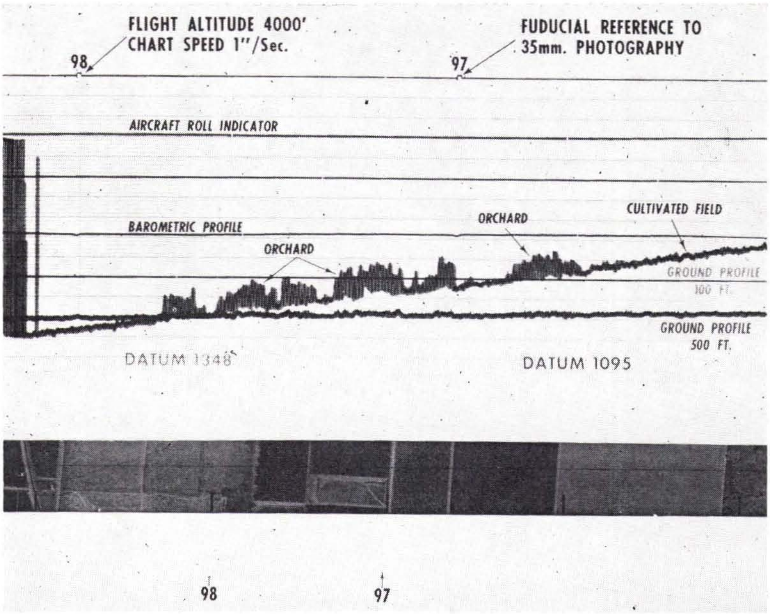

FRONTISPIECE. A representative LASER profile crossing a variety of vegetation. The trees in the orchard on the right have an average height of 10 feet, and those on the left 14 feet. The height of the crop in the cultivated field is 4 to 6 feet.

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Laser Terrain Profiler

Tests indicate that the system is acceptable for the acquisition of vertical control for photo mapping.

INTRODUCTION

THE task of the cartographer is to portray objects on the earth's surface on a map in true positions relative to each other. To a cartographer there are three qualifying conditions for each position, a Northing, an Easting, and an Elevation. These three conditions are unique for they describe one, and only one, point on the earth's surface.

At one time topographic maps were compiled on site and, depending upon the individual topographer, were relatively accurate in horizontal and vertical positioning. However, mapping by this method was localized to small areas. Along came photogrammetry and the compilation was taken from the field to the office.

In the early days of photogrammetry, the geodetic control for each model was established in the field. Two points for horizontal positioning and four points for the vertical were required for each model.

Since 1948 the Army Map Service has used aerial triangulation to bridge models between bands of geodetic control.

In 1949 the Canadians began the practical application of SHORAN to extend ground control from geodetic stations. HIRAN succeeded SHORAN as a greatly improved distance measuring system. The U. S. Air Force has since

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ABSTRACT: *A description of the operational test, conducted by the Army Map Service, of an airborne system to determine its capabilities for establishing vertical control for photogrammetric mapping. The basic subsystems are: (a) a 70-mw helium-neon continuous-wave LASER distance measuring instrument; (b) a sensitive barometric altimeter system; (c) a profile recording system; and (d) a photographic system for path recovery. This paper reviews the planning, the airborne operational procedures, the data reduction techniques, and the final analysis of the results obtained from this test.*

developed SHIRAN, and preliminary tests by the Army Map Service indicate an increased accuracy for this system.

In 1943 Canada began development of the Airborne Profile Recorder, (APR) and by 1952 had obtained vertical accuracies over land surfaces of 50 feet over long flight lines. The Army Map Service conducted aerial triangulation tests in 1958 with improved APR equipment. Results showed that vertical accuracies of 10 feet in flat terrain, and 20 feet in mountainous terrain could be obtained with this equipment.

In 1963 Aero Service Corporation began investigating the use of a LASER beam instead of the Radar. Through the joint effort of Aero Service and Spectra-Physics Incorporated the LASER Profiler System was developed. In March 1965 the Army Map Service became interested in the possibility of this System as a method of procuring vertical control for photogrammetric mapping. Through the cooperation of the U. S. Army Engineer Topographic Laboratories, a contract was negotiated to acquire data for this test.

This paper was prepared to: (a) discuss the planning and objective; (b) describe the airborne operational procedures; (c) explain the data reduction technique; and, (d) present an analysis of the results obtained from the test.

DESCRIPTION OF THE SYSTEM

The LASER Profiler System is composed of four major subsystems: (1) Barometric reference system, (2) Distance measuring system, (3) Recording system, (4) Photographic system.

THE BAROMETRIC REFERENCE SYSTEM

The datum, which the heighting differences of the terrain are referenced, is a pre-selected isobaric surface. This is a pressure surface, and aircraft utilize this surface as a reference to maintain their altitude. Deviations from this reference-in-the-sky must be accurately and instantaneously measured. These deviations are then used as corrections for the LASER measurements. A tail drogue is used to collect air samples and the deviation is measured by a Rosemont Static Pressure Port Calibrator. Corrections are continuously made to the LASER measurements, using electronic analog recording.

THE DISTANCE MEASURING SYSTEM

The LASER unit is the heart of the measuring system. It was designed and developed by Spectra-Physics Inc. The device uses energy of wave length 6328 angstroms; its source of power is a 70 milliwatt, continuous-wave, helium-neon gas laser. The beam is narrow width, 3/4-inch at the source and covers a few square inches on the ground. There are three levels of sensitivities which can operate simultaneously, or in any combination to fit the requirements. The intervals corresponding to these sensitivities are 20 feet, 100 feet and 500 feet. An analog output signal transfers the measurement to the recording system.

THE RECORDING SYSTEM

This system is designed around a Minneapolis-Honeywell Vissicorder, a light beam type with a frequency response of several hundred cycles per second. Data is recorded on a chart which must be permatized in a manner similar to photographic film. Six channels of data can be recorded simultaneously.

THE PHOTOGRAPHIC SYSTEM

A 35-mm strip camera records the photographic path of the LASER beam. The camera, attached to the LASER unit by a fixed mount, is boresighted with the beam, and this alignment can easily be checked during flight. Correlation between the film and the charts is achieved by synchronized fiducial marks.

THE TEST

Preliminary studies of the profile data indicated that the system was capable of excep-

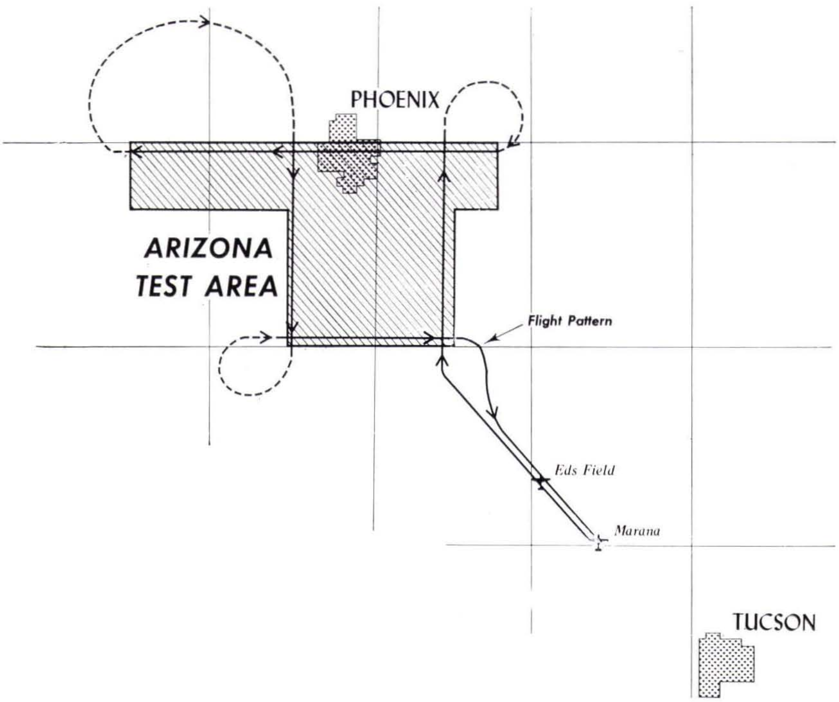

FIG. 1. The general flight plan for each LASAR profile over the test area in the vicinity of Phoenix, Arizona. The flying time for each mission was about 2.5 hours and the distance flown about 375 miles.

tional resolution and relative heighting accuracy. Before acceptance as a tool for mapping, there were three qualities to be determined: (1) the capability of the system to provide vertical control over long flight lines; (2) the limit of the operational ceiling; and, (3) the effects of the airborne datum, and the deviations therefrom, on LASER-determined ground elevations, using long lines of aerial photography and long profile lines flown independently at various altitudes.

Prior to proceeding to the Phoenix (Arizona) Test Area, extensive testing of all the major components was performed by Aero Service Corp. at the North Philadelphia Airport. This included ground and airborne calibration tests. Army Map Service personnel were on hand to assist in formulating the monitoring and inspection procedures to be used.

The mapping photography of the test area used for the photogrammetric evaluation was obtained with the 6-inch focal length KC-4 camera at an altitude of 23,500 feet above mean terrain. Four lines of photography around the perimeter of the test area were used.

Flight lines for the profiles were located on the photography and used by the pilot for flying each mission. The flying altitude was constant over the four lines of photography for each LASER mission. Thus profiles over 165 miles of geodetic controlled area were available for evaluation.

Figure 1 shows the general flight pattern followed for each profile. The base of operation was at Marana Air Park approximately 30 miles north of Tucson.

The airborne datum for each mission was established at Marana and maintained throughout the entire mission. Flying time for each mission averaged 2.5 hours for approximately 375 miles.

Elevations were established on the edge of a taxiway from a U. S. Coast & Geodetic Survey bench mark. The pilot was instructed to gain the desired altitude by circling and then pass over the surveyed line thereby establishing the airborne datum. Eds Field, an abandoned airstrip, was panelled and an elevation established for emergency use. On the return flight the two datums were crossed in a like manner to complete a closure.

A Paulin Microbarograph recorded the change of pressure on the ground at Marana during all flights. Eleven missions were flown and the observed pressure changes ranged from 0 to 70 feet for the 2.5-hour periods.

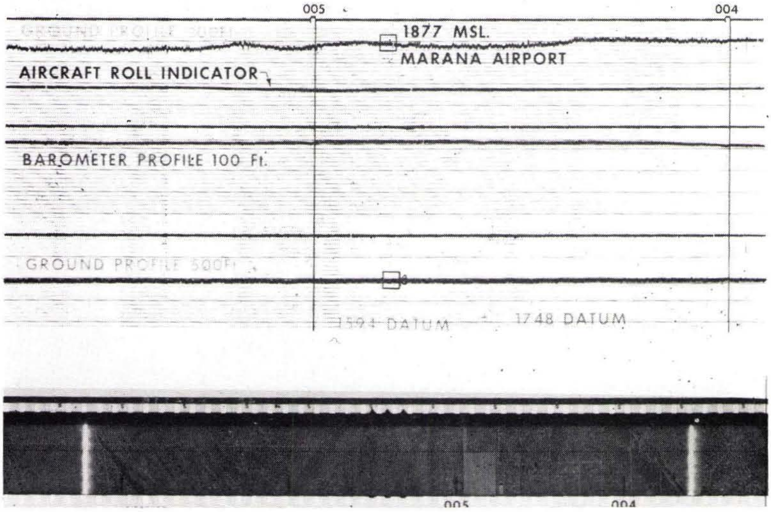

FIG. 2. Example of the recorded chart and the 35-mm path photograph. The flight altitude was 4000 feet and the chart speed was 1 inch per second.

Applying these observed changes as corrections, the closures for the 11 missions ranged from 1 to 14 feet.

Figure 2 is an example of the recorded chart and the 35-mm path film. Six channels of data can be recorded simultaneously. Four channels were used for this test. The record at the top is the corrected ground profile at the 100-foot vertical scale, with the smallest increment being 2 feet. The record at the bottom is the raw ground profile at the 500-foot vertical scale, with the smallest increment being 20 feet.

The barometric profile, at 100-foot scale, is the raw record of the deviations from the selected barometric datum. This signal is mixed, as a correction to the 100-foot ground profile which is thereby recorded as a true ground profile. Roll information was provided by a vertical gyro and is recorded for use as a factor in data reduction, in that during periods of roll, usually of short duration, terrain elevations were not used.

The 35-mm camera was boresighted with the LASER beam and the path of the beam is represented on the film by the line in the center. The synchronized fiducial marks provide easy correlation with the chart. The film shows the beam crossing the taxiway where the true ground elevation is 1877 feet msl. (mean sea level).

Figure 3 is part of the mission shown in Figure 2, and represents data collected about one hour from the start of the mission. The fiducials are set at a 10-second interval, and the ground distance between fiducials is approximately 0.7 of a mile. The path of the beam crosses a built-up area and correlation between the path film and the profile is quite simple. At the 100-foot scale, the shape and size of the buildings are clearly outlined. The 500-foot scale profile is compressed into five major divisions at the bottom of the chart. Note that the last two digits of the datum line at the bottom are the same as in Figure 2. The elevation of this line changes by 100-foot increments or *steps*.

Figure 4 is an example of the *step* changes of both profiles over rapidly changing terrain. The steps are not synchronized between the two profiles; therefore the processing of the data is done independently. From the 100-foot scale ground profile, the elevation of the peak is determined by adding 104 feet to the 2898-foot datum for the elevation of 3002 feet msl. The elevation of the same point on the 500-foot profile is determined from the datum shown on the bottom line as 2427 feet plus the 500-foot step making the raw reading of 2927 feet. The barometric profile at this point is 85 feet which is added as a correction to the raw ground elevation making the elevation of the peak 3012 feet msl. In the 10-second interval between fiducials there are 17 one-hundred foot step changes.

The Frontispiece is representative of the profile crossing a variety of vegetation. On the right is a cultivated field, with a crop height of 4 to 6 feet. Crossing the citrus groves, the narrow beam penetrates the space between the trees to the lowest point. The trees on the right average 10 feet and those on the left

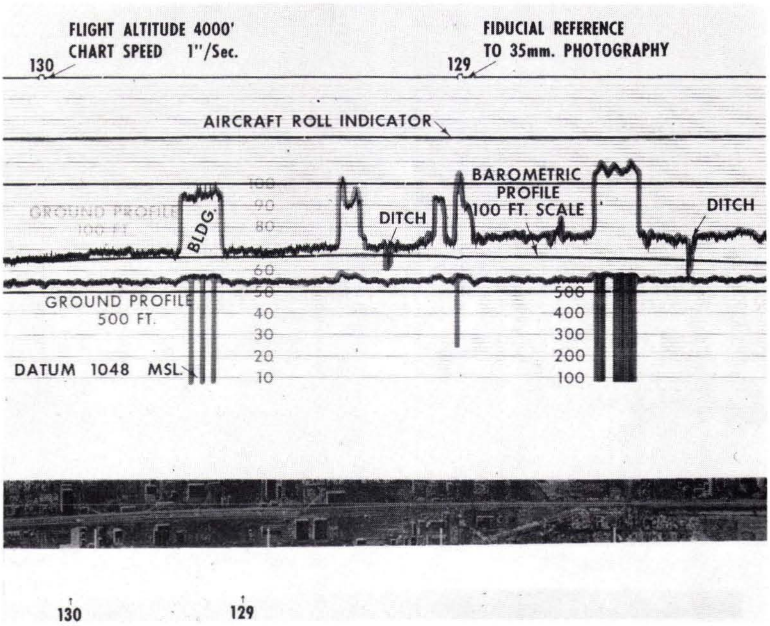

FIG. 3. A part of the mission shown in Figure 2 showing data collected about one hour after the start of the mission.

average 14 feet. Examining the path film it is obvious that the groves on the left are the older trees. At the extreme left, a step change for the 100-foot scale appears.

Figure 5 is representative of the planned procedures for the photogrammetric evaluation. This is a part of a triangulation work sheet and shows the density of points to which measurements were made. The triangles represent the geodetic control spaced at one mile intervals, and the circles are the LASER established control points. The instrument measurements were adjusted to various patterns of ground control using both the strip adjustment method and the single model method.

PHOTOGRAMMETRIC PROCEDURES

DATA PREPARATION

Transferring of the selected vertical control points from the path film to the mapping photography was a simple procedure. The path of the beam is easily followed on the mapping photography, and the continuous profile provides innumerable points from which photogrammetrically acceptable positions can be selected. Two or three points were selected for each model from each profile for this test.

INSTRUMENTATION

The four strips of photography were

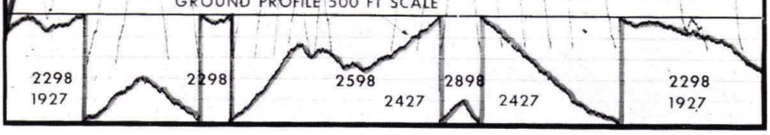

FIG. 4. An example of the *step* changes of both profiles over rapidly changing terrain.

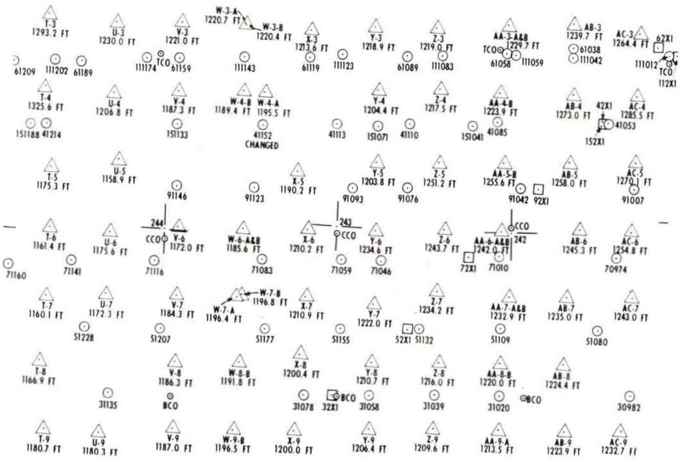

FIG. 5. Part of a triangulation work sheet showing the density of measured points. The general grid spacing is one mile.

bridged on a Zeiss C-8 Stereoplanigraph using the standard Army Map Service undisturbed-model method. The positions of the geodetic control was determined by the instrument operator from field sketches.

ADJUSTMENT

The instrument coordinates were adjusted to geodetic coordinates and to the LASER established elevations using the standard Army Map Service routines for the Honeywell-800 computer.

The first step in this phase of the operation was to evaluate the geodetic control. This control network was established by resurvey during the period 1960–62. Physical changes during the years since have made numerous points photogrammetrically unacceptable. The horizontal tolerance of 5 meters was used for each point with a known horizontal position. The vertical tolerance was not rigidly set, for it was decided that comparative results would be more significant.

The strips were adjusted vertically using the least squares method employing a 3rd degree x-tilt and a linear y-tilt equation. Single models were adjusted to a least-square-fit to control, which is the standard procedure for a Camera Service Test.

With the same set of instrument coordinates (x, y, and z) adjustments were made to various patterns of control. Geodetic points were used as check points for comparative results. Table 1 is a typical example of both the procedure and results. This is a composite of the four strips showing the distribution of errors, by class, as determined from two independent adjustments. (1) Each photogrammetric extension was adjusted to a line of geodetic points at the edge of the strips. Differences between the photogrammetrically determined elevation and the geodetic elevations at check points were noted. These differences are shown in the chart on the left. (2) Two lines of LASER-established control points were substituted for the geodetic control, and the extensions were again adjusted. Differences noted at the same check points are shown in the chart on the right.

ANALYSIS

With the limited time available for this presentation, the description and results of this test are necessarily general. This was the first test of the LASER Profiler System as it would be employed for a mapping project. In Table 1 the comparison is made to the most rigid geodetic control requirements. These accuracy figures, although not conclusive, are nevertheless quite promising.

All airborne profilers depend on the use of isobaric surfaces as a level reference. These surfaces are not stable and a correction for this datum must be included. Although our information was limited, it seems that ground-based barometers can record the changes at these lower altitudes with sufficient accuracy for a correction to this surface. A continuing study must be made of these surfaces if we are to use them as a vertical reference.

Positive photo identification of control points has always been a major problem for

TABLE 1. FREQUENCY DISTRIBUTION OF ERRORS

	Geodetic Control					*Laser Control*				
Range of Error (ft)	*Strip 1*	*Strip 2*	*Strip 3*	*Strip 4*	*Percent of Total*	*Strip 1*	*Strip 2*	*Strip 3*	*Strip 4*	*Percent of Total*
0– 4	47	34	46	49	47.2%	66	69	45	46	60.6%
5– 9	47	48	29	19	38.3%	43	32	30	23	34.3%
10–14	20	18	7	4	13.1%	5	3	8	3	5.1%
15–19	—	4	1	—	1.4%	—	—	—	—	—
Total Check Points	114	104	83	72	100.0%	114	104	83	72	100.0%

Each strip was adjusted by holding a line of control on each edge, and the residual errors observed at the same check points.

LASER control used were obtained from profiles flown at 3000 ft. and 6000 ft. altitudes.

No. of Control Points Held

Strip	*Geodetic*	*Laser*	*Models*
1	64	47	14
2	47	48	10
3	51	50	14
4	48	37	10

the compiler. The most outstanding quality of this system is the simplicity of selecting acceptable control points. The 35-mm path film precisely records the path of the beam. The high resolution of the recorded LASER profile provides additional verification for selecting acceptable control points. Thus, the selection of photogrammetrically acceptable points on the mapping photography can be done with confidence. Perhaps we can assume the comparative results shown in Table 1 verify this quality.

Examination of the profiles show a consistant degradation with increasing altitude. Our evaluation indicates that the accuracy is stable up to 10,000 feet above mean terrain. At 15,000 feet the recorded profile seems to be useable for some mapping. At the 17,000-foot altitude the record was not useable.

DISCUSSION

Today we have two airborne systems for acquiring vertical control for photogrammetric mapping: (1) the Radar TPR for high altitudes and simultaneous operation with mapping photography; (2) the LASER TPR which is limited to lower altitudes and is an independent operation. Both systems depend on an isobaric surface as a datum reference. Operational requirements would dictate which system should be used.

The Radar TPR requires a large body of water or level land surface to establish its reference datum. The LASER system needs only a profile of a few hundred feet to accomplish the same. In addition, the data reduction techniques for the Radar TPR involves considerable time and effort since photogrammetric triangulation and adjustment must be made in order to transfer elevations to positions required by the compiler.

It is at this stage of mapping procedures that the LASER Profile shows tremendous possibilities. Profiles flown through the side lap area of the mapping photography could provide to the compiler those four vertical points required for each model simply by locating the profile line on the photo side lap area.

This was the first comprehensive test of the complete system. So that this test would more closely approximate true conditions during an actual mapping operation, it was conducted as such because we were seeking factual information and not merely theoretical accuracies. The mission was completed and the LASER TPR is acceptable for acquisition of vertical control for photogrammetric mapping.

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