*Operational Procedures and Test Coordination for Use of a Photogrammetric Triangulation System**

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ABSTRACT: *A Photogrammetric Triangulation System employing the ballistic plate camera appears to be the answer for a range instrumentation standard which meets the accuracy requirements demanded in space vehicle flights. Such a system housed in mobile, portable units is described. The operation of the system in obtaining space position data by means of a least squares adjustment of the data is also briefly described. Criteria to be used in personnel selection and in coordinating the operation of such a system are presented.*

INTRODUCTION

THE Philco Western Development Laboratories procured a Photogrammetric Triangulation System,† designed and manufactured by the Instrument Corporation of Florida, for use as a range instrumentation standard for optical and electronic tracking systems and for missile and statellite trajectory data. Aware from previous experience that personnel requirements and coordination are extremely important, criteria for personnel selection were established and a general approach to coordination was formulated. The criteria are presented here, prefaced by a description of the equipments and the procedure and techniques used in the operation of a Photogrammetric Triangulation Station.

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REVIEW OF DEVELOPMENTS TO DATE

It has been only recently that a very strong effort has been manifested for the development of an instrumentation standard with which to evaluate electronic and optical equipment used in space instrumentation. Formerly each system was judged solely by its adequateness or by the contribution it made toward resolving the problems of increased accuracy.

Approximately three years ago it appeared that the Askania cinetheodolite would evolve into a standard which could be used for range instrumentation purposes throughout the missile industry. This was during the time that the ballistic plate camera was first being evaluated and a system of operational base lines was being developed to meet the requirements of increased accuracy demanded by the ballistic missile industry. Now with the development of the Photogrammetric Triangulation System, it is felt that for years to come the PTS will serve as an instrumenta-

† Credit for the optical system and electronic support equipment design is given to A. K. Schiefer and M. Friedland, respectively, of Instrument Corporation of Florida.

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tion standard that will adequately fill the needs of the many requirements in all optical and electronic fields.

The ballistic plate-camera triangulation system is the most accurate method of obtaining space position data. This system is the only known instrumentation system for which the bias errors are less than the random error of measurement. The random errors are currently three to six seconds of arc with the camera system being used at the Atlantic Missile Range.

Equipment Description

The following figures show the equipments that make up a single Photogrammetric Triangulation Station. The block diagram (Figure 1) illustrates the system concept of a PTS Station. For ease of presentation, the entire system is divided into *three basic subsystems* indentified as recording, processing, and data reduction.

The *recording portion* consists of the camera and shutter operation, a frequency standard, time reference (WWV receiver, VLF receiver) a light source detector, tape recorder, oscillograph, shutter programmer and single sideband communication equipment.

The *processing portion* is either an automatic or manual operation which provides for processing and drying the data plates on location, immediately after exposure.

The *data reduction portion* consists of a digitized comparator, code converter, and a flexowriter to convert all plate data to punched tape, ready for processing by an S-2000 computer (located at Palo Alto, California). A modulator and demodulator is being provided to transmit the tape data from the camera site to the control center for final forwarding to the computer by teletype. The complete system is housed in three identical mobile shelters. Each one is capable of operating as the master station to provide the shutter operation sequence to all cameras for the type of data required for a specific test.

Figure 2 is an illustration of the mobile shelter. It is 7 feet wide, 7 feet high, and 12 feet long. Aluminum is used throughout except for the interior of the electronics compartment which is plywood. The optics compartment is an arrangement of four thermopane windows all electrically operated; this forms a very satisfactory "dome" for temperature control. Each shelter is provided with two air conditioners which ensure adequate temperature control for world-wide operation.

A typical PTS camera site (Figure 3) consists of a cement pad on which the shelter is set. The four piers are isolated from the pad for stability. The three piers surrounding the center pier are supports for the tripod contained in the shelter. For operational use, the tripod is isolated from the shelter. The center pad is for a bench mark reference for station location. A portable generator system provided with the system is parked at least 200 feet from the camera location in order to eliminate any vibration. The small trailer provides adequate space for field personnel to make repairs, and to store test equipment and spare parts. When operating in isolated areas, this trailer could provide adequate living quarters for periods of two or three days. Figure 4 is a photograph of the shelter showing the general configuration and wheel arrangment that is provided; the camera

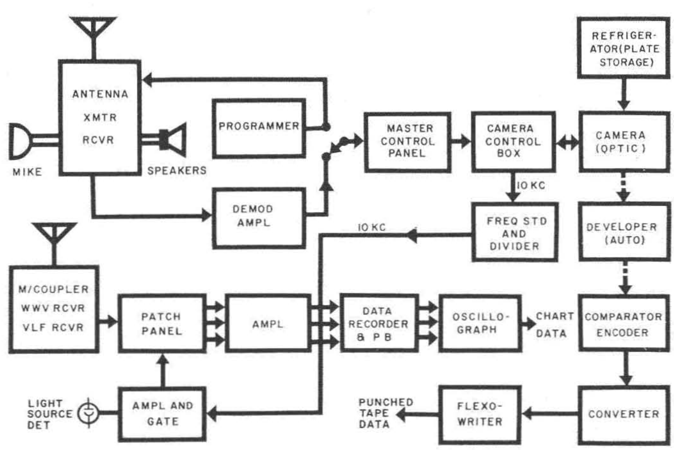

FIG. 1. Photogrammetric system station.

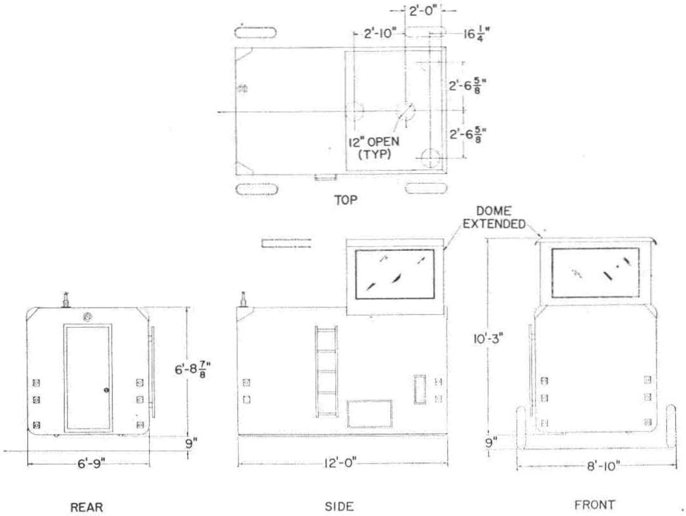

FIG. 2. Shelter (PTS).

extends above the roof level from the optics compartment.

A view of the electronics portion, showing the master control panel, recorders, communications equipment, programmer, and power supplies, is given in Figure 5.

Figure 6 is a view of the area where processing and data reduction equipment are mounted. The open area in the lower right-hand corner will hold the processing unit; the bench area is for data reduction equipment. A view of the camera, tripod, and the work area for the camera operator is given in Figure 7. The left-hand side shows the control panel and communications box. Around the isolated tripod, one can see a guard rail for protection against manual disturbance during operation. Also visible are two plate-holder boxes and weather-recording equipment. The camera design reflects the careful consideration given to the exacting job of photogrammetric triangulation. The heart of the system is the Zeiss-Topar lens. With a focal-length of 210 mm. and a plate-format of 180 mm.×180 mm., the lens is capable of a resolving power of 250 lines per mm. Coverage angle of the camera is 46 degrees. As the lens is a 60-degree cone, a roll capability design in

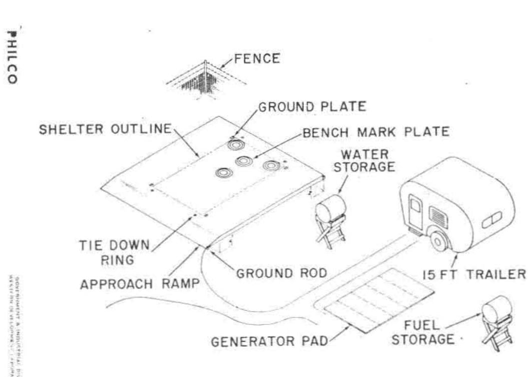

FIG. 3. Master site—PTS.

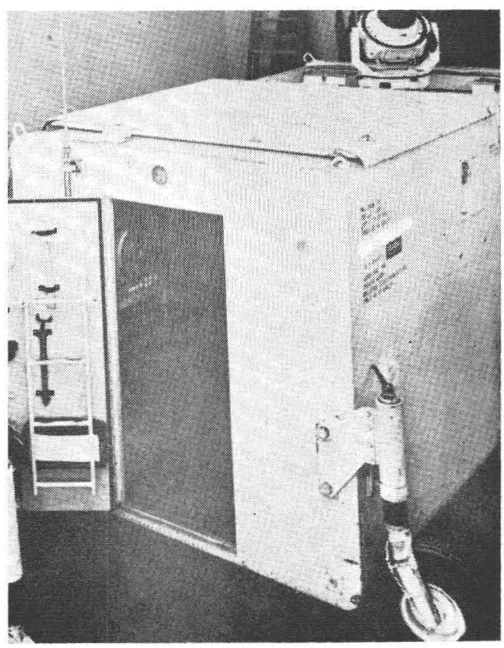

FIG. 4. Shelter.

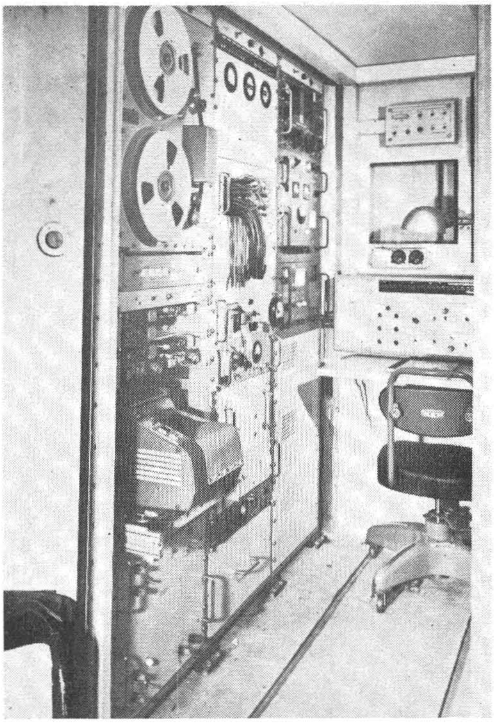

FIG. 5. Electronics area.

the camera will provide angular coverage of 57 degrees from corner to corner of the recording plate.

CALIBRATION PROCEDURE DURING OPERATION

The operation procedure for making star calibrations varies with the area of the celestial sphere being photographed, but in general is as follows: A few minutes prior to an event which is to be photographed, the camera is prepared for full operation. At the conclusion of this preparation the camera is not touched until the operation has been completed. A series of successive star exposures of 2, 1, $\frac{1}{2}$, and $\frac{1}{4}$-seconds, separated by intervals of 30 seconds, are made. This produces, from each star in the field of view, four point images of varying size. The shutter is then closed and remains so, until it is time to record a series of events along a given trajectory. The shutter is then opened (remote control) and data points are photographed as desired. After an elapsed time of from one to five minutes, the shutter is again closed, and within one minute the above calibration is repeated. The plate now consists of a series of missile-borne flashing light-images recorded against a background of hundreds of superb reference points provided by the star images.

As the precise time of each exposure is recorded, the direction from the observing station to any recorded star can be accurately computed by means of standard astronomical formulas. From the plate measurements of at least three images of stars of known direction, it is possible to determine the precise orientation of the camera. In practice 20 to 30 stars are measured, and the orientation is computed from a least squares ajdustment. This minimizes the influence of any measuring errors (human errors) to such an extent that the calibrated orientation may be regarded as error free. Both the pre- and post-calibration stars are used in the reduction, and this makes possible detecting any significant change in orientation which may have occurred during the critical interval between calibrations.

Once the orientation of a camera has been computed, the directions from the camera to the recorded data points may be computed from the measured x and y plate coordinates of their images. The position of each missile point can then be determined by special triangulation of corresponding rays produced by three or more stations. While two stations are sufficient for a triangulation with the PTS, three cameras are employed in a least squares triangulation. This not only leads to improved accuracy, but provides a very valu-

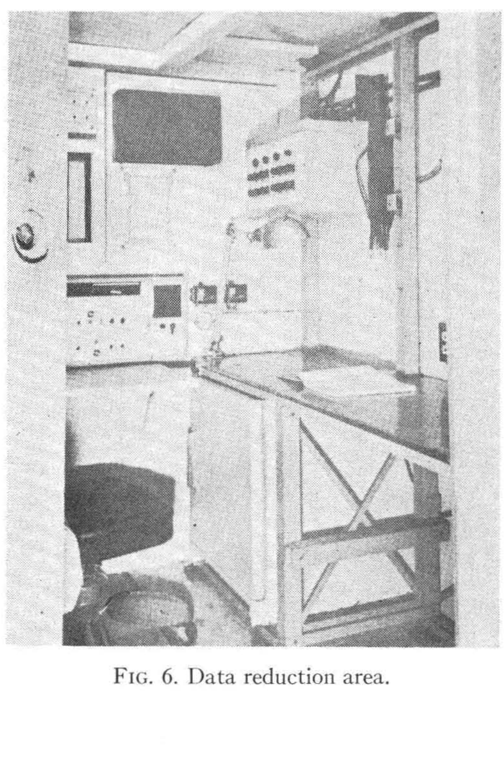

FIG. 6. Data reduction area.

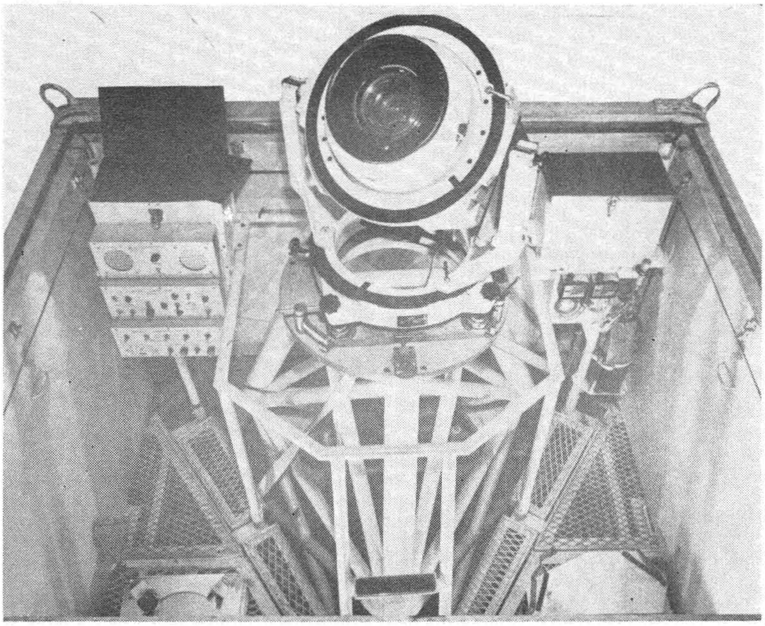

FIG. 7. Camera and Tripod.

able check on the internal consistency of the system.

PERSONNEL REQUIREMENTS

The paramount but often the least weighted of the factors that comprise a successful photogrammetric triangulation operation is the makeup of the field personnel. Upon the skill and judgment of these persons rests the correct operation of equipments, reduction of data and finally the analysis of the data. Thus, it is of the utmost importance to organize the available skills to obtain maximum efficiency; failure to do so will contribute, otherwise, to deficiencies in the final data. The author supervised the field operation of a ballistic camera system and from this experience can offer the following criteria for selection of field personnel:

1. The operator must have a real interest in this field of work and be desirous of making it his life work.
2. He should be thorough and satisfied only when a task is completed in a workmanlike manner; he should feel that no result is valid until every test of its accuracy has been applied.
3. He should show great initiative and work with resourcefulness and enthusiasm.
4. He should have every desire to study not only the system he is associated with but all related subjects.
5. He should be reliable and of sound judgment.
6. He should be a perfectionist in all that he does.

Having field personnel that meet these criteria only basic instructions need be given to the operating personnel in order to assure accurate test results.

TEST COORDINATION

While preparing for and during all Photogrammetric Triangulation System operations, it is of the utmost importance that the test coordinator be located in the most ideal position in order to direct the activities of the three camera sites. This is accomplished by locating the conductor at the base of operations of the system to be evaluated, and providing communications with all persons involved in the test. Communication to the camera sites is obtained by a fourth set of single sideband radio equipment. Thus the test conductor has complete knowledge of equipment status, weather reports, test progress, and status of the equipment to be evaluated.

A most important group to be considered in reference to test coordination is the data analysis unit. This unit's responsibility is to compare and evaluate, as the name implies, the resultant data from tests, and to advise the proper people as to errors and corrections to be made in the equipments being evaluated. It is also a task of this unit to plan tests and flight plans that will provide or simultate the necessary dynamic operating conditions to properly evaluate and calibrate range equipment.

Conclusions

The Photogrammetric Triangulation System represents the application of sound design principles to the solution of instrumentation problems defined by the most rigid of performance specifications. The system is completely self-contained and independent in operation. Its performance has already demonstrated a sound instrumentation and engineering approach, and it has become the range standard for all optical and electronic instrumentation and systems. When operated as specified, the system will provide data to an accuracy of 1 part in 200,000, which is 10 times greater than the next most accurate system in use today, the tracking Cinetheodolite.

*A Photogrammetric Radio Telescope Calibration**

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Introduction

A radio telescope with a reflector 40 feet in diameter is operated by the Ohio State University Department of Electrical Engineering. The reflector was designed to be a paraboloid of revolution with a focus of 18 feet. Although the structure, shown in Figure 1, was designed and built within the Department of Electrical Engineering, the errors accumulated during construction were not known. Once erected, its size prevented any simple direct measurement of the reflector. It became obvious that a photogrammetric method that would measure photographs of the telescope rather than the telescope itself would be desirable, if reasonable accuracy could be obtained with available equipment. Encouraged by some kind advice and ideas from Professor Frederick J. Doyle, and armed with the facilities of the Institute of Geodesy, Photogrammetry, and Cartography which include a Wild A-7 Autograph, the author undertook to calibrate the telescope by a photogrammetric method.

There are two different photogrammetric approaches to the problem of measuring such a geometric figure: one approach is to employ a system that requires exact knowledge about the position and angular attitude of the camera; the other approach is to employ a system that requires only approximate knowledge of the position and angular attitude of the camera. Of course, both approaches require a precision camera, but less field work is required in the second approach since instrument set-up time is reduced.

The second approach is the subject of this paper, and the purpose is to investigate the

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