The Dual Aircraft Mapping System

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ABSTRACT: *The Dual Aircraft Mapping System was designed to acquire, by a completely airborne system, all necessary data for compilation of maps in areas of little or no control. It consists of two aircraft flying abreast of each other taking simultaneous aerial photographs; making an electronic distance measurement between aircraft at the instants of exposure; and recording continuous terrain profiles. Results of tests proved that the system can provide a means for topographic mapping to an arbitrary datum solely from data obtained by airborne equipment, or to a known datum if an elevation, a position and an azimuth are available anywhere within the area.*

WITH the trend of warfare changing and portending the possibility of many isolated and remote military operations, it is apparent that new methods and techniques must be designed and perfected to fulfill the requirements for accurate maps. Because these operations may be of a spontaneous nature without indication as to time or location, speed in preparation of the required maps is essential. It can be assumed, however, that in many situations, the areas to be mapped will be inadequately controlled and that due to difficult terrains, bodies of water, or enemy action, will not be readily accessible to occupation prior to the military operation. This will render extension of control to the areas difficult and extremely time consuming (if possible at all) when attempted by conventional methods.

In circumstances such as these an ideal capability would be one in which all the required mapping data are acquired by a completely airborne system, and accurate maps compiled without reference to ground-control. Such a system would produce topographic maps of known scale to an arbitrary datum, however, any point would be true in position and elevation relative to any other point on the map. Concurrent with, or subsequent to, the acquisition of data and compilation of maps, control could be extended to the area by conventional methods or by a completely airborne system. Necessitating only a few horizontal and vertical ground-control points, the coordinate axes of the map and the vertical-control would be quickly adjusted to true datum.

The Dual Aircraft Mapping System represents such a capability. In concept it consists of two aircraft, each equipped with an aerial mapping camera, an airborne profile recorder, a means for measuring the distance between aircraft, and supplementary equipment to operate, instrument, and tie the system together. In operation, the aircraft fly abreast of each other on parallel flight lines with each taking simultaneous vertical mapping photography and making and recording measurements of the distances between aircraft at the precise instant of each exposure (Figure 1). Throughout the length of each dual flight, each aircraft records the terrain profile and aircraft clearance. With a measured distance between aircraft at each exposure point, and the forward exposure interval of the cameras set for a specific base-height ratio, each dual flight results in a series of laterally overlapping models, each with a measured airbase, and two parallel strips of in-line models (Figures 2 and 3). A series of dual flight-strips with a common overlap area between adjacent strips would provide similar coverage of a block area.

To determine the feasibility of the Dual Aircraft System, the U. S. Army Engineer Geodesy, Intelligence and Mapping Research and Development Agency (GIMRADA) prepared the general design of a system. To contract for its installation, test, and evaluation, a specification was prepared which out-

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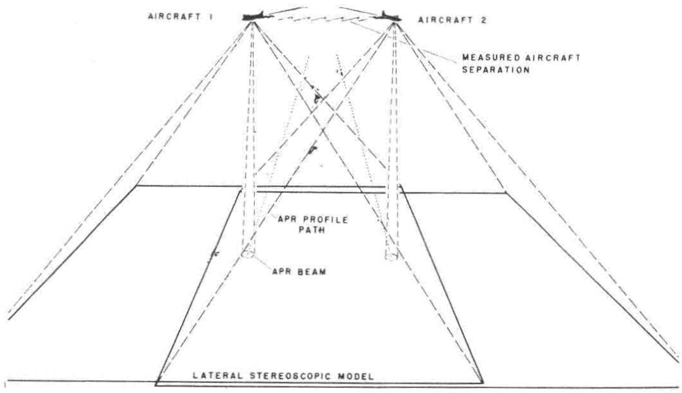

FIG. 1. This diagram shows the spacial geometry at an exposure point of the Dual Aircraft System. At the instant of each exposure, a measurement of the distance between aircraft is made.

lined the contemplated concept and defined the requirements and objectives. Although the requirements were purposely restrictive to assure attainment of the objectives, sufficient latitude was permitted to profit by the contractor's experience, ideas, and ingenuity.

The overall program was divided into three phases. The first phase required the contractor to select and assemble the necessary equipment; to develop methods for operation of the entire system; and to prepare complete plans of procedure for the latter two phases. In selection of equipment, it was stipulated that only off-the-shelf items be used, that is, no new development was to be undertaken. The second phase involved the actual installation of equipment and instruments into the aircraft; conducting the necessary checkout tests; and the full operational test of the system over a designated test area. The third and final phase required the contractor to reduce the data; establish horizontal and vertical control nets with the reduced data and to evaluate the accuracy of the established control by comparison with true ground control.

The Arizona Test Area, which is approximately 29×34 miles square and contains over 900 evenly distributed horizontal and vertical-control points, was selected as the test area. The nominal above-mean-terrain flying altitude of about 20,000 feet and aircraft separation of 12,000 feet were specified in order to realize the most convenient number of models and control points within each model. This would result in four dual strips, each consisting of two flights of fourteen in-line models and fifteen lateral models. The base-height ratio for both in-line and lateral models would be a nominal 0.6 and the percentage of side-lap between dual flights a nominal 20 per cent. Specified tolerances on data to be acquired were in most cases based on past performance or known capabilities, and in those cases where new and untried techniques were to be used, tolerances were based on accuracies required to realize the desired end results.

Award of the contract was made on 30 April 1959 to Fairchild Aerial Surveys, Inc. of Los Angeles, California. The contractor immediately initiated work on the design of a

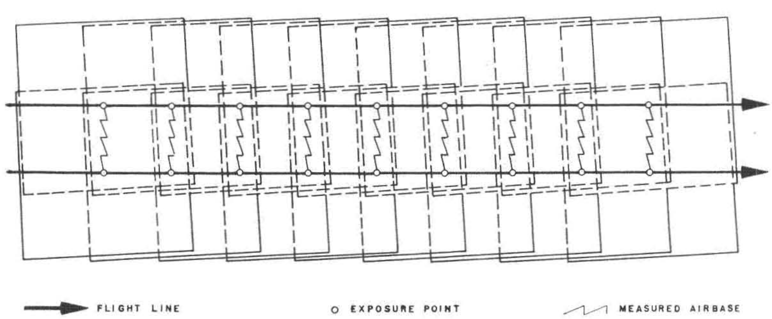

FIG. 2. Photographic configuration of a dual strip.

system and preparation of plans of procedure for the second and third phases. Work was then started on installing equipment in the aircraft. On completion of installation and calibration tests in the aircraft, operations were shifted to Phoenix, Arizona. Exact flying altitude and aircraft separation were computed to accommodate the variations in terrain relief within the test area and techniques were worked out to develop and maintain the proper flight pattern.

The system, as planned by the contractor, initially consisted of two B-17 aircraft; however, one was destroyed by fire, necessitating the substitution of a Lodestar. This required a re-adjustment of equipment due to the smaller load-carrying capacity of the substituted aircraft and, because of its considerably slower speed, the Lodestar was made the master-craft, requiring the B-17 to maintain its correct relative position in flight.

Each aircraft was basically equipped with a T-11 aerial camera and a Canadian Applied Research Laboratory Mark V-APR complete with 35 millimeter tracking camera. The measurement of distances between aircraft was accomplished by the adaptation of two systems, the Fairan and the Tellurometer. The Fairan, an adaptation of Shoran and Hiran units designed by the Fairchild Aerial Surveys Corporation and used for gross measurements to the nearest 50 feet, consisted of an AVQ-5 in the master-craft and an APN-84 in the slave. The APN-84 is the airborne portion of a conventional Shoran or Hiran unit, and the AVQ-5 is the notation for an airborne Shoran unit APN-3 modified by internal changes in the circuitry. The counter for the Fairan was located on a recording panel and a duplicate was located in front of the slave-craft pilot to assist him in maintaining proper distance from the master-craft.

The Tellurometer, used for refined measurements, consisted of the master unit in the slave-craft and the remote unit in the master-craft. Windows, large enough to accommodate the antenna dish, were cut in each aircraft and the units mounted against them. A duplicate Cathode Ray Tube Scope with leads to the master unit was mounted on a recording panel which was photographed by a 35 millimeter recording camera at each instant of measurement. The in-flight measurements, being by necessity instantaneous, prohibited repeated readings as is customary in ground application. A check was made of Tellurometer files, randomly selected, and it was found that a disparity of less than one foot could be expected if the first readings were used rather than adjusted measurements from repeated readings. Position of equipment relative to the antenna was measured in both aircraft for the purpose of reducing Tellurometer measurements to camera-to-camera distances. Data pertaining to the attitudes of the two craft relative to each other at the instants of measurements were also needed for this reduction.

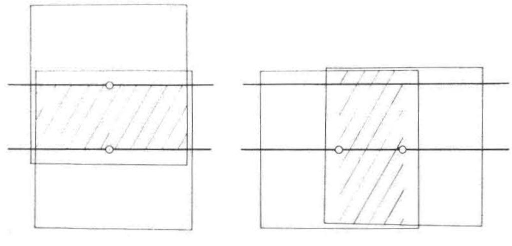

FIG. 3. Configurations of lateral and in-line models.

Prior to installing the Tellurometer units in the aircraft, a series of ground tests were made over measured ranges to determine the effects of the wing tips at various degrees of aircraft crab, angular limitations of the instrument, effects of the plexiglass windows, and effect of Fairan transmission. Results of these tests showed that no reception interference was noted until a crab-angle of 15 degrees 30 minutes was reached, which brought the wing tip into line of sight. This interference did not introduce an appreciable error. Rotation of the master unit antenna by 10 degrees to either side of line-of-sight produced only negligible error. In testing the effects of the plexiglass windows on the operation of the Tellurometer, it was found that a slight wave-shift resulted. The small measurement difference caused by the wave-shift was applied as a constant in the data reduction process. Also tested and proven on the ground was the fidelity with which the image on the CRT scope could be photographed.

The slave-aircraft was equipped with a B-3 Drift Meter with the special application of maintaining the aircraft abreast of each other to within a specified tolerance. By introduction of a prism into the instrument, the line-of-sight was converted from vertical to side-looking, enabling the operator to view the master-craft. By means of adjustable protractor rings on the drift meter, and knowledge of the current drift angle, the slave-craft maintained its proper in-line-of-flight position relative to the master-craft.

Both aircraft were equipped with Traveling

Grid View-finders for the purpose of measuring the drift angle to keep the T-11's on track, however, the one in the slave-craft also operated the entire system. It was adjusted to provide the proper in-line-of-flight overlap which, at the instant of each exposure, generated an electrical pulse that simultaneously did the following on the slave-craft:

1. Triggered the T-11 camera.
2. Triggered the two 35 mm. panel cameras.
3. Triggered the two main pens of the APR unit to impart fiducials.
4. Triggered the step-relay to operate the 35 mm. tracking camera at five exposures to one of the T-11 and APR fiducial pens.
5. Operated all counters and initiated the radio signal sent to the master-craft to perform the same function there. A time delay network was added to the slave-craft circuitry to assure a close synchronization of all equipment.

Pre-operational calibration of each APR unit consisted of tests to determine the parallelism of the tracking camera and antenna axes and "second echo tests" to determine the calibration constants.

All mapping data were indexed and recorded by means of fiducial counters during the actual acquistion. All flight data necessary for the reduction of mapping data was instrumented on recording panels and photographed by 35 mm. panel cameras.

On completion of the second or data acquisition phase, the third and final phase was initiated by the contractor. Fairan and Tellurometer readings were reduced, combined and adjusted to camera-to-camera distances. On each of the vertical mapping photos a clearly defined photo image, close to the principal-point and labeled "practical photo-center," was selected and marked. Horizontal ground-control points to be used as pass-points were selected and marked on the photos, making certain that the number and distribution of points were adequate for evaluation. Control-point descriptions, with coordinates and elevations withheld to prevent possible bias, were used for this purpose.

Vertical-control for the leveling of models was obtained by reduction of APR data. Inasmuch as each flight was independently tied to the isobaric surface, adjustments were made to bring both flights of a dual strip to a common datum. This resulted in the APR vertical-control of each dual strip to be on an independent, arbitrary datum.

Instrumentation work was done on the C-8 Stereoplanigraph at a scale of 1/20,000. The lateral models of each dual strip were set up first, establishing scale by introduction of camera-to-camera distances reduced to Bx settings, and leveling to APR-derived elevations. Machine coordinates were recorded for all pass-points and "practical photo-centers." From the machine coordinate Z-values, actual elevations of pass-points and "practical photo-centers" were computed to the arbitrary datum of the dual strip. Using lateral model derived horizontal coordinates of the "practical photo-centers," coordinate measurements were made on which to base all in-line models.

The in-line models of each dual strip were then set up, establishing scale and leveling by means of coordinate measurements and computed elevations from the lateral models. Machine coordinates were recorded for all pass-points and "practical photo-centers" and elevations were computed to the dual-strip vertical datum from the machine coordinate Z-values. The in-line models permitted the establishment of control in the overlap areas between the dual strips.

Since all models were set up independently without carry-over, each was on its own xy coordinate system. Models within dual flights were adjusted to each other by best possible fit of common pass-points, and the coordinate-axes of each model were translated and rotated to a common system. Using the same procedure, the dual strips were brought to a common arbitrary coordinate system. This resulted in each pass-point having several coordinate values, the number depending on the number of models in which it appeared. Weighted means were computed and a single set of coordinate values were established for each pass-point.

As previously stated, each dual strip had its own vertical datum and, to bring them to a common datum, the vertical differences of common pass-points in the overlap areas between dual-strips were computed and meaned. Using these mean values, adjustments were made to the strips and thus networks of horizontal and vertical control, each tied to an arbitrary datum, were established.

Tests of the accuracy of the established horizontal-control required adjusting the network to one true, horizontal-control point and an azimuth without disturbing the scale or configuration of the network. The coordinate-axes of the horizontal network were translated to attain coincidence of the true point and the established point and then rotated to attain coincidence of the azimuths. In a similar manner the vertical-control was adjusted to true datum by means of one vertical-control point.

Positional differences between true and established points and vertical differences between true and established elevations were computed from which the horizontal Circle of Probable Error and the vertical Standard Deviation of errors were computed. The size of the established network was approximately 765 square miles and contained 206 established points. Evaluation of the 206 points resulted in a horizontal CPE of 35.5 feet and a Standard Deviation of vertical errors of 16.5 feet.

This test and test results proved without doubt the capability and practicability of the system. This first attempt was a "bread board model" in which several of the components used were not designed for this application. From experience and information gained in this test, it is obvious that the system can be improved considerably in both equipment and techniques which will probably improve accuracy.

Many applications of this system are foreseeable in both military and domestic mapping operations. In the military sense, a particular advantage is that maps of known scale can be quickly compiled and made available for use prior to occupation or extension of control to the area. These maps can be oriented for limited use by the user until ground control is established and the maps adjusted to true datum. Typical applications, besides normal mapping missions, in which this system would be particularly advantageous include the mapping of areas of difficult accessibility including islands and those areas under recent atomic bombardment, uncontrolled areas, and/or areas in which military operations are anticipated and maps are quickly and urgently needed. Other applications in which this system would be adaptable are the study and measurement of clouds and ocean waves.

*The Optimization of Photographic Systems**

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ABSTRACT: *A quantity which is useful for optimizing photographic systems is the signal-to-noise ratio. This ratio is expressed as a function of the photographic parameters by means of Selwyn's equation Several examples of optimizing the signal-to-noise ratio are given. These result in the derivation of several well-known concepts in photography. In the case of exposure this procedure leads to the maximum resolving power criterion. The significance of resolving power is clarified. The magnification of the final image is an integral part of the system. A simple derivation of Selwyn's equation is given.*

INTRODUCTION

PHOTOGRAPHY is gradually changing from an art into a science. The traditional approach to photographic problems has been by trial and error. For example, if obtaining an optimum photographic exposure were particularly important, one photograph would be taken at the estimated proper exposure, a second taken with less exposure and a third taken with more exposure. One of these pictures probably would have an exposure close to the optimum.

Although the trial-and-error solution is still useful for many photographic problems, it is unsuitable for the general problem of the design of photographic systems. For example, some photographic problems involve the design of the vehicle which carries the camera. The vehicle and camera as a whole must be designed for optimum performance. Too many variables are involved to use trial-and-error methods. Moreover, because of the considerable expense involved, it is important that the best possible photographic per-

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