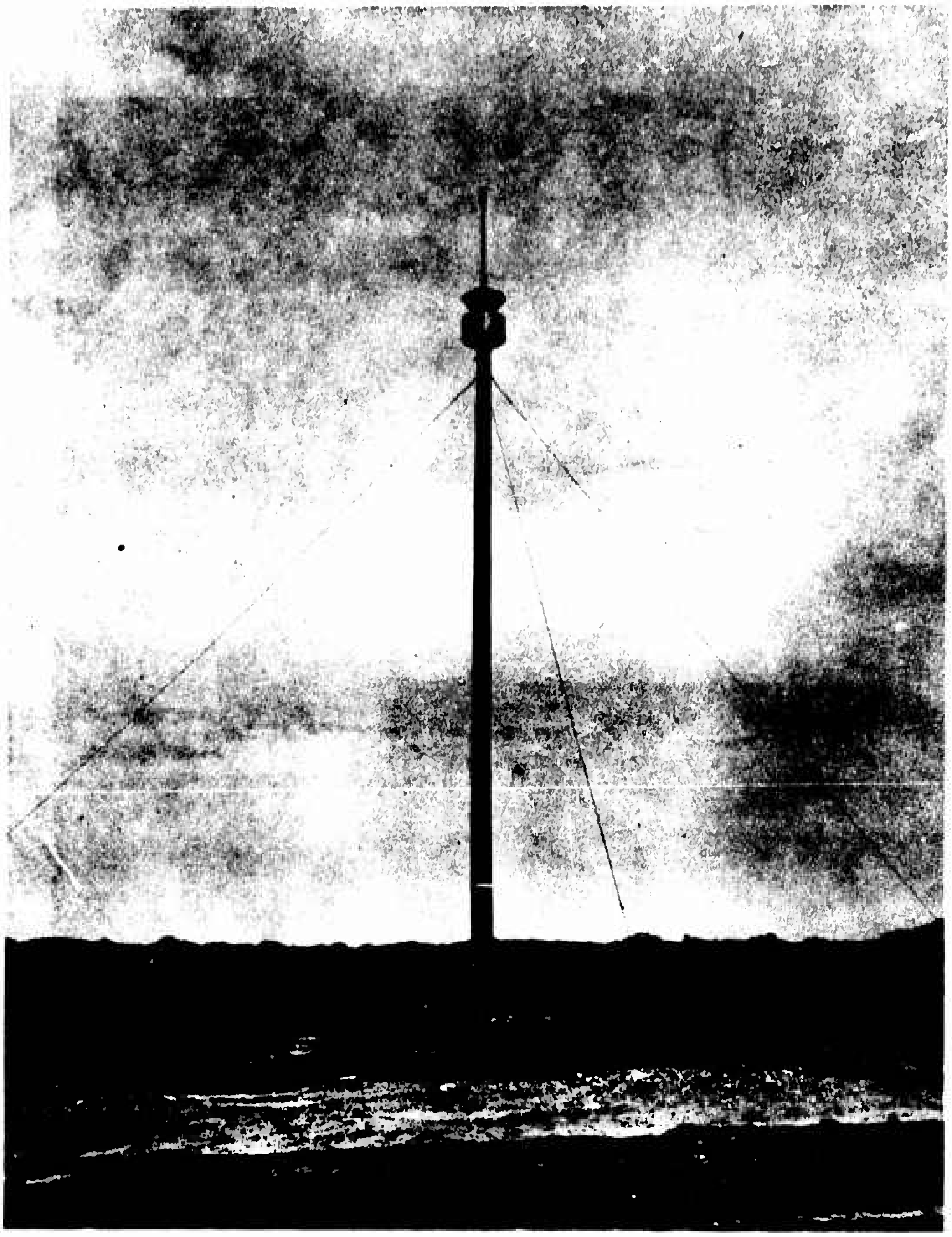

FIGURE 14. RTCDS "2.75 IN. TARGET"

The special target erected near the center of the 2.75 in. Baseline Accuracy Target Array for use as an atmospheric calibration target for the RTCDS.

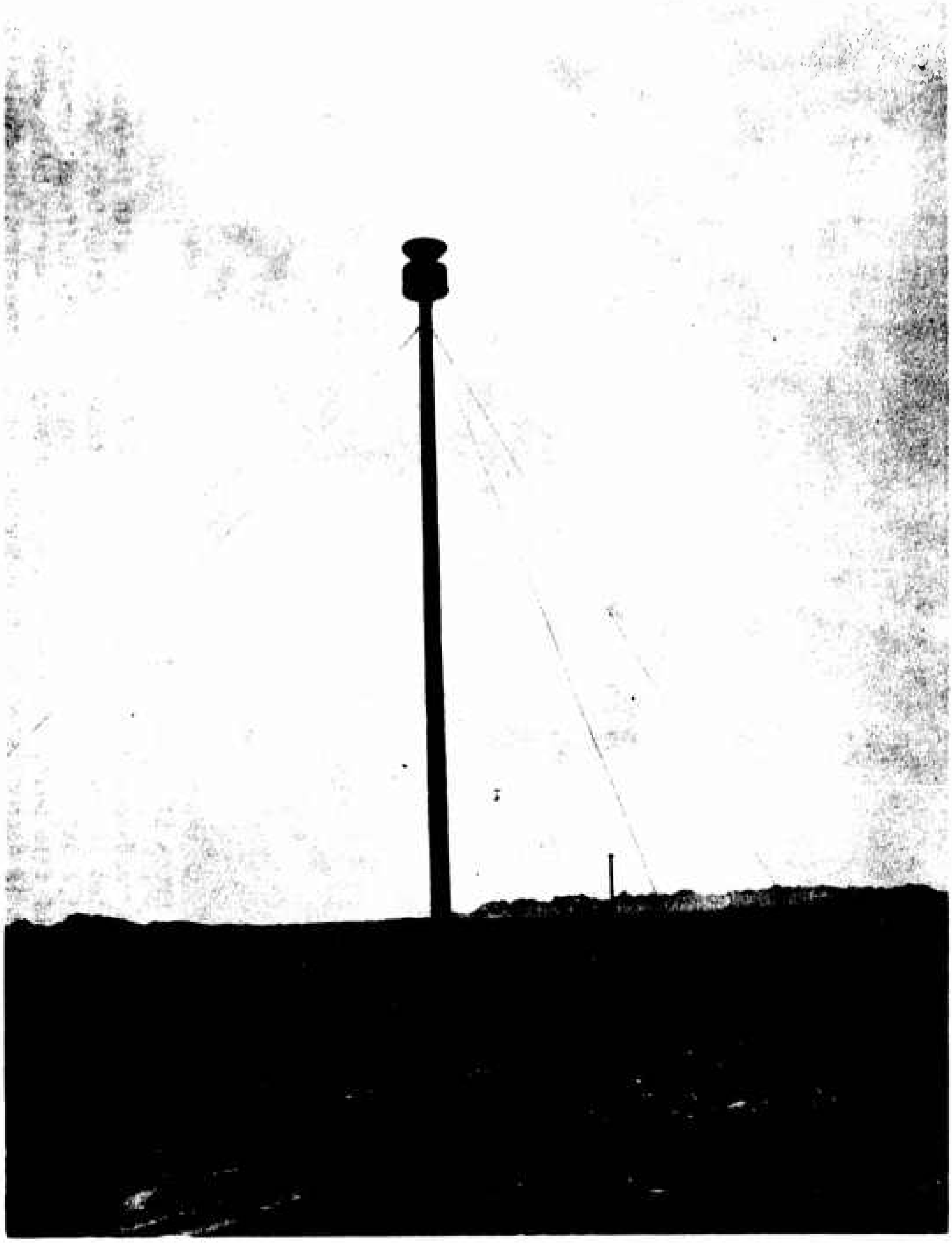

FIGURE 15. RTCDS FRAN SITE TARGET

The special target erected to provide a common point for the evaluation of the static accuracy of the RTCDS.

FIGURE 16. RTCUS CINETHEODOLITE FILM READER

The semiautomatic film reader permits the reading and evaluation of the film frames taken with the real-time digital cinetheodolite, EOTS-FC. The system is comprised of a modified Contraves Projection Desk, with necessary electronics; a Beehive Data Terminal; a Data General, NOVA 1220 Computer; a Kennedy Buffered Formatter; and a Kennedy Tape Recorder. The frame of film being observed is projected onto the measuring table where the digital measurement of tracking error is accomplished by the operator. At the same time, the digital data from the film data matrix is directed through an optical reading system to photo cells for automatic readout to the computer. The computer processes the data, displays the raster information on the data terminal, and records it on the tape recorder.

APPENDIX B

LETTER DATED 31 MARCH 1971, FROM TECOM TO CG, WSMR, SUBJECT "WSMR SUPPORT TO YPG FOR PROCUREMENT OF CINETHEODOLITE MODIFICATION AND REAL-TIME DATA SYSTEM"

DEPARTMENT OF THE ARMY Mr Treat/dlo/234-3350-5278
HEADQUARTERS, U. S. ARMY TEST AND EVALUATION COMMAND
ABERDEEN PROVING GROUND, MARYLAND 21005

AMSTE-TS-I

31 MAR 1971

SUBJECT: WSMR Support to YPG for Procurement of Cinetheodolite Modification and Real-Time Data System

Commanding General, White Sands Missile Range, ATTN: STEWS-PL, White Sands Missile Range, New Mexico 88002
Commanding Officer, Yuma Proving Ground, ATTN: STEYP-MT, Yuma, Arizona 85364

1. References:

a. Unclas teletype, STEYP-MTS, YPG, 152350Z Mar 71, subject: Request for Technical Assistance (Incl 1).

b. Meeting at WSMR, 23-24 Apr 71, subject as above, attended by representatives from USATECOM HQ, YPG and WSMR.

2. In reference 1a, YPG requested assistance in designing a system and preparing specifications for a real-time cinetheodolite data system. The meeting referenced in 1b was held to discuss possible WSMR support and the technical aspects of the task of providing a real-time cinetheodolite data system at YPG.

3. As agreed in the referenced meeting, WSMR will provide, in support of YPG, the necessary government effort for system analysis and design, procurement, installation, checkout, testing and operator training of a real-time cinetheodolite space position system. The basic equipment available at YPG includes four each Model C Contraves Cinetheodolites, an EMR Model 6130 Computer, and a range communication system. The system analysis and design will include provision for cinetheodolite encoders, encoder to data modem interface, data modems, communication system requirements, computer input and output interfaces, computer capacity and software requirements, and data display requirements. WSMR will consider, during the system design phase, future data system growth to include additional data channels for other end sensors such as laser trackers, radars, miss-distance systems, etc., and the use of the system for exchange of pointing information between sensor systems. The cinetheodolite modification will be limited to the addition of precision synchro gear boxes and encoders to provide low-accuracy real-time data.

31 MAR 1971

AMSTE-TS-1
SUBJECT: WSMR Support to YPG for Procurement of Cinetheodolite Modification and Real-Time Data System

4. Funding in the amount of $407,000 is available for system procurement and other non-salary costs associated with the task. A fund citation will be provided by YPG.

5. WSMR will provide a monthly letter status report to YPG, with a copy to USATECOM, ATTN: AMSTE-TS-1, starting in May 1971. The first status report will include a task plan with milestones. Revised cost estimates, if required, for task accomplishment will be included in the monthly reports. YPG will review and coordinate system performance criteria, the conceptual system design, and all procurement specifications. Final system performance will be jointly agreed upon by YPG, WSMR and USATECOM Headquarters.

6. Funds should be obligated at the earliest possible time consistent with a thorough technical analysis and procurement procedures, but not later than February 1972. The goal for completion of an operational system is no later than February 1973.

7. In support of the effort, YPG will provide:

a. A single point of contact for all exchange of information with the WSMR support team.

b. Administrative support including office space, typing support, telephones, etc.

c. Technical support including design information on existing and planned YPG systems.

d. Technical support of systems acceptance testing and checkout.

e. Equipment operators for training and system validation.

8. Deviations from the above plan will require the approval of USATECOM Headquarters.

FOR THE COMMANDER:

George T. Morris, Jr.

1 Incl
as

GEORGE T. MORRIS, JR.
Colonel, GS
Director, Test Systems Analysis

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APPENDIX C

ANALYSIS AND DESIGN OF A REAL-TIME CINETHEODOLITE DATA SYSTEM FOR YUMA PROVING GROUND

REPORT

ANALYSIS AND DESIGN OF A REAL-TIME CINETHEODOLITE DATA SYSTEM FOR YUMA PROVING GROUND

MAY 1971

INSTRUMENTATION DEVELOPMENT DIVISION
INSTRUMENTATION DIRECTORATE
WHITE SANDS MISSILE RANGE
NEW MEXICO

NO
24 Jan 74

SYNOPSIS

PROBLEM: Generate moderate-accuracy space position data in real time of aircraft armament systems under test at Yuma Proving Ground.

APPROACH: Analyze YPG capabilities in terms of existing equipment, personnel and facilities, giving consideration to all feasible alternatives, and propose that which appears to produce the most cost-effective results.

RESULT: The most cost-effective technical solution is a high-accuracy cinetheodolite modification and maximum use of the existing telecommunication and computer facilities.

RATIONALE: The high-accuracy modification will not only fulfill the real-time data requirement, but will also allow production of most of the post-flight data without requiring that the film be read. This avoids significant film-reading costs.

COST: For a systems-oriented, turn-key contract, the cost is estimated to be $962,110.

SCHEDULE: Total project time is 18 months.

PREPARED BY:

JOHN C. DAVIES, Project Leader

OLIVER L. KINGSLEY, Member

KENNETH B. BELLINGER, Member

PATRICK S. QUINLAN, Member

WALLACE W. DILLARD, Member

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CHARLES M. JOHNSON, Advisor

WILLIAM A. RICE, Advisor

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INTRODUCTION

On 31 March 1971, TECOM charged White Sands Missile Range with the responsibility of providing support to Yuma Proving Ground for the procurement of cinetheodolite modifications and a real-time data system. The specific charge was as follows: "WSMR will provide, in support of YPG, the necessary government effort for system analysis and design, procurement, installation, checkout, testing and operator training of a real-time cinetheodolite space position system. The basic equipment available at YPG includes four each Model C Contraves cinetheodolites, an EMR Model 6130 computer, and a range communication system. The system analysis and design will include provision for cinetheodolite encoders, requirements, computer input and output interfaces, computer capacity and software requirements, and data display requirements. WSMR will consider, during the system design phase, future data system growth to include additional data channels for other end sensors, such as laser trackers, radars, miss-distance systems, etc., and the use of the system for exchange of pointing information between sensor systems. The cinetheodolite modification will be limited to the addition of precision synchro gear boxes and encoders to provide low-accuracy real-time data."

This charge was intended to implement a solution to a problem extant at Yuma Proving Ground at the present time, i.e., to provide the capability of vectoring helicopters to a predetermined location. The two programs currently active at Yuma which require this capability are the Cheyenne Test Program and the 2.75 inch air-launched rocket program. The charge to WSMR implied that the system was to provide the capability of fulfilling the requirements of these two programs. At the same time, the government team was charged with performing a system analysis, including a review of project requirements, and design of a real-time data system which would encourage growth to a greater capability as the requirements for real-time data increased.

Consistent with the above, the WSMR team examined the solution indicated by TECOM in light of the current project requirements to insure that the solution proposed would provide the data required by the projects. This report includes that comparison, as well as an analysis of the existing capabilities and facilities of Yuma Proving Ground, including such things as the computer, display systems, cinetheodolite tracker performance, and the Contraves system. It also includes discussion of the systems problem and systems solution in terms of long-term growth, alternative ways of providing the same data, a recommended solution, and cost and time estimates for the recommended solution.

BACKGROUND

Yuma Proving Ground has the mission of planning, conducting, and reporting on engineering, engineer design, production and post-production tests, and supporting desert environmental tests of Army materiel. YPG also has the mission of providing the research and development activities necessary to support these tests. The proving ground has the exclusive mission in TECOM of planning and conducting the engineering tests of air delivery materiel, long-range tube artillery, and support of air delivery tests of other materiel. This mission has recently been expanded by Hq, USATECOM, to include exclusive testing of aircraft armaments, drawing much of this work from other TECOM proving grounds.

The specific mission assigned to the WSMR support team was to provide the Yuma test range with the capability of aircraft armament testing by installation of a real-time vectoring system capable of tracking helicopter aircraft flying below 400 feet altitude. In line with the systems analysis responsibilities assigned to WSMR, the project team identified the accuracy requirements of currently-active projects. It was noted that documentation of project requirements was sparse. Thus, interviews with Materiel Test Directorate personnel (Technical Test Support Division) and with project managers of the 2.75 test program and the Cheyenne test program were held. It was the observation of the project team that, to a great extent, requirements were being phrased in terms of the capability of the proving ground to produce data of a certain accuracy, rather than in the context of what accuracy data the project required in order to meet the program test objectives. This is not intended to be critical, or to suggest alternative methods of establishing range documentation, but rather reflects the situation as observed by the project team.

The long-range projection for YPG mission consists of aircraft armament testing, including scoring and target control, continued testing of ammunition and weapons, and the possibility of tests of laser-type weapons systems against drone aircraft and/or missile targets. In the event that either aircraft or missile targets are employed at Yuma, and if precision trajectory data is required, a substantial increase in film reading workload would result. Other areas of significant film-reading workload include pyrotechnic flare testing in which low accuracy trajectory data is required. The data are presently provided by cinetheodolites.

Thus, one aspect of the current YPG process which is given special consideration in this report is the present film-reading capability to support the anticipated range workload.

PROJECT REQUIREMENTS

2.75 PROGRAM

The test requirements for the 2.75-inch program currently active at YPG are contained in a letter dated 2 July 1970, the subject of which is "Test Program Request No. RK-1141 for 2.75 Inch Baseline Accuracy Tests," addressed to the Commanding General, USATECOM. The purpose of the test program is to determine the angular dispersion in range and deflection of the Mark 40 standard FFAR Warheads about a mean point of impact, and the angular error in range and deflection about a land target, when fired in a number of configurations. The real-time data requirements arise from the following test methods: "For any given set of slant range, air speed and dive angle desired at the time of firing, the pilot will be instructed to fly at a specified altitude and air speed along a path suitably marked on the ground. At a particular time, to be determined by either visual observation through a transit or by radar, the pilot will be released from his approach path and instructed to aim and fire at the target. The pilots will be allowed to fire their rounds within 10 seconds after release from their approach path. The release points will be so calculated as to bring the helicopter to the approximate desired velocity, dive angle and slant range prior to the end of 10 seconds."

According to the test directive, ground instrumentation will consist of cinetheodolites for position, velocity and acceleration data (post flight); transit or radar data to determine the release point along the approach path; a means of obtaining the rocket impact points; adequate camera coverage to complement the airborne camera systems; ground targets; voice recording of all conversations between the helicopter crew and the ground camera crews, and telemetry support. Prime data to be obtained during the tests is:

a. Path of the helicopter prior to firing, consisting of altitude in meters versus range from target with time in seconds, starting at release point.

b. Position in space relative to target center in meters at time of firing.

c. Velocity components in ft/sec of helicopter at time of firing.

d. Acceleration components at time of firing: Linear and angular components of the helicopter and linear components for the launchers in ft/sec^2 and $degrees/sec^2$, respectively.

e. Photographic coverage of launcher.

Other data is required but is not relevant to the task charged to WSMR. The measurement accuracies required by the test directive are expressed in terms of standard deviations and are as follows:

a. Linear Position: ±3 meters.

b. Linear Velocity: ±0.6 meter/sec.

c. Linear Acceleration: ±4.5 meter/sec^2.

d. Angular Position: 0.1 degree.

e. Angular Velocity: "1% of measured data."

CHEYENNE REQUIREMENTS

The data requirements for this project are contained in the Test Plan Army Preliminary Evaluation II of Advanced Aerial Fire Support System (AH-56A), dated June 1970, revised April 1971. The test program to be supported by YPG consists of the APE II and APE III series of tests. The objectives of these series are as follows:

a. APE II: To evaluate the weapons system from both quantitative and qualitative viewpoints. Limited weapons accuracy, avionics performance and crew station operation will be included as part of this evaluation.

b. APE III: To determine to what extent armament subsystems meet specification and to evaluate the avionics subsystem (navigation, communication, sensors, and computer) from both a quantitative and qualitative point of view.

The instrumentation requirements for these tests are as follows:

a. Record all readiness data with respect to productive flight hours, mission aborts and operating time. Readiness data includes, but is not limited to, range ready, instrumentation status, armament ready, on-board optical instrumentation ready and aircraft ready.

b. Record all voice communications between crew members and crew-to-ground.

c. Obtain the aircraft position at time of fire by the use of four cinetheodolites.

d. Measure projectile impacts, when impact occurs, to the nearest inch on the 32 x 40 foot vertical target by means of recording transit or whatever other technique is applicable.

e. Measure the impact of projectiles which miss the vertical target to ±1 meter, probably to be accomplished by means of a chase aircraft and aerial photography.

f. Measure X, Y, and Z of the aircraft at 5 frames-per-second, beginning 10 seconds prior to release time and ending 10 seconds after firing, by means of the existing cinetheodolite system.

At this point, data accuracy requirements are only implied. No required data accuracies are cited for the flight path. High accuracy is indicated for the point of fire determination by virtue of the requirement for the use of 4 cinetheodolites. Considering the requirement for impact measurement of ±1 meter in the ground plane, one might assume a ±1 meter requirement for the aircraft flight path during the fire run.

In addition to the above, a large amount of data is presently being recorded on-board the aircraft. These data are tabulated in Appendix 6 to the cited document. Data reduction requirements are also contained in the referenced document.

The desirability of meaningful numerical displays for the use of the flight controller is also apparent from a review of this document. The data requirements indicate the desirability of computing the first-round hit probability immediately after the mission, and making these data available to the flight controller prior to the initiation of the next pass. Additionally, cumulative probabilities could also be generated and displayed. Velocity data would appear to be required by virtue of the fact that a portion of the evaluation is concerned with the doppler-heading attitude-reference system. A portion of the evaluation is also concerned with the laser range-finder on-board the aircraft. The instrumentation system must produce data sufficiently accurate to permit meaningful evaluation of the slant range determined by the on-board laser ranging device.

Based on a review of the cited document and some speculation, the data requirements, expressed as standard deviations, are itemized as follows:

a. Linear Position[1]: ±1 meter.

b. Linear Velocity: ±0.2 meter/sec.

c. Linear Acceleration: ±1.5 meters/sec.

d. Angular Position: ±0.15 degree.

e. Angular Velocity: ±0.32 degree/sec.

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1. Subsequent conversations with Cheyenne project personnel at YPG have indicated that they would be satisfied with an accuracy of ±2 meters.

It should also be noted that a requirement to determine the trajectory of the TOW missile after launch may arise in the future. If this occurs, it may have an impact on the ability of the cinetheodolite system to support the real-time operation, or on the TOW instrumentation.

DISCUSSION OF EXISTING EQUIPMENT AND CAPABILITIES

A discussion of the present capability of Yuma Proving Ground in terms of equipment and personnel to support a real-time data system is relevant to the present problem because of the direction by TECOM that the YPG task team make maximum use of existing facilities in accomplishing the objective. Personnel are discussed in the context of the equipment which they support because of the possible impact of the modification of that equipment on the ability of the YPG staffing pattern to support such modified equipment. Discussions relating to what modifications might be necessary are reserved for a later section.

CINETHEODOLITES

YPG has eleven Model C Contraves cinetheodolites configured for two-man tracking, four of which are mounted in mobile astrodomes. The remaining seven are emplaced at fixed sites. None of the astrodomes are slaved to the cinetheodolite azimuth axis. All of the instruments are reported by YPG to be in excellent condition. The newest of the instruments are those mounted in the mobile astrodomes.

The cinetheodolites are not equipped with data gear boxes. Each instrument has a 33 element slip-ring assembly, but only one of these slip rings can be clearly indentified as being a spare. Six instruments are equipped with 4X/12X tracking optics, while the mobile instruments have 4X/20X tracking optics. All instrument electronics are of the tube type. The instruments are presently operated at either 5 or 25 frames-per-second, and all film records are recorded on Ektacolor film, exposed and processed to an ASA rating of 160. Film processing is accomplished by a contractor, located in the city of Yuma, who processes the film with a twelve-hour turn-around time.

CINETHEODOLITE TRACKER PERFORMANCE

YPG currently has a maximum of twelve cinetheodolite operators, six of whom are classified by YPG as excellent trackers. The total of twelve operators includes four maintenance personnel and some individuals from Geodetic area. Since one of the possible solutions to the vectoring and post-flight aircraft armaments testing problem is the use of cinetheodolites, which are precisely tracked by the operators and for which no boresight corrections to the data are made, it is desirable to assess the ability of the cinetheodolite trackers to precisely track the helicopter.

Three demonstration flights of a Cheyenne helicopter were held on 25 March 1971 and instrumented by Sites 8, 9, and 10. The film of the three flights from three stations was obtained by the Yuma task team, along with the listings of boresight tracking errors. A 5 sample/second sample rate was used by the cinetheodolites. Each flight lasted a nominal ten seconds. The operators were not conditioned to do the best tracking, so that the data is representative of typical tracking performance that might be obtained. The resulting variability of boresight error is composed of several components. Among these are the granularity of the film reader which is approximately .02 mils, the dial and coding process which amounts to approximately .02 mils, film quality, random and gross reading errors, instrumental errors, and the operators tracking error. Aside from any gross reading errors, the greatest contributor to the boresight error will be the operators tracking error.

The listing of boresight corrections from the above-mentioned flights were analyzed to determine the standard deviation about the mean of the tracking errors from several sites on several operations. These data are included in Table I. It can be observed that the standard deviation estimates for the azimuth tracker exceed the paired values for the elevation tracker in two out of three of the sets of data. This is a reasonable result since the elevation operator for horizontal flight has virtually no tracking task to perform. The tracking bounds and the range of the tracking bounds are displayed in Table II. In agreement with the above comment regarding variability, the larger range of tracking error is generally associated with the azimuth tracker.

It is possible that the standard deviation for both axes could be reduced to approximately .15 mils if the following were accomplished:

a. Motivate the operators to do the best possible.

b. Utilize one-man tracking.

c. Optimize the gain and damping of the aided tracking system for low-rate tracking problems.

However, the confidence with which these results can be transferred from the two-man rate-controlled aided-tracking system to the one-man rate-plus-acceleration aided-tracking system is unknown at this time. It is not unreasonable to assume equivalent performance since the competition between the azimuth and elevation trackers is eliminated in the one-man system. Tracking tests will be conducted in the immediate future to validate this assumption.

TABLE I. TRACKING VARIABILITY AND BIAS FOR CINETHEODOLITE OPERATORS WITH CHEYENNE HELICOPTER TARGET

	TRACKING OPERATOR AND SITE NUMBER					
	H - HORIZONTAL TRACKER			V - VERTICAL TRACKER		
VARIABILITY ITEM	H-8 (MILS)	H-9 (MILS)	H-10 (MILS)	V-8 (MILS)	V-9 (MILS)	V-10 (MILS)
Standard Deviation	0.28	0.17	0.14	0.19	0.12	0.16
Bias Estimate	0.16	0.21	0.14	-0.21	-0.53	-0.11
Sample Size (Number of Frames)	47	49	49	47	49	49

TABLE II. TRACKING BOUNDS FOR CINETHEODOLITE OPERATORS WITH CHEYENNE HELICOPTER TARGETS

	TRACKING OPERATOR AND SITE NUMBER					
	H - HORIZONTAL OPERATOR			V - VERTICAL OPERATOR		
TRACKING BOUND	H-8 (MILS)	H-9 (MILS)	H-10 (MILS)	V-8 (MILS)	V-9 (MILS)	V-10 (MILS)
Upper Limit	0.74	0.71	0.55	0.14	-0.34	+0.30
Lower Limit	-0.20	-0.12	-0.12	-0.53	-0.76	-0.41
Range of Limits	0.94	0.83	0.67	0.67	0.42	0.71

SYSTEM GEOMETRY

The portion of YPG designated for aircraft armaments is the Cibola Range Area. Six cinetheodolite sites have been constructed in this area in approximate form of an L. Three sites are located along a North-South baseline approximately 12,000 meters long while three sites are located along the East-West leg approximately 8,400 meters long. A map showing the sites locations in the Cibola Range Area is included as Figure 1. Maximum and minimum ground ranges from each site in this complex to the Cheyenne and 2.75 flight paths are indicated in Table III. In order to assess the ability of this geometry to provide the data required, the six sites were utilized in a computer simulation of cinetheodolite systems performance. Systems consisting of four, three, and two cinetheodolites were considered in various combinations of the six sites. Tables IV, V, and VI show the various combinations of available sites. Table IV was computed for the nominal firing point for Cheyenne helicopters, Table V for the nominal firing point for the 2.75 program, and Table VI for the nominal firing point for moving targets. The angular variability factor of 60 seconds of arc was chosen on the basis of the six sets of tracking error data derived from the cinetheodolite tracker performance analysis. The average horizontal root mean square (rms) value about the rotor hub was 52 seconds of arc for the three sets of horizontal tracking errors, while the average vertical rms value about the rotor hub was 71 seconds of arc for the three sets of vertical tracking errors. The angular variability would be smaller if the tracking operators were instructed to center on the helicopter rotor hub. In any case, the 60 seconds of arc is a reasonable figure to use for system simulation studies.

All of the three-and-four instrument systems can meet an average requirement for space position data of three meters or less near the firing point. The two-station system requires inclusion of Site 9 in the data reduction solution in order to meet an average requirement of three meters for the Cheyenne firing point. The other two firing points can be instrumented with two-instrument systems and still meet the data requirements of three meters at low altitudes.

FILM READING

The present film reading capability of YPG consists of two Telereadex 29E front projectors, suitable interface electronics, a keyboard for manual entry of the azimuth and elevation dial readings and paper tape and card outputs. The capability of this film reading system could have a determining influence on the solution ultimately implemented, primarily because film reading forms a serious constraint on the ability of YPG to accommodate a large volume of work. In order to estimate the ability of YPG to assume aircraft armaments testing, the maximum capacity of the film reading system was computed and translated into the maximum capacity of YPG to absorb aircraft armaments testing similar to the type in progress. For this computation, a reading rate of 100 frames per hour for a single

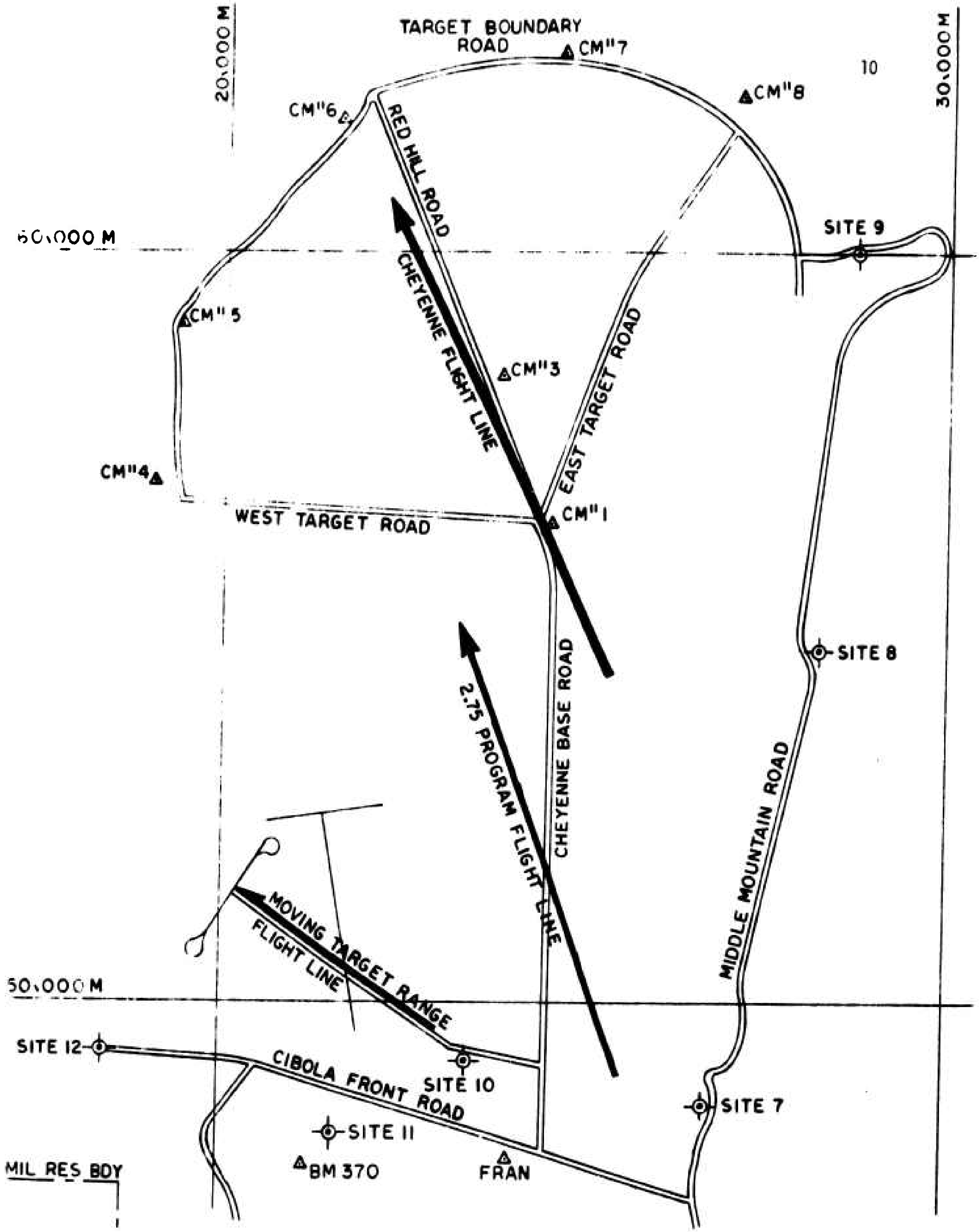


FIGURE 1
MAP OF CIBOLA AREA

TABLE III. GROUND RANGES TO FLIGHT PATTERNS (METERS)

SITE	2.75 PROGRAM MAX	2.75 PROGRAM MIN	CHEYENNE PROGRAM MAX	CHEYENNE PROGRAM MIN
7	7,400	1,290	13,030	5,950
8	6,440	4,500	8,530	3,220
9	11,590	7,400	5,630	6,440
10	5,950	1,930	11,750	5,630
11	7,080	3,860	12,550	7,400
12	7,560	6,760	12,070	8,850

TABLE IV. CINETHEODOLITE PERFORMANCE SIMULATION USING CONTRAVES SITE FOR LOW ALTITUDE* NOMINAL FIRING POINT FOR CHEYENNE HELICOPTERS

CONFIGURATION NUMBER	SITES UTILIZED YPG SITE NUMBERS	ANGULAR VARIABILITY STANDARD DEVIATION (SEC OF ARC)	AVERAGE SIGMA $\bar{s} = \sqrt{(s_x^2 + s_y^2 + s_z^2)/3}$ (METERS)
1	7, 8, 9, 10	60	2.02
2	7, 8, 9, 11	60	2.00
3	7, 8, 9, 12	60	2.00
4	7, 8, 9	60	2.54
5	7, 9, 11	60	2.22
6	7, 9, 12	60	2.15
7	7, 8	60	5.79
8	7, 12	60	4.55
9	7, 9	60	2.98

*Space point about 100 feet above surface.

TABLE V. CINETHEODOLITE PERFORMANCE SIMULATION USING CONTRAVES SITES FOR LOW ALTITUDE* NOMINAL FIRING POINT FOR 2.75 ROCKETS

CONFIGURATION NUMBER	SITES UTILIZED YPG SITE NUMBERS	ANGULAR VARIABILITY STANDARD DEVIATION (SEC OF ARC)	AVERAGE SIGMA $\bar{s} = \sqrt{(s_x^2 + s_y^2 + s_z^2)/3}$ (METERS)
1	7, 8, 9, 10	60	1.40
2	7, 8, 9, 11	60	1.37
3	7, 8, 9, 12	60	1.39
4	7, 8, 9	60	1.96
5	7, 9, 11	60	1.78
6	7, 9, 12	60	1.65
7	7, 8	60	2.53
8	7, 12	60	1.79
9	7, 9	60	2.37

*Space point about 100 feet above surface.

TABLE VI. CINETHEODOLITE PERFORMANCE SIMULATION USING CONTRAVES SITES FOR LOW ALTITUDE* NOMINAL FIRING POINT, MOVING TARGET

CONFIGURATION NUMBER	SITES UTILIZED YPG SITE NUMBERS	ANGULAR VARIABILITY STANDARD DEVIATION (SEC OF ARC)	AVERAGE SIGMA $\bar{s} = \sqrt{(s_x^2 + s_y^2 + s_z^2)/3}$ (METERS)
1	7, 8, 9, 10	60	1.32
2	7, 8, 9, 11	60	1.18
3	7, 8, 9, 12	60	1.33
4	7, 8, 9	60	1.93
5	7, 9, 11	60	1.48
6	7, 9, 12	60	1.40
7	7, 8	60	2.35
8	7, 12	60	1.42
9	7, 9	60	2.44

*Space point about 100 feet above surface.

operator on each machine, and 200 frames per hour for two operators on each machine was assumed. The time required to load and align a single roll of film was assumed to be 5 minutes. Based on two machines operating on a three-shift, five-day-per-week basis, and operating productively for 21 of the 24 hours per day, a total of 12,600 productive machine minutes per week are available. Furthermore, assuming an average mission time of 10 seconds, a frame rate of 5 frames per second and 3 cinetheodolites operating per mission, the maximum range capacity using a single operator on each machine is 133 missions per week. For two operators on each machine, the maximum capacity is 252 missions per week. These estimates are slightly optimistic since no time was allowed in the film reading process to read the orientation target.

TIMING

The IRIG timing system at YPG consists of generation, distribution, and terminal equipment. The time code generator currently in use is an Astrodata Model 6190 and is located at Building 3519. One kilohertz modulated IRIG B is the principle timing format in use. Time-of-day of the time code generator is checked on a daily basis with WWV, with appropriate account being taken of the transmission lag from Boulder to Yuma. Pulse-rate outputs from the time code generator are made available for generation of the synchronized shutter pulses for operation of the Contraves cinetheodolites. The Contraves cinetheodolite system operates in a master-slave concept, with the shutter pulses being superimposed on the IRIG B timing.

At the present time, formats A, C, D, and E are available for distribution from dc level-shift or modulated-carrier outputs of the time code generator. The IRIG B output consists of one dc level-shift channel and seven modulated-carrier channel outputs. Six of the modulated-carrier outputs drive land-line circuits to such locations as the telemetry ground station, telemetry data center, blockhouse, electronic maintenance shops and photo repair facility. The seventh channel is the output to the primary range timing transmitter, a 250 watt VHF FM unit operating at 150.765 megahertz. This transmitter provides primary coverage for the Kofa Range Area. A timing repeater is installed at Site 4 in the Cibola Range, which is also used as the control point and master station for the Cibola cinetheodolite system. Wireline and distribution amplifiers, galvanometer drivers, neon drivers and various other types of equipment are available for applications requiring such equipment. In addition, several locally designed and fabricated neon drivers, some of which are equipped with galvanometer drivers, are available for aircraft installation. These are designed principally for use on aircraft armaments testing.

TELECOMMUNICATIONS

The existing telecommunications plant, illustrated in Figure 2, is composed of three switching centers, a cable network, one microwave and three VHF radio systems. The main central office is located in Building No. 5,

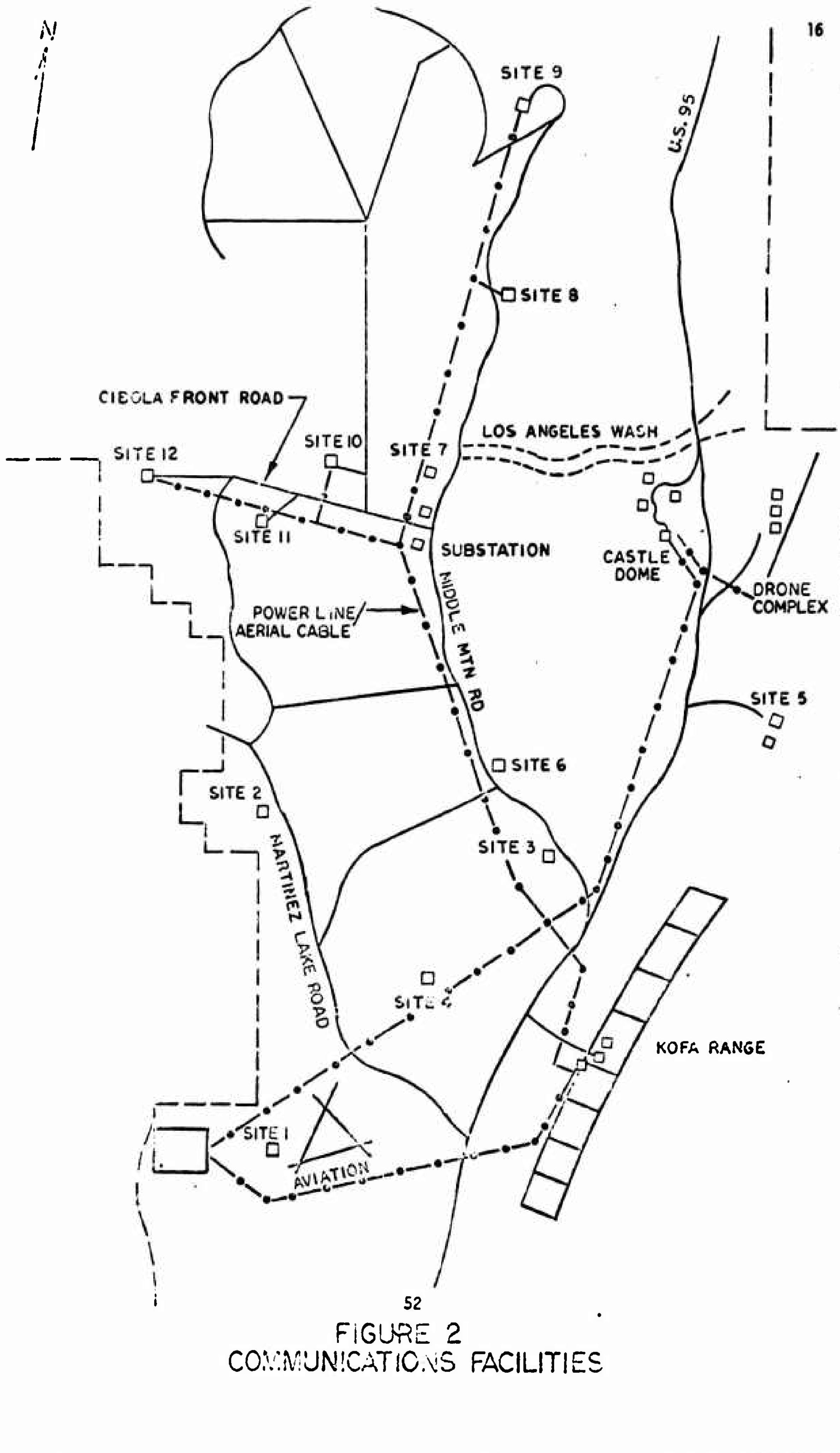


FIGURE 2
COMMUNICATIONS FACILITIES

Headquarters Area and consists of a 1000-line Stromberg XY switch, the Communication Center and the IBM 360/20, Team-Up D terminal. The Kofa Range Center is located in Building No. 3519 and consists of a 200-line North Electric XY switch, the time generator and the time distribution VHF transmitter. The Castle Dome Center is located in Building No. 6000 and contains a 300-line Stromberg XY switch. In addition, a short-haul microwave, handling TV operates between the Muggins Mountains and Hill 630 near the Army Air Field. The telemetry "L" band microwave, when used, operates between Site 7 and Kofa Range Center. The Range Control VHF radio network is centralized at Range Control located near Site 4.

A two-year-old 50-pair aerial cable runs from the Kofa Range Center parallel with Middle Mountain Road to Site 9. This cable is co-located on power line poles which provide primary service of 34.5 KV to the substation at the junction of Cibola Front Road and Middle Mountain Road, and primary tie service of 12.47 KV to the existing cinetheodolite sites. In addition, the aerial cable from Kofa Range Center to the junction of U. S. Highway 95 and Middle Mountain Road is parallel with, and in close proximity to the Parker Dam-Gila Substation 169 KV transmission line. This cable has an induced 60 cycle voltage of 6 to 12 volts depending on the annual seasons. Consequently, the cable must be further evaluated and renovated prior to utilization.

From the junction box located at the intersection of Cibola Front Road and Middle Mountain Road, a 25-pair aerial cable extends west to Site 12 and is co-located on the 12.7 KV service line to Sites 10, 11, and 12.

The Telecommunications staff for plant installation and maintenance is quite small. Thus, the capability to operate and/or maintain any new and complex equipment must be provided.

TELEMETRY SYSTEM

The current YPG telemetry data center consists of an EMR 6130 computer with the following major peripherals:

a. Central processing unit (no floating point arithmetic hardware).

b. I/O Keyboard.

c. Two 16K, 16-bit word, core storage modules.

d. Two 9-track tape drives.

e. Disc file (one million 16-bit word capacity).

f. 600 line-per-minute, on-line printer.

g. On-line card reader.

h. On-line card punch.

i. On-line teletype terminal.

j. Real-time telemetry interface.

k. Paper tape reader/punch.

l. Frame synchronizer.

m. Bit synchronizer.

n. A to D converters.

o. D to A converters.

p. Signal simulator.

q. Perturbation generator.

r. Time code generator and time interface.

Items l through r are connected to the telemetry interface through a data distributor or a subchannel. Five input subchannels and five output subchannels on the telemetry interface are not used at the present time.

The greatest real-time telemetry workload (2.75 program) in terms of rate is described as follows:

a. Bit Rate: 144K bps.

b. Bits/Word: 12.

c. Words/Sec: 12,000.

d. Words/Frame: 120.

e. Frames/Sec: 100.

f. Words Processed: 6.

g. Processing Time: 1×10^{-3} sec (approximate).

The 6 data words are scaled and output to D/A converters for display on strip chart recorders. Timing analysis indicated that the current telemetry real-time process used approximately 13 percent of the available computer time or 130,000 microseconds per second. I/O time on this system is easily obtained but computations using floating-point arithmetic will require major amounts of time.

Use of the computer to accomplish trajectory computations will absorb most of the remaining time on the system. Any significant increase in future telemetry real-time computational workload cannot be accommodated if floating-point computations are used.

YUMA COMPUTER CAPABILITY

YPG currently has the EMR 6130 computer system described above. Items a through j are relevant to the proposed real-time data system. System software includes a FORTRAN compiler, a machine-language assembler, and a batch-processing monitor. EMR has supplied a real-time executive control monitor, but it has not been used at YPG. The only real-time data processing being accomplished is the formatting, scaling, and output to strip-chart recorders of six channels of telemetry. Personnel with computer hardware-level software experience are not in abundance. One electronic technician has good real-time I/O software experience with the telemetry data. At least two mathematicians are also available who know FORTRAN and might be helpful. However, all the above personnel are engaged full-time with other tasks.

In order to assess the ability of this computer system to perform the required real-time computations, a simple two-station space position solution program was written in FORTRAN, interfaced with an assembly language program to read the real-time clock, and the calculations timed. Floating point (FP) calculations were software implemented due to lack of FP hardware and are consequently very time consuming. FP multiply and divide take just over 100 microseconds, while calls to math routines (SIN, COS, SQRT, etc.) averaged around 650 microseconds each with the test data.

The two-station solution assumed a baseline of 20K feet with initial azimuth of 45° and 315° and elevations of .5° each. All angles were incremented by .5° for 100 program passes. The solution required 14 milliseconds-per-pass, and included three floating-point additions, six floating-point subtractions, fourteen floating-point multiplications, ten floating-point divisions, six calls to SIN, six calls to COS, and two calls to SQRT. No attempt was made to precisely verify accuracy of FP calculations, but a rough check indicated reasonable results. EMR 6130 floating point is quite similar to the 32-bit implementation on the IBM system 360, and should be adequate for the range of numbers expected for the YPG real-time application.

According to analysis of the results obtained, the EMR 6130 computer system should be capable of receiving real-time data from four cinetheodolites, performing a simple selection scheme and computing at least one two-station solution. Additionally, the computer should be fast enough to smooth the position data (assuming a fast filter is used, e.g., QD), obtain derivative data, and output these data to display devices. How much more display computation can be done (i.e., transformations to target coordinate systems, computation of velocity vector azimuth, time-to-target, etc.) will depend on a more complete timing analysis of the system.

Ample core storage is available for problem solution and the peripheral equipment is adequate, although one additional seven-track tape drive might be useful for compatibility with other computer systems in the future. Additional real-time interface equipment is necessary for data modem input to the computer and display data output from the computer, and can probably be obtained from the standard EMR product line.

Since it appears that the YPG EMR 6130 is adequate for the cinetheodolite solution, no further study will be undertaken at present. However, one final point regarding YPG computer capability is required. If any significant amount of real-time computation is added to the EMR 6130 work-load (additional work which would require processing simultaneously with the cinetheodolite and telemetry data generated by the 2.75 or Cheyenne programs), the EMR 6130 would most assuredly be unable to perform.

M-33 RADAR

YPG has two M-33 radar systems, one of which is located at Site 7. The use of the M-33 radar for the vectoring problem encountered in aircraft armament testing would require a beacon on the helicopter. This beacon is not compatible with the C-band beacon required for use with the MPS-25 radar. Nominal angular accuracy of the M-33 radar is 0.5 mil, subject to proper calibration and other operational constraints. The M-33 has a plotting board facility, but does not have digital readout capability.

MPS-25 RADAR

YPG currently has on loan from WSMR an MPS-25 radar and operational crew. The system is located at Site 4. The nominal angular accuracy estimate for this radar, as determined by Operation Precise (conducted at WSMR and reported in Report 4 dated July 1966), is 0.2 mils for angle and 5 yards for range. These estimates are for missile flight trajectories free of ground clutter and other problems, such as that which might be encountered from modulation of the signal by the helicopter rotor. The MPS-25 is equipped with a display capability incorporating an analog computer and two plotting boards, along with other peripheral equipment. The duration of the loan is for six months. The future status of the MPS-25, after the loan period, cannot be determined at the present time.

WORKLOAD

As mentioned previously, the aircraft armaments testing workload expected to be assumed by YPG could have a significant impact on the alternative ultimately selected for implementation, principally because of the constraints imposed by film reading capacity. To determine the effect of these constraints the following forecast was generated:

a. A standard mission is defined as 10 seconds of flight, with three cinetheodolites operating at 5 frames/sec.

b. The following 2.75 program workload forecast is assumed correct:

27 passes/day

3 days/week

6 seconds/pass

5 samples/second

5 minutes/pass

c. The following Cheyenne program forecast is assumed correct:

8 passes/day

3 days/week

20 seconds/pass

5 samples/second

5 minutes/pass

Then, the total number of frames of data/week generated by each program is:

2.75 Program	7290
Cheyenne	7200

or roughly 14,500 frames/week. Each standard mission generates 150 frames of data, thus the projected workload for the 2.75 and Cheyenne programs is 97 standard missions/week.

SYSTEMS PROBLEM

Aside from the question of what type of sensor is to be employed in the real-time vectoring system to be implemented at YPG, consideration must be given to a systems design philosophy for a real-time data system. In general, the real-time data system should have the following capabilities:

a. It should accept data from cinetheodolites, radars, the laser tracker proposed for YPG, any special instrumentation in the pyrotechnic test area, telemetry, and any other end-sensors, such as tracking telescopes, TV trackers and the like, that might reasonably be expected to be employed at YPG. Without having definitive technical information available on the characteristics of the output of these sensors, it is desirable to configure the input to the real-time data system in such a way that the likelihood of compatibility with the sensors is a maximum. The generalized real-time data system should have the capability of processing the data from a multiplicity of these sensors singly or in groups, and producing real-time output for aircraft control (vectoring) and other valid uses for real-time data. It additionally should have the capability for generating the X-Y position of the aircraft or target, and outputting these data to sensors of the same set for acquisition purposes. Certain fundamental decisions are required regarding the real-time data system which are not completely defensible from a technical or economic point-of-view. In most cases, these decisions have been made on the basis of maximizing systems capability while maintaining "reasonable" cost. An example of this type of heuristic decision is the one involving bit rate, wherein a bit rate of 2400 bps can be achieved for the same cost as a bit rate of 1200 bps.

Another fundamental decision which is required in the systems solution is that of sampling rate. Based on the current workload at YPG, a sampling rate of five samples-per-second would appear to be adequate for any real-time application. However, because of the foregoing comments, a higher sampling rate is indicated in the solution because it incurs no additional cost, and because the proposed instrumentation is capable of making meaningful measurements at a higher rate.

A vital portion of the systems problem is concerned with the telecommunications plan. A number of alternatives for providing communications support to the real-time data system exist, ranging from use of the existing communication facility to installation of a completely new facility dedicated to the real-time data system.

System considerations indicate the desirability of certain constraints being placed on the systems design. Some of these constraints are as follows:

a. Inputs should be synchronous and phase-locked.

b. All range, azimuth, and elevation data should be in a natural binary format.

c. Quality tags for data should be provided. This is particularly true if the cinetheodolite solution is implemented so that the computer will be able to identify the data which the operators, i.e., the trackers, have judged to be acceptable.

d. Frame and word synchronization should be established in the computer interface.

e. Data word lengths should be in multiples of 8 bits.

f. Maximum use of off-the-shelf equipment, modified as necessary, should be made in order to meet systems objectives with minimum cost.

SYSTEMS SOLUTION

In discussing the proposed solution to the YPG real-time data problem, it is efficient to establish certain constraints on the system in order to simplify the process of evaluation of the components of that system. The method of analysis to be employed will be to specify systems parameters and to then evaluate the alternatives within each subsystem on a technical and an economic basis, and to make a subsystem selection rather than considering all combinations of all subsystem alternatives in making a single selection. To this end the following systems parameters have been selected as being desirable:

a. Bit Rate: The basic bit rate for the system has been chosen at 2400 bps. The rational behind the selection of this rate is that it does not require a particularly high quality communications line, it costs no more than a 1200 bps system, it will accommodate word lengths and sampling rates sufficient for most conceivable YPG real-time data requirements, and off-the-shelf equipment, compatible with this rate, is available.

b. Word Lengths and Format: The word length selected is 120 bits per word. This word length was selected to be compatible with the sampling rate discussed below. A typical message format is shown in Figure 3, and is discussed below:

(1) Synchronization Code: This code marks the beginning of the data message.

(2) Instrument ID: The instrument identification code represents an alphanumeric site designator. Bits 6, 7, and 8 represent the alpha character and bits 9 through 15 represent the numeric character.

(3) Quality Tags: This binary field has been included to provide cinetheodolite sensor, orientation, and tracking quality information and allows for future needs.

(4) Azimuth: This is a 24-bit data field with the MSB left adjusted in the data field. Bit 49 is the MSB for azimuth and represents 180 degrees. These angles are always positive and therefore no sign bit is used. The LSB represents $21.4576733 \times 10^{-6}$ degrees.

(5) Elevation: This is a 24-bit data field and is identical to the azimuth data field, except that bit 73 is the MSB of elevation.

(6) Range Rate: This is a 24-bit data field with the LSB right adjusted in the data field. Bit 120 is the LSB of range rate and has a weighting of one yard per second. The range rate data field has a sign bit in the MSB position (bit 97). If range rate is not desired or not available, this field will be used for time.

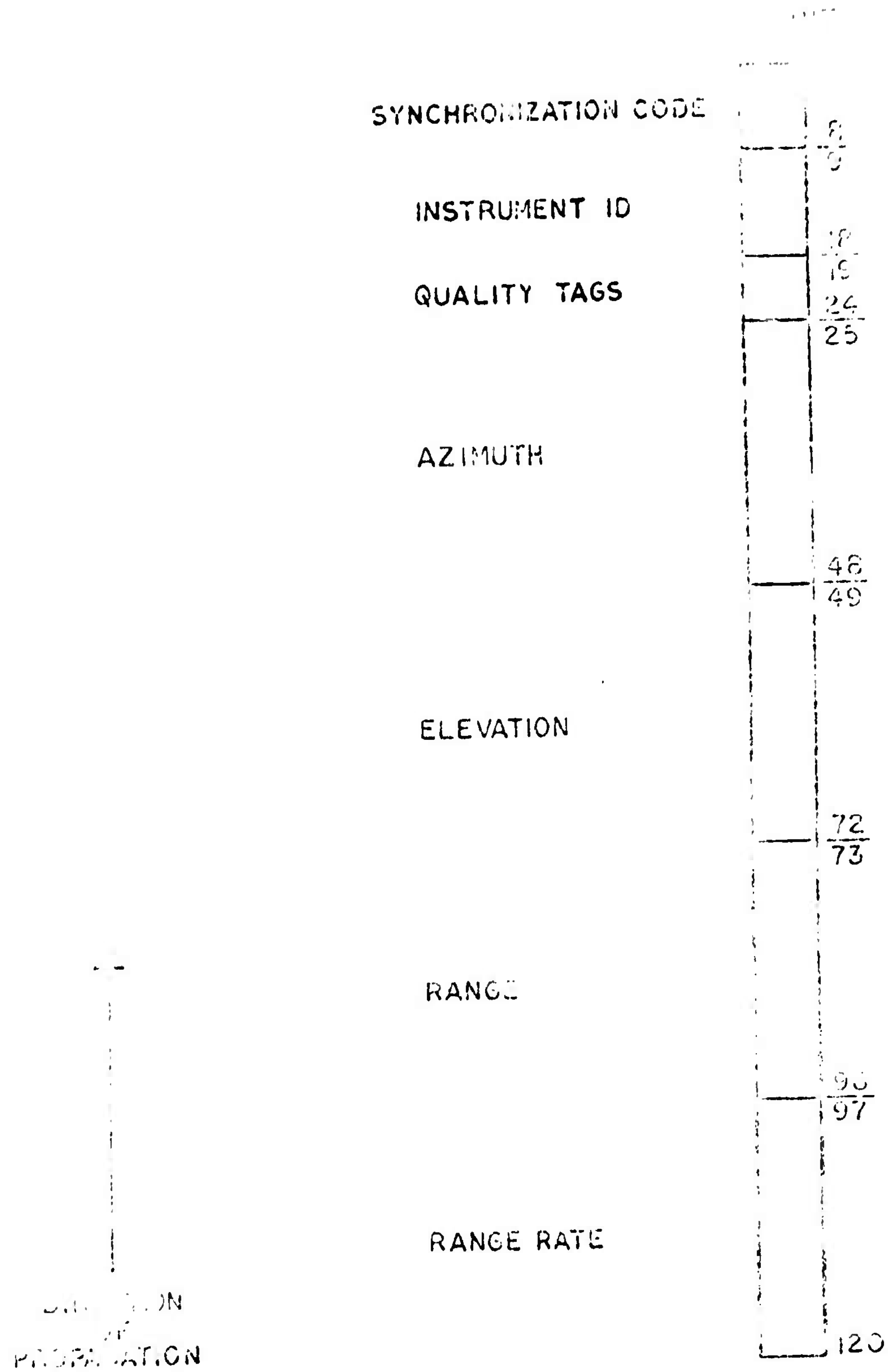


FIGURE [illegible]
TYPICAL MESSAGE FORMAT

Cartesian coordinates of the target (X, Y, and Z) can be inserted in place of the range, azimuth, and elevation data fields. These data fields (X, Y, and Z) will be right adjusted in each particular field with the LSB weighting equal to one yard. The MSB will be the sign bit.

c. Sampling Rate: A basic sampling rate for data transmission for real-time purposes was selected as 20 samples-per-second. Although this sampling rate exceeds the rate requirements of most objects under test at YPG at the present time, the ability to accommodate rates up to 20 samples-per-second is believed to be beneficial, particularly if any-real-time data requirements on high performance vehicles, such as missiles, arise in the future. For the planned real-time data system, the sampling rate will be input to the computer at 20 samples-per-second, but will be average out and computed at a 5 samples-per-second rate.

d. Timing and Synchronization: Timing and synchronization of the data transmission system will be accomplished by means of the standard IRIG timing system presently in use by addition of components required at the point of generation to insure synchronization of the data transmission system.

SYSTEM COMPONENTS

SITE DATA HANDLING EQUIPMENT

Site data handling equipment will consist of a time code translator/generator, data formatter, and modem. This site equipment will provide the necessary time correlation and synchronization required by the computer. The modem will be a 1200/2400 bps unit and, in conjunction with the data formatter, will provide the basic data rate of 20 samples-per-second to the computer.

TIMING

Modernization of the YPG timing generation system is highly desirable but not required. The present time code generator is not capable of maintaining accurate time synchronization with other ranges, such as WSMR, due to instability of the internal oscillator. A high-precision oscillator, a LORAN C radio receiver, and a stand-by power supply for critical portions of the time generation system should be installed at the master timing station. These new items will be the basic building blocks of a modern timing generation station and will provide stable, dropout-free synchronization.

COMPUTER AND DISPLAY

The computer problem was discussed at length in the paragraph on existing equipment, in which it was concluded that the EMR 6130 computer was adequate for the immediate job. All that is required to make this computer fully useable is procurement of a suitable computer-modem interface unit, including software, and the software for the real-time computation problem. Since personnel may have a determining influence on the success of the overall task, consideration is also given to this area. Each of these areas are discussed below:

a. Computer Hardware: Procure a unit to interface with data modems from the required sites, utilizing hardware from the EMR standard product line, and add this equipment to the existing maintenance contract.

b. Computer Software: Investigate the possibility of using the EMR real-time executive monitor to control processing priorities. If the EMR system is too complex or time consuming, a simple executive system can be developed to operate under the batch monitor. If the latter alternative is chosen, some work will have to be done in rerouting system error exit routines. According to YPG requirements, the system need not be made extremely failsafe in that we will not be dealing with safety or unmanned vehicle control. The multiple-station space position can be written in FORTRAN, as well as the filter and necessary display routines. Assembly language programming will be required for real-time input and output plus what is necessary for executive control. Because of the possibility of multi-programming existing real-time telemetry work with the display calculations, additional sophistication of the executive software may be required. A simplified flow-chart for the real-time cinetheodolite solution is shown in Figure 4.

c. Personnel: Steps should be taken to staff a permanent real-time software group of at least three persons with assembly language programming experience and training in basic mathematics. EMR should be able to provide executive software development guidance and necessary software training. Sufficient equipment exists presently at YPG to develop and checkout the real-time software system.

d. Displays: Procure two (two-pen, two-arm) plotting boards, six four-digit numerical displays, and ten 12-bit status displays. Interface the display equipment with hardware from the standard EMR product line and add this equipment to the existing maintenance contract.

In order to avoid possible security problems arising from connecting output lines to a computer engaged in classified work, it is recommended that a command control and display facility be established in the secure area immediately adjacent to the computer. This facility can then be used as the ground control point for the vectoring operation, and can also serve as a location for recording the voice communications required by the projects. Procurement of voice recorders, etc., necessary to support this activity will also be required.

RECEIVE: 20 SAMPLES PER SECOND
COMPUTE: 5 CYCLES PER SECOND
OUTPUT 5 TO 20 SAMPLES PER SECOND AS REQUIRED

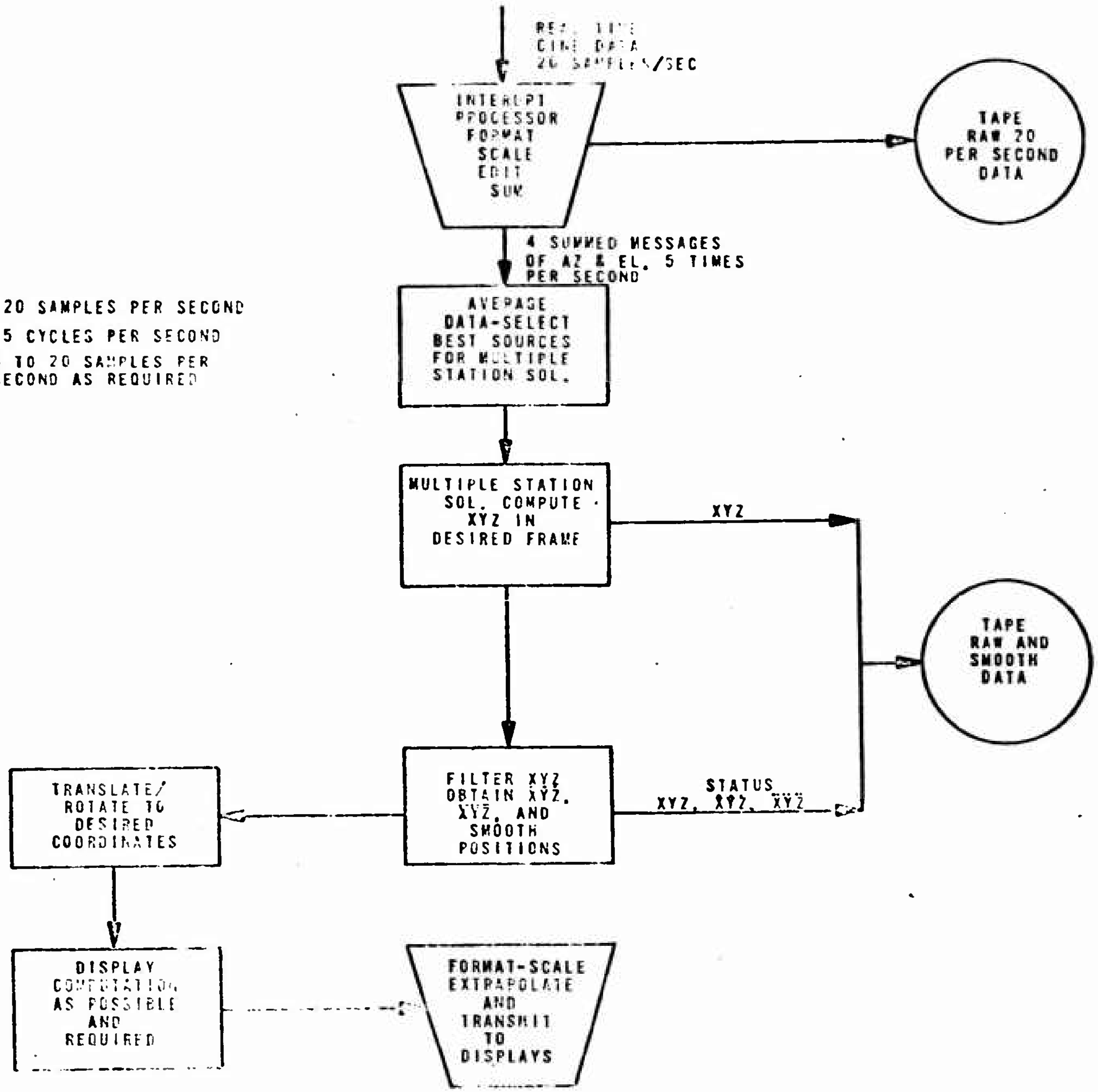


FIGURE 4 SIMPLE COMPUTATIONAL FLOWCHART FOR DISPLAY OF REAL-TIME CINETHEODOLITE DATA

DATA COMMUNICATIONS

Selection of the data communication alternative is complicated by the fact that the existing aerial cable is not adequate for the job, but it is believed that renovation may be possible. As mentioned previously, the power system and telecommunications cables are installed on common poles. The power system is a 4-wire, with one ground wire per mile. The telecommunication cable is an aluminum-sheath aerial cable of the figure 8 configuration. The telecommunication cable is ungrounded and has a 12 volt ac component to ground.

a. Dedicated Cable: This alternative consists of renovation of the aerial cable running from Site 7 to the Kofa range area, and dedication of these circuits to the data transmission job. The absence of definitive data regarding the condition of this cable renders the cost estimates somewhat speculative. The most cost-effective solution will be almost entirely dependent on the cost of cable renovation. The estimated cost of this alternative is as follows:

Modems (Data Sets) 6 ea		$14,850
Line Amplifiers 18 ea		12,000
Intercom System		3,500
Basic Equipment Costs	SUBTOTAL	30,350
Miscellaneous (10% Basic)		3,035
Spares (7% Basic)		2,124
Installation & Engineering (100% Basic)		30,350
Cable Renovation		15,000
	TOTAL	$80,859

b. Cable Carrier and Existing Plant: This solution makes maximum use of existing cable plant. However, the existence of the 6-12 volt ac component on the cable and lack of high frequency filters in the power lines reduces the probability of success. Estimated cost is as follows:

Modems (Data Sets) 6 ea		$14,850
Carrier, 47A 24 channel		16,000
Power System (Carrier) 2 ea		4,000
Repeaters, Carrier, 2 ea		4,000
Intercom System		3,500
Basic Equipment Cost	SUBTOTAL	42,350
Miscellaneous (10% Basic)		4,235
Spares (7% Basic)		2,964
Installation & Engineering (100% Basic)		42,350
Quonset Hut Renovation		4,000
Cable Renovation		15,000
	TOTAL	$110,899

c. Cable Carrier Via Installation of Cable to Castle Dome: This solution utilizes that section of the existing cable plant wherein the existing ac voltage component is a minimum. Further, the addition of the proposed cable length will have a marked effect on the long-range telecommunication cost analysis. Estimated costs are as follows:

Cable, Aerial 6.5 Miles Installed 15,000/Mile	SUBTOTAL	$97,500
Carrier, 47A 24 channel		16,000
Power System (Carrier) 2 ea		4,000
Repeaters, Carrier, 4 ea		8,000
Modems (Data Sets) 6 ea		14,850
Intercom System		3,500
Basic Equipment Cost Less Cable	SUBTOTAL	46,350

Miscellaneous Equipment (10% Basic)		$ 4,635
Spares (7% Basic)		3,244
Installation & Engineering (100% Basic)		46,350
Quonset Hut Renovation		4,000
Cable Renovation		5,000
	TOTAL	$207,079

d. Microwave and Cable: This solution utilizes that section of the existing cable where the ac voltage component is less than 0.5 volt. The microwave would bypass the cable section passing through the high voltage power fields. Estimated costs are as follows:

Diversity Microwave 4 ea		$20,000
Tower, 150 ft guyed		4,000
Antenna 4 ft Dish, 2 ea		800
Multiplex, VF, 24 channel, 2 ea		50,000
Modems (Data Sets) 6 ea		14,850
Intercom System		3,500
Basic Equipment Costs	SUBTOTAL	93,150
Miscellaneous Equipment (10% Basic)		9,315
Spares (7% Basic)		6,520
Installation & Engineering (100% Basic)		93,150
Quonset Hut Renovation		4,000
Cable Renovation		5,000
	TOTAL	$211,135

For the purposes of this study and at this point in time, it will be assumed that the least costly alternative is feasible. Additional effort will be expended to better define cable condition and cost of renovation. A thorough economic analysis will be made and a solution recommended subsequent to these studies.

SENSORS

a. Unacceptable Alternatives:

(1) MPS-25 Radar: The MPS-25 radar is considered an unacceptable alternative because of the difficulties of obtaining Z data satisfying project requirements when the aircraft is below 400 feet in altitude. The radar can vector the helicopter to the firing line with a nominal countdown as required, and can also provide a digital readout of helicopter position within three seconds after the firing signal is received at the radar site. However, the radar cannot provide adequate real-time altitude data below 400 feet. Even if the radar were relocated closer to the firing lines, such as at Site 7, there would still be problems with ground clutter, multipath and rotor modulation of the signals. The post flight accuracy of ±3 meters cannot be met by the MPS-25 radar. Computer smoothing of the radar data, while making the data apparently more precise, could introduce bias into the result because of the multipath problem.

(2) M-33 Radar: The M-33 radar cannot provide the real-time altitude data nor post-flight data required for the reasons given above.

(3) Nike Ajax/Hercules Radar: A Nike Ajax or Nike Hercules tracking radar could be adapted to provide the required vectoring and immediate post-flight position data with a probable accuracy of ±10 meters. Expert opinion holds that the Hercules radar would probably be better suited to solve the problem than the MPS-25. However, the problems of low-altitude tracking and rotor modulation also exist for the Nike radars. The post-flight data accuracy requirements of ±3 meters could not be met by either of these radars.

(4) DOVAP: A DOVAP system with proper system geometry could meet the vectoring requirements, the two-minute post-flight requirements, and the post-flight data accuracy requirements. The on-board transponder antenna would require shielding to prevent rotor modulation of the signals. It would be necessary for a new system to be installed in the 900 megahertz band because of frequency allocation problems. Although it is theoretically possible to apply bias frequency in order to keep the cycle count away from zero, it is the opinion of the project team that implementation in a practical and operating system may prove difficult and that there exists a substantial risk in development of such a system. A further constraint is the fact that it would require essentially three systems to achieve proper systems geometry because of the 3 flight paths under consideration.

Finally, the cost of such a system is estimated to exceed $1,000,000 for the DOVAP system alone, and does not include data links, modems, computer interface, display and all the other peripherals of the real-time data system.

b. Acceptable Alternatives:

(1) Laser Tracking System: The Sylvania Division of General Telephone and Electric has proposed to Headquarters, USATECOM, a Precision Aircraft Tracking System utilizing a pulsed laser for this instrumentation application. According to the proposal, the system will produce data accurate to within 1 foot at slant ranges of 30,000 feet and angular data accurate to 0.1 milliradian at the same range. These accuracies are sufficient to meet the real-time and post-flight data requirements of all projects currently active at YPG. The system is only partially developmental in that a similar item, with somewhat less accuracy, was designed and produced for McDonnel-Douglas, and is currently being used in the DC 9 aircraft evaluation program being conducted at the Marine Air Station, Yuma, Arizona. There is not sufficient data at this time to properly assess the validity of the manufacturer's claims. It is known that the system has never been calibrated using a primary standard on moving targets, and that the dynamic accuracies quoted in the proposal are, at the moment, citations of precision rather than accuracy. The system accuracy has been proven on static targets. For the purposes of the economic analysis to follow, it will be assumed that the system will have the performance required for this problem. The cost will be assumed to be $600,000.

(2) Low Accuracy Cinetheodolite Modifications. The charge to the task team by Headquarters, USATECOM, specified that "cinetheodolite modification will be limited to the addition of precision synchro gear boxes and encoders to provide low accuracy real-time data." Inspection of Tables IV, V, and VI shows that the minimum residual to be expected from the sites tested in the MSPARC simulation of the Cibola range occurs for the combination of Stations 7, 9, and 12 in all cases. The angular variability assumed in this simulation was 60 arc seconds. The low accuracy cinetheodolite modification promises to provide an angular variability of approximately 300 arc seconds, so that the minimum average residual for the optimum station configuration will be 10.75 meters for the Cheyenne program, 8.25 meters for the 2.75 program, and 7 meters for the moving target range. Performance on the Cheyenne program can be improved to 10 meters by adding Station 8 to the 7, 9, and 12 combination. However, the increase in performance is deemed to be insufficient to justify the expense of an additional sensor for the real-time problem. Using the low accuracy encoders, the system cannot provide the post-flight data report without reading the film and reducing the data in a post-flight mode. The cost of this alternative, exclusive of all costs common to this alternative and the high accuracy cinetheodolite modification alternative, is estimated to be $25,000 per instrument, for a total of $75,000.

(3) High Accuracy Cinetheodolite Modification: An alternative to the cinetheodolite modification specified by TECOM consists of the installation of precision shaft-angle encoders providing data equivalent to the current coded-dial data, digital recording of these data on the film format, procurement of a compatible film reader, installation of one-man aided tracking units, and other work necessary to bring the Model C Contraves to a functional equivalent of the Model F Contraves. Using the data generated and displayed in Table I in the MSPARC simulation of the Cibola range, the data presented in Tables IV, V, and VI are derived. The angular variability of 60 arc seconds for total system error consists primarily of the operator's tracking error as verified by the tests described earlier in this report. It can be seen by examination of these three tables that the ±3 meters post-flight data requirement of both the 2.75 program and Cheyenne program can be met by a combination of Stations 7, 9, and 12 in real time, thus obviating the need for the film reading process for generation of the post-flight data report. The costs incurred through the high accuracy cinetheodolite modification consists of $80,000 per instrument, and $100,000 for a compatible film reader, for a total first cost of $340,000.

c. Economic Analysis: It is evident that all three of the acceptable alternatives will produce the vectoring data required of the real-time data system. One might be tempted at this point to select the least expensive solution to this particular problem. However, it is evident that, due to the workload and the current film reading capability of YPG, serious difficulties may arise in the future because of the limited ability of YPG to read film with their present equipment. It is therefore relevant to consider the applicability of these alternatives to the solution of a problem of providing the post-flight data report, and to establishing which of these alternatives can produce that data report for minimum cost. To this end the following analysis is applicable:

Let

P_j = first cost of alternative, j = 1, 2, 3

Q_j = annual operating cost of alternative, j = 1, 2, 3

j = 1, Laser Tracker

j = 2, Low-Accuracy Cinetheodolite

j = 3, High-Accuracy Cinetheodolite

From the above,

P_1 = $600,000

P_2 = $ 75,000

P_3 = $340,000

Estimates of operating costs for all three systems are based on the following assumptions:

100 standard missions/week

Field operators are committed full-time

Labor rates of \$3.00/hour

Labor costs are avoidable, i.e., personnel may be productively employed in some other capacity

All real-time data system costs other than the first cost and operating costs of the sensor alternatives are common, and hence irrelevant to the analysis.

Maintenance costs of all systems are roughly equivalent.

Operating costs are computed as follows:

Laser Tracker:

2 operators required

2,080 hours/year

$Q_1 = 2 \times 2{,}080 \times 3 = \$12{,}480/\text{year}$

Low Accuracy Cinetheodolite:

6 trackers required

6 film-readers required

$Q_2 = 12 \times 2{,}080 \times 3 = \$74{,}880/\text{year}$

High-Accuracy Cinetheodolite:

3 trackers required

2,080 hours/year

$Q_3 = 3 \times 2{,}080 \times 3 = \$18{,}720/\text{year}$

The economic service life of the three alternatives are assumed to be 8 years since they parallel ADPE-type equipment. Further, an interest rate of 10% is assumed in accordance with AR 37-13. Since there is no "income" to be derived, a minimum cost technique is indicated. Table VII displays the computations performed.

TABLE VII. ECONOMIC ANALYSIS, SENSORS

	LASER	LOW-ACCURACY CINETHEODOLITE	HIGH-ACCURACY CINETHEODOLITE
A. First Cost	$600,000	$ 75,000	$340,000
B. Operating Costs	12,480	74,880	18,720
C. Discount Factor Uniform Series Present Worth, i = 10% n = 8 years	5,597	5,597	5,597
D. Present Worth of Operating Cost B x C	69,850	419,103	104,775
TOTAL PRESENT WORTH, A + D	669,850	494,103	444,775

The discounted cash-flow analysis above indicates that the high-accuracy cinetheodolite solution holds a slight edge over the low-accuracy modification. There are several intangibles that tend to favor the high-accuracy alternative. They are:

(1) A portion of the existing cinetheodolite system is completely renovated, modernized, and provided with an expanded production capability.

(2) High-volume production of data to an accuracy of ± 1 meter is possible by virtue of the semi-automatic film reader.

(3) For helicopter testing, installation of a light source on the test aircraft and digitized TV-type trackers to the cinetheodolites would provide ± 1 meter data without recourse to film reading. This growth capability could be realized for as little as $40,000 total cost.

(4) Three-shift operation of the existing film readers would be avoided.

The principal disadvantage lies in the facts that the high-accuracy cinetheodolites will be more complex, require more training and maintenance, and YPG will have two types of cinetheodolites in use, thus requiring some software modification when the two types are used in a single reduction.

RECOMMENDED SOLUTION

Based on the preceding analysis, the WSMR task team recommends the high-accuracy cinetheodolite solution. Figure 5 depicts a representation of this solution, and also indicates the recommended manner of implementation. A turn-key contract is recommended, with the prime contractor awarding two or three subcontracts. Three are assumed for the cost estimate which follows.

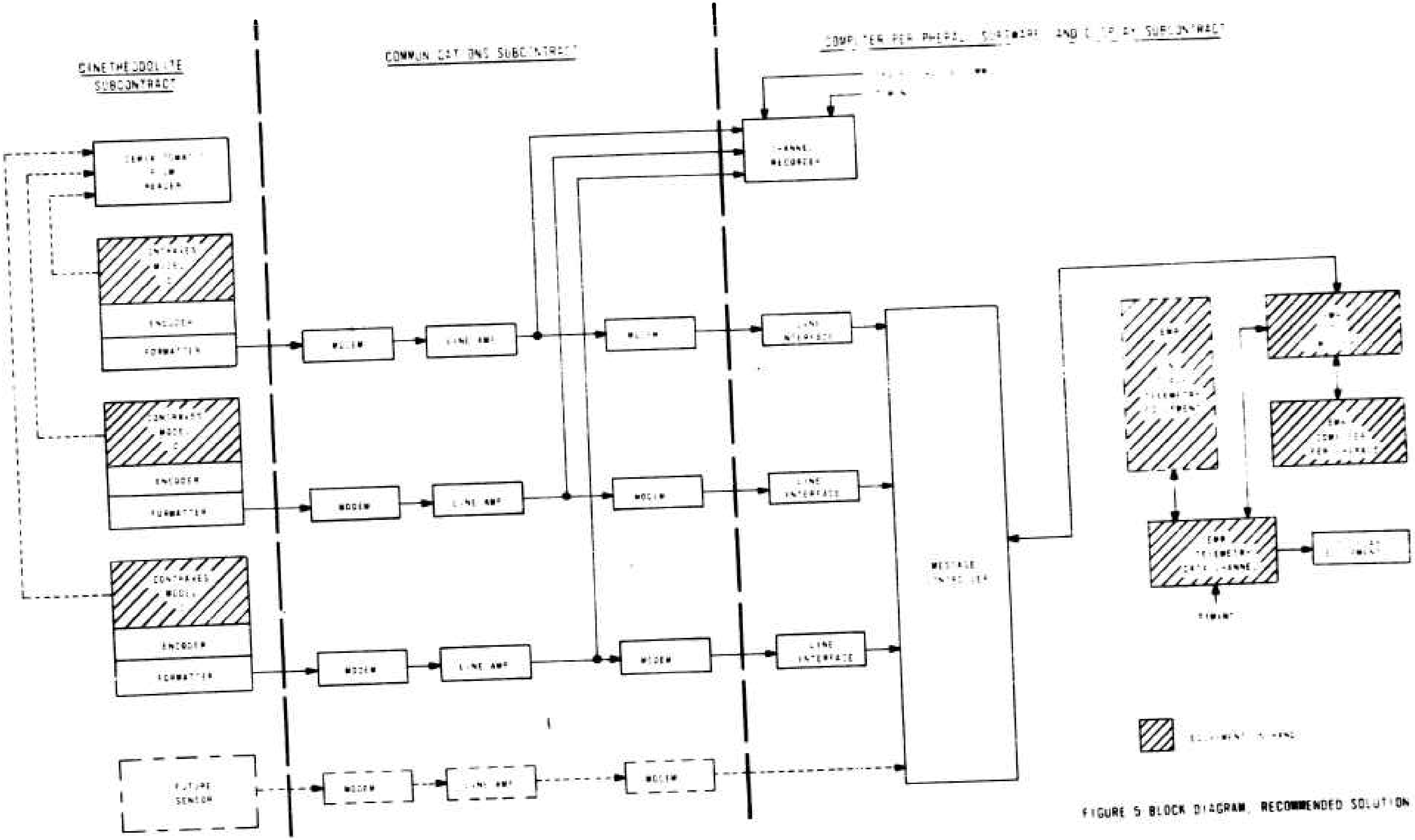


FIGURE 5 BLOCK DIAGRAM, RECOMMENDED SOLUTION

COST ESTIMATE

CINETHEODOLITE SUBCONTRACT

ITEM		UNIT COST	TOTAL COST
Install 19-bit encoder system		$ 60,000	$180,000
Refurbish cinetheodolite		5,000	15,000
Install new slip-ring assembly		1,650	4,950
Install one-man aided-tracking unit		12,000	36,000
Freight, two ways		1,600	4,800
Semi-automatic film reader		102,000	102,000
Freight		2,400	2,400
	SUBTOTAL		$345,150
Installation/test		4,000	12,000
	TOTAL		$357,150

NOTE: Estimate based on recent information and includes all overhead G&A and profit. Subcontractor is responsible to the prime contractor for installation, test, and documentation of his equipment. Off-shore procurement costs are estimated at $114,600.

COMMUNICATION SUBCONTRACT

Cost of the communication subcontract is $85,900, as itemized previously and includes installation, test, and documentation.

COMPUTER PERIPHERAL, SOFTWARE, AND DISPLAY SUBCONTRACT

Costs for this subcontract are estimated as follows:

a. Hardware Items:

(1)	Data communications message controller	$ 13,700
(2)	Line interface chassis	3,300
(3)	Line interface units	16,000
(4)	Engineering charge, line interface units	3,000
(5)	14-channel tape deck	20,000
(6)	Digital to analog converter	4,000
(7)	Converter boards	1,600
(8)	Plotting boards, 2 ea, 30 x 30	36,000
(9)	Decimal displays, 4 ea	10,000
(10)	Interface to telemetry data channel	1,000
(11)	Miscellaneous	3,000
	TOTAL	$111,600

b. Software:

Two man-years at $20,000 ea — $40,000

c. Total Costs:

Software		$ 40,000
Engineering Burden at 130%		52,000
	SUBTOTAL	92,000
G&A at 10%		9,200
		101,200
Profit at 7%		7,084
	SUBTOTAL	108,284
Hardware*		111,600
	TOTAL	$219,884

*Hardware costs are derived from catalog prices of applicable equipment and includes all burden, G&A, and profit.

PRIME CONTRACT COSTS

Systems management, 1 man-year at $25,000		$ 25,000
System engineering, 2 man-years at $15,000		30,000
Installation services, 2 man-years at $10,000		20,000
Engineering burden at 130%		71,500
Installation burden at 40% (installation)		8,000
		154,500
Cinetheodolite subcontract		$357,150
Communications subcontract		85,900
Computer system subcontract		219,684
	SUBTOTAL	$817,434
G&A at 10%		81,743
	SUBTOTAL	$899,177
Profit at 7%		62,942
	TOTAL	$962,119

SCHEDULE

Because of some uncertainties in the plan at this time, particularly the communications alternative and ADPE approvals, a detailed schedule is not too meaningful. However, based on the recommended solution and TECOM approval by 1 July 1971, the following list of milestones will form the constraint on the detailed schedule:

Issue report	25 May 71
TECOM approval	1 Jul 71
Draft D&F	7 Jul 71
Draft PD	7 Jul 71
Draft request for ADPE	7 Jul 71
Prepare solicitation	14 Jul 71
D&F approval*	1 Aug 71
ADPE approval*	1 Aug 71
SPRB approval*	7 Aug 71
Modify solicitation	12 Aug 71
Issue solicitation	14 Aug 71
Bidders briefing (at Yuma)	28 Aug 71
Receipt of proposals	14 Oct 71
Proposal evaluation	14 Nov 71
Negotiations	1 Dec 71
Contractor selection	7 Dec 71
Prepare contract	14 Dec 71
SPRB contract approval*	21 Dec 71
Contract award	23 Dec 71
Design review	7 Feb 72
Installation	1 Oct 72
Acceptance test	28 Nov 72
Turnover	14 Dec 72

*This is a very tight schedule which is extremely sensitive to the time required to obtain the requisite approvals. Hand-carry of <u>all</u> higher-headquarters documentation is assumed.

APPENDIX D

SURVEY DATA, HORIZONTAL AND VERTICAL CONTROL

1. CINETHEODOLITE TARGETS; PROJECTION - TRANSVERSE MERCATOR; ARIZONA WEST ZONE

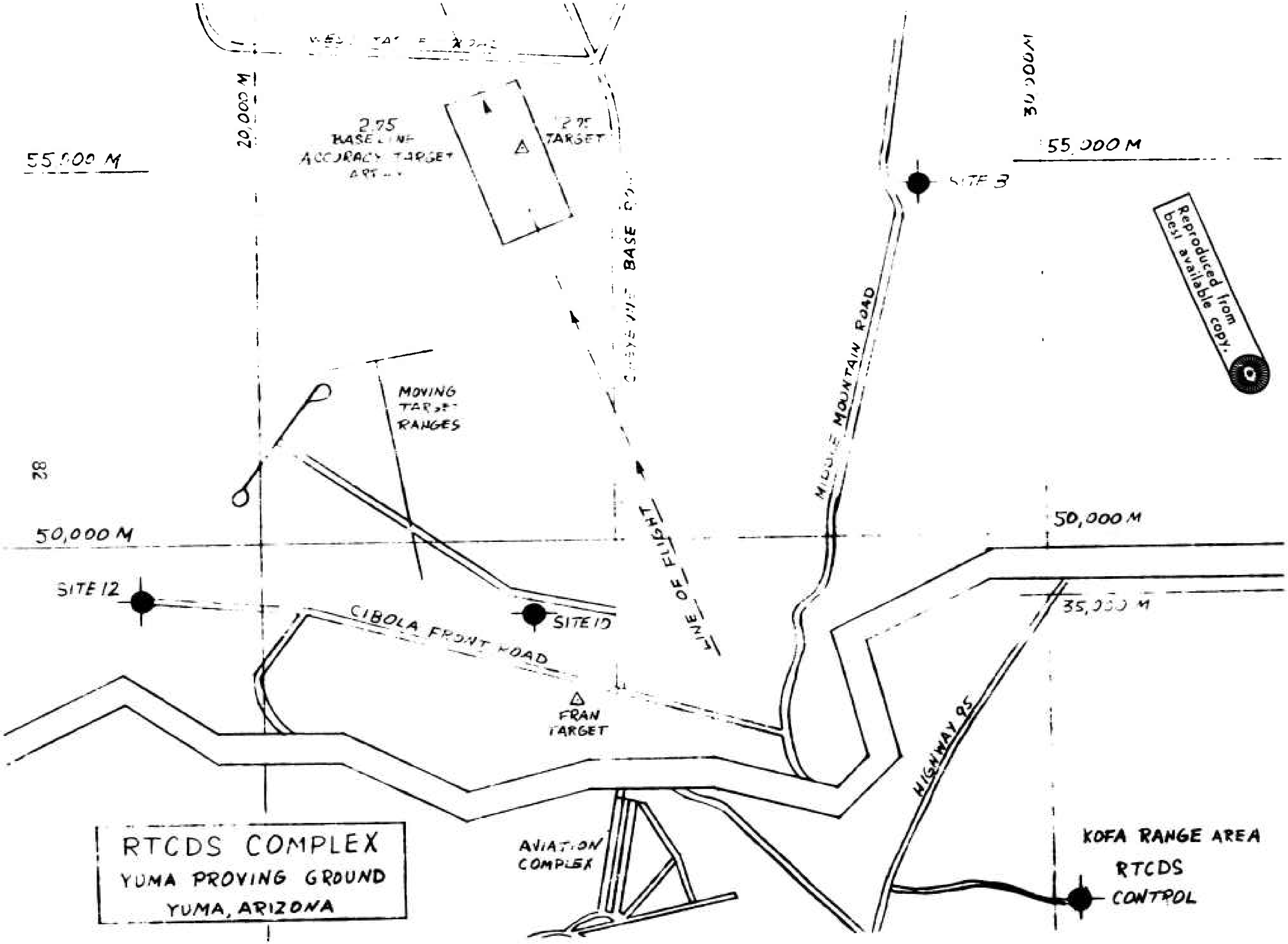
		AZIMUTH (FROM GRID NORTH)			VERTICAL ANGLES			SLOPE DISTANCE
		DEG	MIN	SEC	DEG	MIN	SEC	(METERS)
a. Contraves (RTCDS) Site 8								
(1)	Board	359.8375	50	15.0	000.1021	06	07.4	1214.26
(2)	Pole	044.7239	43	26.2	001.0330	01	58.7	1184.67
(3)	Pole	141.8528	51	10.1	000.3348	20	05.3	0952.49
(4)	Pole	179.9658	57	57.1	359.3592	21	33.2	1204.76
(5)	Pole	225.0606	03	38.3	358.8756	52	32.0	1229.83
(6)	Pole	270.0367	02	12.2	359.1305	07	49.7	1206.41
(7)	Pole	314.9530	57	10.9	359.6366	38	11.7	1205.60
b. Contraves (RTCDS) Site 10								
(1)	Board	003.5791	34	44.9	000.2833	16	59.8	1306.96
(2)	Pole	048.5556	33	20.2	000.6748	40	29.2	1113.21
(3)	Pole	093.5398	32	23.3	000.8024	48	08.8	1229.63
(4)	Pole	131.3830	22	58.7	000.5066	30	23.6	1283.89
(5)	Pole	183.4808	28	51.0	359.8288	49	43.7	1086.01
(6)	Pole	220.4009	24	03.1	359.4766	28	35.6	1306.45
(7)	Pole	273.3775	22	39.1	359.3832	22	59.6	1408.23
(8)	Pole	318.7106	42	38.3	359.8326	49	57.4	1099.71
c. Contraves (RTCDS) Site 12								
(1)	Board	359.0635	03	48.5	000.8879	53	16.4	1295.13
(2)	Pole	043.9890	59	20.5	000.5461	32	46.1	1243.21
(3)	Pole	089.0890	05	20.6	000.2940	17	38.3	1222.28
(4)	Pole	134.3688	22	07.5	359.8936	53	37.1	1176.54
(5)	Pole	191.0545	03	16.1	359.1688	10	07.9	0918.61
(6)	Pole	212.8307	49	50.4	359.4903	29	25.1	1124.23
(7)	Pole	260.5142	30	51.0	359.8244	49	27.9	0874.27
(8)	Pole	313.9086	54	30.9	000.4246	25	28.6	0815.32

2. CINETHEODOLITE SITES AND RTCDS TARGETS

	X (YPG METERS)	Y (YPG METERS)	Z (METERS ABOVE MSL)
a. Contraves Site 8	28207.734	54796.017	230.042
b. Contraves Site 10	23413.074	49304.478	146.238
c. Contraves Site 12	18417.588	49325.331	109.442
d. "2.75" In. Target	23431.40	55221.26	200.76
e. "Fran" Target	23977.45	47990.24	160.57

APPENDIX E

MAP, RTCDS COMPLEX


RTCDS COMPLEX
YUMA PROVING GROUND
YUMA, ARIZONA
55,000 M
20,000 M
2.75
BASE LINE
ACCURACY TARGET
2.75
TARGET
30,000M
55,000 M
SITE 3
BASE
MIDDLE MOUNTAIN ROAD
MOVING
RANGES
LINE OF FLIGHT
50,000 M
50,000 M
SITE 12
SITE 10
CIBOLA FRONT ROAD
35,000 M
FRAN
TARGET
HIGHWAY 95
AVIATION
COMPLEX
KOFA RANGE AREA
RTCDS
CONTROL

APPENDIX F

REPORT, SYSTEM ENGINEERING TEST PLANS AND PROCEDURES, WITH CHANGES

GOERZ
INLAND
SYSTEMS DIVISION

301 ALPHA DRIVE, PITTSBURGH, PA 15238 • TEL 412-782-3516 • TWX 710-664-2082

December 28, 1973

Procurement Directorate
STEWS-PR-A, Building 1830
White Sands Missile Range
New Mexico 88002

Attention: R. Swisher

Reference: Contract DAAD07-73-C-0023

Subject: Data Item 000114, System Engineering Test Plans and Procedures

Gentlemen:

The changes and clarifications to the subject item listed in your letter of 20 December 1973 are acceptable to Goerz-Inland Systems Division and will be incorporated by amendment. A copy of your letter is attached.

As a result of discussions with K. Bellinger, we will also delete the following from item 000114:

P8 Par. 1, After "... from the photographic record"
Delete "... with correction for the tracking error".

P12 Par. 1, After "... the flight test will be assessed"
Delete "... with boresight or tracking error correction applied."

Sincerely,

GOERZ-INLAND SYSTEMS DIVISION

George A. Economou
Vice President

GAE/joc

EN: White Sands Letter of 20 December 1973

CC: DCAS
DBA

DEPARTMENT OF THE ARMY
US ARMY WHITE SANDS MISSILE RANGE
WHITE SANDS MISSILE RANGE, NEW MEXICO 88002

Mr. Swi... r/.

S...S-PR-A

1973 DEC 20

Goern-Inland Systems Division
ATTN: Mr. Economou
301 Alpha Drive
Allegheny County
Pittsburgh, PA 15238

Gentlemen:

Reference Contract DAAD07-73-C-0023, request confirmation that the following changes/clarifications will be incorporated into Data Item 000114, System Engineering Test Plans and Procedures, dated 16 November 1973:

a. Reference second paragraph of page 6:

Direct and dump zenith angles will agree approximately unless there is a cinetheodolite malfunction.

b. Reference third paragraph of page 6:

The site 10 zenith angle is the total zenith angle.

c. Reference bottom of page 7:

The term "total zenith angle refraction error' is defined in paragraph 4 of page 10.

d. Reference second paragraph of page 11:

700 feet above MSL is approximately 100 feet above terrain across center of target area.

e. Reference formula given in the middle of page 12:

Change the formula to read $H_{corr} = Hc + R(\theta_R - \theta_o)$ with the limitation that for negative values of $R(\theta_R - \theta_o)$, H_{corr} shall not decrease the incentive cutoff of 3 meters and that the incentive schedule between 5 and 3 meters shall compress linearily as the 5 meter point is reduced toward 3.

Sincerely yours,

HERBERT C. CARLSON
Contracting Officer

GOERZ INLAND
SYSTEMS DIVISION

November 16, 1973

CONTRACT DAAD07-73-C-0023

ITEM 000114

System Engineering Test
Plans and Procedures

TP-964A

Description and Purpose: To establish methods, procedures, test sequence and schedules to be utilized in the testing of the real time Cinetheodolite Data System.

Par. (4.2) Test Plan (PD-2221-72) . . . . "The plan shall specifically include, but not be limited to, plans for the following:

(a) Static Pointing Accuracy in 3.1.1

(b) Dynamic Pointing Accuracy in 3.1.1

Section I, Paragraph 2, Payment for Accuracy greater than 5 meters (Contract DAAD07-73-C-0023).

KOLLMORGEN CORPORATION

SUMMARY:

The test plan will verify the accuracy of the system and verify the system operation. Execution of the systems test plan is based upon successful completion of the subsystem engineering tests (000115,000116) and the use of operating procedures described in the operating manuals of the various subsystems which are individually specified as separate line items.

The system test plan sequence is as follows:

1. Static Accuracy Test (3.1.1 PD2221) - - 3 December
    a. Real Time
    b. Post-flight Operating Mode
2. Dynamic Accuracy Test (3.1.1 PD2221) - - 3 December
    a. Real Time
    b. Post-flight Operating Mode.
3. Dynamic Accuracy Greater Than 5 Meters - - 3 December (Section I, Par. 2, DAAD07-73-C-0032)

1. TEST PLAN BASIS

The test plan and operating procedures have been derived from the assumption that the largest sources of error in the Real Time Cinetheodolite Data System will be the refraction and tracking errors rather than the instrumental or data reduction errors. The refraction assumption follows from the observation the cinetheodolite elevation angles will be between -15 arc minutes and +1 degree when the target helicopter is within the accuracy target array area.

The concern with refraction error is increased by the almost grazing incidence of the line of sight. For all three stations, the line of sight from the cinetheodolite to the target is only 10 to 20 arc minutes above the terrain. As Bomfords' "Geodoesy" states, "This fact . . . . . makes it essential to observe reciprocal angles. One way observations are of little value."

As an example, using Bomfords' data, if, we assume an adiabetic gradient for dry air and a non-grazing but near horizontal line of sight, we find 0.3 meter error over 5 kilometers. For grazing lines of sight, Bomford states, "A graze 50 ft. long through such a gradient would produce a curvature of 1 arc second." A 5 kilometer graze would produce a curvature of 6 arc minutes or 9 meters error.

The cases are not cited to establish that refraction will necessarily degrade the RTCDS but that refraction calibration is vital and that care must be exercized to minimize the effects of refraction. To attempt a software correction based on atmosphere measurements is impractical since topography, wind velocity and the duirnal variation have a primary effect on refraction.

In optimizing, topography is clearly excluded from the optimization. Wind velocity and time of operation are the only variables available. Ironically, the wind and time conditions which minimize refraction also minimize resolution and image quality. For image quality, ideal conditions are stable atmospheric gradients which occur with low wind velocity and stable temperatures. There conditions occur most often after sunrise and before sunset when refraction errors are maximized.

Bomford (P. 164) has tables which show refraction errors of 110 arc seconds at 0600 decreasing to less than 10 arc seconds between 1130 and 1500. Eddy conductivity variations because of wind velocity, show a 30 arc second error at zero wind velocity at 1130 with a drop to zero refraction error with higher velocity.

Even with optimum time of day and wind velocity, consistant RTCDS performance will not be possible without the refraction calibration target. A practical and simple refraction calibration is possible because of the short, (2 kilometer) trajectory and the low 100 ft. altitude of the target vehicle. This allows the use of a 50 ft. calibration target in the center of the target range. Comparison of the real time observed elevation angles with the elevation angles determined from the first order survey will allow the software operator to insert a refraction error correction for each cinetheodolite station.

The calibration target is intended for use solely with targets at extremely low elevation angles, less than one degree. It is strongly recommended for operational use by the Government.

The static test target located at the Fran marker, affords a second opportunity for further refining refraction error test and calibration. The Fran location was selected as the static test target because its proximity to Site 10 minimizes refraction errors. The approximate target elevation angles and ranges from Site 10 are:

Calibration Target	28 minutes	5.8 Kilometers
Fran Static Target	30 minutes	1.4 Kilometers

The azimuth angle between the two targets from Site 10 is approximately 160 degrees.

This geometry will allow the monitoring of refraction error by observing both the static and the calibration target from Site 10.

The operator would use the main optics to site the Fran static target and calibration target. The siting for both targets will be made in both the direct and dump or plunged modes. The calibration target at 5.8 Kilometers will have between 4 and 16 times the refraction error that will be observed for the static target at 1.4 Kilometers. From Site 10, the sum of the Zenith angle to the static target and Zenith angle to the calibration target shall be the total Zenith angle. These observations of the Site 10 total Zenith angle, if the direct and dump modes agree, will be an assessment of refraction error in the determination of Z. This is based on the use of factory tested encoders of better than 2-second accuracy and resolution and the measurement at low elevation angle where orthogonality error is not a significant error contribution.

The difference between the observed Site 10 Zenith angle and the Site 10 Zenith angle determined from the Site 10 instrument location and the first order survey determination of the same total Zenith angle will be a practical estimate of the refraction error in the siting of the static target from Site 8 and Site 12.

This is based on the assumption that the total Zenith angle refraction error will be predominantly the result of the longer 5.8 Kilometer path to the calibration target rather than the 1.4 Kilometer path to the static target from Site 10. The assumption here is that refraction will be proportional to the square of the slant range. The Site 10 to static target Zenith angle refraction error because of the 1.4 Kilometer path will be only 5% of the total Zenith angle refraction error.

In the triangulation determination of Z for the static target, the line of sight from Site 10 will be deviated a negligable amount because of the 1.4 Kilometer distance. The line of sight from Site 12 to the static target, 5.8 Kilometers away, will be deviated by refraction by an angle almost equal to the Site 10 total Zenith angle. Site 8, with an 8.2 Kilometer slant range, will have a refraction error approximately double the refraction error observed in the Site 10 total Zenith angle.

With this reasoning, it is proposed that the observed Site 10 total Zenith angle refraction error be used to correct the Z or height tolerance if the X and Y determination of the static target is with the specified ±½ meter. If Θ is the observed Site 10 total Zenith angle refraction error, R_8 is the slant range from Site 8 to the static target and R_{10} is the slant range from Site 10 to the calibration target; then T_{corr}, the adjusted vertical tolerance shall be:

$$T_{corr} = \pm(½ \text{ meter} + \Theta R_{10} \frac{R_8^2}{R_{10}^2}) = \pm(½ \text{ meter} + 2\Theta R_{10}).$$

The System Incentive Accuracy has been designed to approximately nullify the effect of refraction error in determination of the incentive award. The first order elimination occurs by virtue of the evaluation which compares the real time position determination with the post-flight position determined from the photographic record with correction for the tracking error.

The error which is uncompensated is the refraction error variation between the optical axis and the target. Since an average ±82 arc second tracking error can occur even at the minimum 3 meter incentive error, a variation in the refraction error over this small angle can lead to significant error contributions. The refraction error can then vary from station to station as a function of the tracking error for each station.

The error can equal the ½ meter increments in the incentive scale. This linear increment subtends 6 to 8 arc seconds at the cinetheodolites

Since refractive anomalies can be greater than the incentive increments, it is proposed that the 3 meter incentive base be adjusted to compensate for the refraction anomalies. The test plan will include the visual and photographic observation or the separation of the calibration target and an additional crossbar within 3 meters below or above the existing target.

The actual angular length of the target separation as observed from each station shall be used to determine the refraction corrected equivalent to the Z-component of 3 meter base of the incentive standard. This correction for refractive anomalies will allow all test flights to be used for the incentive accuracy tests.

Recognizing the advantage to the contractor and the Government of operations of the RTCDS under conditions of better image quality, the contractor offers to start the accuracy tests during the early morning when image quality will be high but refraction error will also be high.

These tests, under normal operating conditions, will test the effectiveness of the refraction calibration under worst case conditions. The contractor will perform these tests for the record only if the refraction error compensation outlined above is used in assessing the static and incentive accuracy results.

2. SYSTEM SPECIFICATION DISCUSSION

2.1 STATIC TARGET

Accuracy (3.1-1C) "The system shall measure the position of a contractor selected target to an absolute accuracy of ±½ meter in both real time and post-flight operating modes."

Static target from site will be measured by real time and photographic observation with all three stations.

Orientation targets and calibration targets will be observed and photographed prior to static target measurement.

Real time position determination shall agree with first order survey static target position to accuracy of ±½ meter in the horizontal plane.

The accuracy goal of the vertical component of the static target position determination in real time and post flight shall be corrected for refraction by using the difference between observed Site 10 total Zenith angle and the first order survey determined total Zenith angle.

The corrected vertical tolerance shall be:

$$T_{corr} = \pm(\tfrac{1}{2}\text{ meter} + 20R_{10}).$$

For 0 = 20 arc seconds,

$$T_{corr} = \pm(\tfrac{1}{2}\text{ meter} + 2.10^{-4}.8.10^{3}_{m}) = \pm 2.1\text{ meter}.$$

2.2 SYSTEM DYNAMIC ACCURACY (3.1.1 (b), (a))

Target of 100 knots velocity will be tracked and measured. With fifty sequential five per second samples, real time space position data shall agree within ±½ meter with post-flight space position determination using cinetheodolite film reader to assess the photographic record without measuring tracking error. Orientation shots will be used. Calibration shots will be used only if YPG program can accomodate.

2.3 SYSTEM INCENTIVE ACCURACY (Exhibit I, Par. 2)

Target will be the Government helicopter flying at 100 knot velocity along the "Line of Flight" path designated on the Red Hill, Arizona map of PD 2221. Helicopter will maintain an altitude of 700 feet above sea level within the target rectangle area. Course and altitude corrections will be limited to the flight path prior to vehicle entry of the target rectangle. Within the rectangle, the helicopter will maintain a straight line of flight both in course and altitude.

Fifty sequential five per second samples will be used per flight test. The minimum numbers of flight tests will be sixteen (16) successful out of a series of twenty (20) on three separate days. The maximum number of flight tests will be thirty (30).

The preflight calibration sequence will include sighting and photographing with the main optics of the main calibration target and the 3 meter cross bar. "The real time and photographic determination of the 3 meter vertical length will be used to refraction correct the 3 meter incentive goal."

The correction shall be applied as follows:

The film record of the flight test will be assessed with boresight or tracking error correction applied. The orientation and calibration target shots will be used in the YPG data reduction.

If:

H_0 = 3 meters

R = range from station to calibration target

$\theta_0 = \frac{3}{R}$

θ_R = observed angle subtended by 3 meter target at site.

Then:

$H_{corr} = H_0 + \left| R(\theta_0 - \theta_R) \right|$,

where $\left| \theta_0 - \theta_R \right|$ is the maximum observed from any station.

Example:

If: $\theta_0 - \theta_R$ = 20 arc seconds = 10^{-4}

R = 7.500 meters (Site 12)

Then:

H_{corr} = 3 meters + $\left| 7500 \ (10^{-4}) \right|$ meters

= 3.75 meters.

3. TEST PROCEDURE

3.1 All stations call in (0730)
Verify Intercom Operation

3.1.2 Cinetheodolite and CTU checkout (0730-0830)

3.1.2.1 Verify CTU operation including IRIG B reception.

3.1.2.2 Checkout drive and local camera operation.

3.1.2.3 Load camera

3.1.2.4 Operate readout in test mode

3.1.2.5 Operate readout in normal mode and check zero adjust setting by sighting with main optics on calibration target and static target.

3.1.3 DATA SYSTEM CHECKOUT (0730-0830)

3.1.3.1 Test tape playback into data system to verify operation of:

1. Control room intercom
2. Receive Modems
3. MDIU
4. Computer and software
5. Plotter and displays

3.1.4 Communication and Data Acquisition System Checkout (0830-0930)

3.1.4.1 Predetermined cinetheodolite digital values entered and transmitted to verify:

1. Cinetheodolite and the IDF real time outputs.
2. Modem transmission.
3. Line quality.
4. Modem receivers.

3.1.4.1 (cont.)

5. MDIU
6. Software operation.
7. Display system.
8. Plotter.
9. Discrete events input unit.

3.1.5 Radio Checkout (0900-0930)

3.1.5.1 Preflight transmit and receive verification to helicopter.

3.1.6 Pre-mission calibration (0900-1000)

3.1.6.1 Check and adjust cinetheodolite level.

3.1.6.2 Verify boresight OGT to main optics using orientation targets.

3.1.6.3 Orientation targets sequence.

1. Precise setting on target boards using both main optics and OGT.
2. Test controller inputs DEIU for specific orientation target.
3. Cinetheodolite controller initiates signal for photographing and real time output of orientation targets.

3.1.6.4 Static Target Sequence

1. Precise visual setting using main optics.
2. Photograph and transmit data upon cinetheodolite controller command.

3.1.6.5 Calibration Target

1. Precise visual setting using main optics.
2. Photograph and transmit real time output.

3.1.6.6 Refraction Correction

1. Sight 3 meter calibration cross bar with main optics.
2. Photograph 3 meter cross bar.

3.1.7	Test Operation	(1000)
3.1.7.1	Helicopter Takeoff	(1000)
3.1.7.2	Dry Run	(1010)
3.1.7.3	Live Run	(1025)

1. Helicopter on flight path final prior to crossing Cheyenne Road.
2. Test controller vectors helicopter to flight path prior to Indian Wash.
3. Real time data and photographic recording initiated 20 seconds prior to helicopter entry into target rectangle.

3.1.8 Abort Sequence

3.1.8.1 Controller verifies status of helicopter, cinetheodolite stations, record and reproduce and plotters.

3.1.8.2 Announces test re-initiation time.

3.1.8.3 Actuates DEIU re-initialization

APPENDIX G

INCENTIVE TEST OPERATIONS LOG

	TIME	EVENT	ANALOG TAPE FOOTAGE
14 MAR 74	10:50:00	Analog Tape On	
DAY 073	10:52:50	Start Calibration	
	11:09:00	On Line	800
	11:14:00	Flight #1	870
	11:16:18	To Calibration TGT	
	11:16:48	To Helicopter	982
	11:18:14	At Release PT	1039
	11:19:06	Release (CB)	1069
	11:19:56	Camera/Tape On	1099
	11:20:14	Mark	1109
	11:20:38	Camera/Tape Off	
	11:27:43	RTCDS On Line	1403
	11:28:16	To Calibration TGT	
	11:31:17	Release (CD)	1536
	11:32:25	Abort	1573
	11:34:50	Release (CD)	1659
	11:35:42	Camera/Tape On	1697
	11:35:59	Mark	
	11:36:22	Camera/Tape Off	1710
	11:47:07	Flight #3 (CE)	2111
	11:49:45	To Helicopter	
	11:51:19	Release (CE)	2270
	11:52:07	Camera/Tape On	2296
	11:52:27	Mark	2309
	11:53:11	Camera/Tape Off	
	11:57:48	RTCDS On Line	2330
	12:00:51	At Release PT	2413
	12:01:01	Release (CF)	
	12:01:52	Camera/Tape On	2452
	12:02:12	Mark	
	12:02:30	Camera/Tape Off	
	12:07:34	RTCDS On Line	2667
	12:08:33	To Calibration TGT	2703
	12:09:19	To Helicopter (CG)	
	12:11:17	Release (CG)	2806
	12:12:04	Camera/Tape On	2820
	12:12:24	Mark	2848
	12:12:48	Camera/Tape Off	

	TIME	EVENT	ANALOG TAPE FOOTAGE
	13:53:00	Calibrations (CH)	
	14:10:00	Calibration Complete	650
	14:13:33	Stop Analog Tape	733
	14:23:38	Tape On	
	14:26:08	To Helicopter	
	14:28:03	All Go	903
	14:28:23	Release (CI)	910
	14:29:10	Camera/Tape On	
	14:29:28	Mark	956
	14:29:53	Camera/Tape Off	973
	14:34:30	RTCDS On Line	1043
	14:39:21	All Go	1206
	14:39:37	Release (CJ)	
	14:40:27	Camera/Tape On	1245
	14:40:44	Mark	1254
	14:41:07	Camera/Tape Off	1270
	14:46:14	RTCDS On Line	1469
	14:50:00	Release (CK)	1699
	14:50:43	Camera/Tape On	
	14:51:01	Mark	1640
	14:51:25	Camera/Tape Off	
	14:56:00	Run (CL)	1861
	14:58:59	To Helicopter	1940
	15:08:15	Release (CL)	
	15:09:06	Camera/Tape On	2319
	15:09:21	Mark	2327
	15:09:43	Camera/Tape Off	
	15:14:34	RTCDS On Line	2352
	15:31:48	Analog Tape On 2363	
	15:34:08	Release (CM)	2450
	15:35:07	Camera/Tape On	
	15:35:16	Mark	2489
	15:35:39	Camera/Tape Off	
18 MAR 74	13:17:51	RTCDS On Line	737
DAY 077	13:21:13	Helicopter at Release PT	865
	13:23:20	Release (DB)	951
	13:24:20	Camera/Tape On	980
	13:25:00	Mark	
	13:25:00	Camera/Tape Off	
		Film Break on Site 12/Scrub Run	

	TIME	EVENT	ANALOG TAPE FOOTAGE
	13:45:52	Start Analog Tape	1337
	13:47:19	Release (DC)	1415
	13:48:19	Camera/Tape On	1450
	13:48:40	Mark	1465
	13:49:03	Camera/Tape Off	1478
	13:57:31	RTCDS On Line	1797
	14:01:23	Release (DD)	1939
	14:02:27	Camera/Tape On	
	14:02:46	Mark	
	14:03:10	Camera/Tape Off	
20 MAR 74	08:31:53	Start Calib (DE)	
DAY 079		Calib Complete	
	08:41:47	RTCDS Loaded	0540
	08:51:16	On Helicopter	
	08:53:35	Release (DF)	0980
	08:54:25	Camera/Tape On	1017
	08:54:41	Mark	1020
	08:55:03	Camera/Tape Off	1100
	09:00:20	RTCDS On Line	1240
		On Calib TGT	
	09:03:38	Release (DG)	1360
	09:04:29	Camera/Tape On	1391
	09:04:46	Mark	1404
	09:05:07	Camera/Tape Off	1417
	09:09:20	RTCDS On Line	1577
	09:09:11	On Calib TGT	
	09:15:14	Release (DH)	1796
	09:15:59	Camera/Tape On	1826
	09:16:19	Mark	1836
	09:16:40	Camera/Tape Off	
	09:21:39	RTCDS On Line	2027
	09:23:00	On Calib TGT	2100
	09:25:14	Release (DI)	2172
	09:26:05	Camera/Tape On	2207
	09:26:25	Mark	2210
	09:26:49	Camera/Tape Off	2231
	09:33:45	RTCDS On Line	2478
	09:33:50	On Calib TGT	
	09:35:54	Release (DJ)	2574
	03:36:42	Camera/Tape On	2596
	09:37:00	Mark	2616
	09:37:22	Camera/Tape Off	

TIME	EVENT	ANALOG TAPE FOOTAGE
09:43:54	RTCDS On Line	2665
09:45:58	Release (DK)	2746
09:46:45	Camera/Tape On	
09:47:01	Mark	2782
09:47:23	Camera/Tape Off	
10:31:59	Mount Analog Tape	0000
	Calibrations (EA)	
	RTCDS On Line	
10:56:12	Analog Tape On	436
10:52:58	Swap System to C	
11:01:14	Release (EB)	620
11:02:10	Camera/Tape On	650
11:02:22	Mark	661
11:02:43	Camera/Tape Off	
11:07:00	RTCDS On Line	866
11:11:16	Release (EC)	998
11:11:54	Camera/Tape On	1021
11:12:14	Mark	1030
11:12:34	Camera/Tape Off	1047
11:18:13	RTCDS On Line	1300
11:26:08	Release (EF)	1557
11:26:55	Camera/Tape On	1587
11:27:14	Mark	1598
11:27:36	Camera/Tape Off	
	*Tape Errors on 9E0476	
	*Cleaned Tape Rec/Rep Heads	
11:36:43	RTCDS On Line	1952
11:41:36	Release (EG)	2115
11:42:24	Camera/Tape On	2167
11:42:43	Mark	2173
11:43:05	Camera/Tape Off	2190
	*Possible Time Hits	
11:49:14	RTCDS On Line	2426
11:52:03	Release (EH)	2527
11:52:50	Camera/Tape On	
11:53:11	Mark	
11:53:32	Camera/Tape Off	2587
12:00:15	RTCDS On Line	2815
12:02:18	Release (EI)	2910
12:02:53	Camera/Tape On	2935
12:03:10	Mark	2943
12:03:35	Camera/Tape Off	2960

TIME	EVENT	ANALOG TAPE FOOTAGE
13:22:53	Calibration (FA)	3041
13:41.39	RTCDS On	3426
13:49:57	Release (FB)	3731
13:50:48	Camera/Tape On	3763
13:51:05	Mark	3773
13:51:27	Camera/Tape Off	
13:54:55	RTCDS Loaded	3960
14:01:45	Release (FC)	4171
14:02:32	Camera/Tape On	4205
14:02:49	Mark	4213
14:03:09	Camera/Tape Off	
14:17:47	RTCDS Loaded	4766
14:19:42	Release (FD)	4848
14:20:39	Camera/Tape On	4883
14:21:00	Mark	4895
14:21:25	Camera/Tape Off	
14:25:44	RTCDS Loaded	5072
14:29:33	Release (FE)	5217
14:30:28	Camera/Tape On	5252
14:30:50	Mark	5262
14:31:15	Camera/Tape Off	5279
14:36:36	RTCDS Loaded	5476
14:39:35	Release (FF)	5593
14:40:25	Camera/Tape On	5623
14:40:48	Mark	5633
14:41:12	Camera/Tape Off	5652
14:46:13	RTCDS Loaded	5843
14:55:01	Release (FG)	6170
14:55:57	Camera/Tape On	6205
14:56:17	Mark	6216
14:56:43	*Camera/Tape Off	

*Color Film

APPENDIX H

INCENTIVE TEST SUMMARY

ALL DATA IN METERS

FLIGHT ID	MEANS** ΔX	ΔY	ΔZ	RMS	STD DEV	RRS
CI	.083	.658	.033	.678	.627	.664
CK	.011	.672	.021	.571	.521	.672
DC	.549	.828	.107	.935	.833	.999
DH	.349	.575	.106	.577	.463	.680
DI	.325	.643	.093	.570	.447	.726
DJ	.385	.516	.086	.473	.339	.649
DK	.411	.653	.070	.608	.476	.775
DF*	-.074	-1.042	.080	1.056	.998	1.047
EB	.253	.341	-.032	.537	.503	.426
EC	.545	.529	.027	.586	.457	.760
EF	.447	.463	-.168	.607	.555	.665
EH	.323	.476	-.085	.692	.650	.581
EI	.493	.570	-.159	.636	.560	.770
FB	.335	.856	.024	.665	.523	.920
FC	.381	.821	-.087	.656	.541	.909

*Two station post flight solution compared with three station real-time solution.

**The maximum Δ was on DF for which Δ two station post flight reduction was used. For all other flights the maximum Δ was no greater than 2.922 meters (Flight DC).

DEFINITION OF TERMS

MEAN

$$X_{mean} = \frac{\Delta X_1 + \Delta X_2 + - - - - - - \Delta X_N}{N} \quad \text{same for } \Delta Y \ \& \ \Delta Z$$

$$\underline{RRS} = \frac{(\Delta X)^2_{mean} + (\Delta Y)^2_{mean} + (\Delta Z)^2_{mean}}{}$$

$$\underline{RRS} = \frac{(\Delta X)^2_{mean} + (\Delta Y)^2_{mean} + (\Delta Z)^2_{mean}}{3 \cdot N}$$

$$\underline{STD\ DEV} = RMS - \frac{(\Delta X_{mean} + \Delta Y_{mean} + \Delta Z_{mean})}{3}$$

APPENDIX I

SUMMARY OF RTCDS TRAINING RECEIVED BY YPG PERSONNEL

	TOTAL NUMBER OF	
	HOURS	PEOPLE
RTCDS Operation, Management Briefing	2	10
RTCDS Operation Training	8	10
Computer Software and Hardware Training	80	5
Computer Hardware and Display Equipment Maintenance Training	40	3
Cinetheodolite Operation Training	32	20
Cinetheodolite Maintenance Training	32	8
Cinetheodolite Film Reader Operation Training	24	5
Cinetheodolite Film Reader Maintenance Training	16	3
TOTALS	154	59

APPENDIX J

SUMMARY OF RTCDS DOCUMENTATION DELIVERED TO YPG

DOCUMENTATION	QUANTITY
System Operating Procedures, TP-968A	5 ea
Instruction Manual, Cinetheodolite EOTS-CF, Vol. I, IM-976	11 ea
Instruction Manual, Cinetheodolite EOTS-CF, Vol. II, IM-976	11 ea
Instruction Manual, Electronic Cabinet and Angle Encoder Associated Components, Cinetheodolite EOTS-CF, Vol. III, IM-976	11 ea
Instruction Manual, Cinetheodolite EOTS-CF, Drawings, Vol. IVA, IM-976	11 ea
Instruction Manual, Cinetheodolite EOTS-CF, Drawings, Vol. IVB, IM-976	11 ea
Instruction Manual, Cinetheodolite EOTS-CF, Drawings, Vol. IVC, IM-976	11 ea
Instruction Manual, Stiff Stick Assembly, IM-976	11 ea
Instruction Manual, Discrete Events Input Unit (DEIU), IM-977	4 ea
Instruction Manual, DAC's and Display Console, IM-978	7 ea
Instruction Manual, EOTS Semiautomatic Film Reader, Vol. I	4 ea
Instruction Manual, Supplement, for Semiautomatic Film Reader, IM-980	4 ea
Instruction Manual, Computer Room Console and Mission Control Console, IM-981	7 ea
Instruction Manual, Multichannel Data Input Unit (MDIU), IM-982	4 ea
DBA Technical Documentation, Real-Time Software, Vol. I	2 ea
DBA Technical Documentation, Real-Time Software, Vol. II	2 ea
DBA Technical Documentation, Real-Time Software, Vol. III	2 ea
DBA Technical Documentation, Software Operating Instructions, Vol. IV	2 ea
DBA Technical Documentation, Appendices, Vol. V	2 ea
DBA Technical Documentation, Software Operating Instructions, MDIU, Vol. VI	2 ea

DOCUMENTATION	QUANTITY
Reference Manual, LBI4123D, GE Mobile Radio MASTR, 25-50 MHz	3 ea
Maintenance Manual, LBI4172C, GE Mobile Radio MASTR, Base Station Receiver Power Supply	4 ea
Technical Manual, 51M-10, Collins, VHF/UHF Receiver	4 ea
Product Description, 51M-10, Collins, VHF/UHF Receiver	1 ea
Manual, EAI Range Plotter, Series 2050	7 ea
Manual, EAI Range Plotter, Scale Factor and Parallax Circuitry 20.0575	7 ea
Manual, Siemens Level Tracer, K2001	4 ea
Instruction Manual, Siemens Level Tracer, K2001	3 ea
Instruction Manual, Lenkurt Electric, 26C1-30015 Data Set	9 ea
Maintenance Manual, Ampex ES-200, Signal Electronics	2 ea
Operator Manual, Ampex FR-2000, Recorder/Reproducer	2 ea
Maintenance Manual, Ampex FR-2000, Tape Transport and Control Circuit	2 ea
Manual, Parts List, Ampex FR-2000, Recorder/Reproducer	2 ea
Instruction Manual, Ampex Voice Monitor Kit for FR-2000	1 ea
Operations Manual, Datametrics, Synchronized Time Code Generator	19 ea
Reference Manual, Beehive Terminal, Models I, II and III	3 ea
Operations and Maintenance Manual, Kennedy, System 8000, Digital Magnetic Tape Recorder	3 ea
Operations and Maintenance Manual, Kennedy, Buffered Formatter Model 8232	3 ea
Reproducible Copies of all RTCDS Engineer Drawings	2 ea
Regular Prints of all RTCDS Engineer Drawings	2 ea