GEODETIC APPLICATIONS

An application of ballistic cameras which will assume greater and greater importance as missile testing requirements become increasingly stringent, has to do with the improvement of the range survey, which is currently regarded as being accurate to about 1 part in 100,000. Newly developed photogrammetric methods, which underwent a successful field test last year, are expected ultimately to improve the range survey to about 1 part in 300,000 or better. The observations required to accomplish this will, for the most part, be acquired purely as by-products of missile tests already programmed for the next few years. It is believed that as the satellite age unfolds, geodetic photogrammetry will find important applications elsewhere.

CONCLUSIONS

The importance of ballistic cameras as a calibration standard is derived from the fact that somewhat conflicting trajectories are obtained from the various tracking systems observing a given missile flight. Such inconsistencies reflect the systematic or bias errors made by the systems. The "bias factor" of a system may be defined as the ratio of the bias in a typical observation to the standard deviation of the observation (the standard deviation, of course, is a measure of the purely random or accidental error). With cinetheodolite data, for example, the standard deviations of the measured angles range typically from 5 to 10 seconds of arc, while the bias errors range typically from 20 to 40 seconds of arc. Hence the bias factor for cinetheodolite data may range from 2 to 8. Again, one of the more precise of the electronic tracking systems is capable of measuring direction cosines having standard deviations of only 2 to 5 parts per million. On the other hand, the biases in the direction cosines usually range from 50 to 150 parts per million giving the system a bias factor of 10 to 75.

The ballistic camera is the only missile tracking system of high precision which can consistently produce data having a bias factor of substantially less than unity. Consequently, it is also the only system of high precision for which statistically meaningful and precise statements can be made concerning the absolute accuracy of the final product. High precision coupled with a low-bias factor thus makes the ballistic camera uniquely qualified to serve as a calibration standard for other instrumentation. It is therefore highly desirable in missile testing to reconcile conflicting trajectories by "hanging" them upon a ballistic camera trajectory which in turn, is "hung" upon the stars.

An Application of Photogrammetry to Radar Research Studies[*]

EARL S. LEONARDO,
Development Engineer, Aerophysics Dept.,
Goodyear Aircraft Corp., Litchfield Park, Ariz.

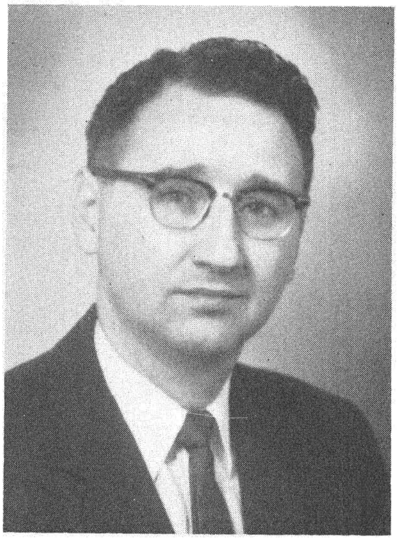
(*Abstract is on next page*)

DURING the past year, Goodyear Aircraft Corporation, in conjunction with the Applied Physics Laboratory of The Johns Hopkins University, carried out a radar return research program sponsored by the Navy Bureau of Ordnance. Its purpose was to accurately identify and measure radar return signals at various depression angles from different types of terrain: cultivated areas, forest, lakes, desert areas, and grasslands or meadows. To a lesser degree, identification of return from cultural targets was also included in the program. Relatively flat land was desired, as the many variations in slope and elevation of mountainous or broken terrain would have required intricate, if not impossible, data-reduction procedures.

For this study, Goodyear developed an accurately calibrated side-looking, non-scanning, strip-mapping radar, which was installed in the nose of a P2V-3W "Neptune" aircraft. The radar antenna was pre-set to look perpendicular to the aircraft's desired heading. Since the antenna was gyro-stabi-

---

[*] Presented at the Society's 25th Annual Meeting, Hotel Shoreham, Washington, D. C. March 10, 1959. This paper is a part of the panel on Special Applications of Photogrammetry.



EARL S. LEONARDO

lized, it maintained its setting within about ±0.25 degree, despite normal variations from the flight path by the aircraft. Figure 1 shows the ground illumination pattern of the radar. At 10,000 feet above the ground, the radar illuminated the sector between depression angles of 10 and 70 degrees, or the strip lying between 0.6 and 9.3 nautical miles from the flight path of the plane. Figure 2 shows how the radar return was displayed in the aircraft on a cathode-ray tube, then photographed by a continuous-strip camera. The resulting strip map had a scale of, roughly, 20 miles to the inch.

ABSTRACT: *A radar research program was undertaken by Goodyear Aircraft Corporation, Arizona Division, to identify and measure radar return signals from various types of terrain. Under this program, the cathode-ray tube presentation from a side-looking radar developed at GAC was photographed by a continuous-strip camera to produce recognizable radar maps. The similarities and dissimilarities between low-resolution radar maps and conventional photographs or maps are discussed and illustrated. A description follows of the photogrammetric and cartographic techniques used to obtain additional data for a comprehensive electronic and mathematical analysis of all the data-recording systems in the complete installation.*

How does a radar terrain photograph differ from a conventional aerial photograph? For one thing, a conventional photograph records almost everything that is visible, but is normally obtainable only under certain conditions of light and weather; radar, of course, is not subject to these limitations. However, radar will record only those features that reflect the transmitted microwave energy back to the antenna. Further, the direction from which a radar scans an area will affect the intensity of the signal return. Despite these differences, remarkable visible similarity exists between Goodyear radar photographs and conventional aerial photographs, or other cartographic material. Figures 3 through 7 are radar maps made with a low-resolution radar system. GAC, Arizona, is also flight testing high-resolution radar systems.

Figure 3 is a radar map of New York City, Central Park on Manhattan Island lies in the center; the Hudson River and New Jersey Shore appear on the left, the East River and Queens on the right. While the area below Central Park on Manhattan has the larger buildings (such as the Empire State Building and other skyscrapers and the buildings around Times Square) it does not show as strong a signal return as the bright area of Queens, with its smaller buildings.

The difference in signal return can be explained as follows. In both Queens and Manhattan, the city blocks are solidly built-up rectangles; but, in Manhattan, the narrow side of the rectangle faces the radar beam, while across the East River in Queens, the long side of the block is so oriented. The long side of the block presents a larger reflecting surface to the radar beam and thus appears as a brighter image, or target, on the radar map. The orientation of the blocks can be verified by consulting large-scale topographic maps of the area.

Figure 4 is a radar map of cotton fields near Chandler, Arizona. The differences in the strength of returned signals are due to the same phenomenon observed in regard to the buildings in Figure 3. The cotton rows parallel to the radar beam present a larger reflecting surface than the rows perpendicular to the

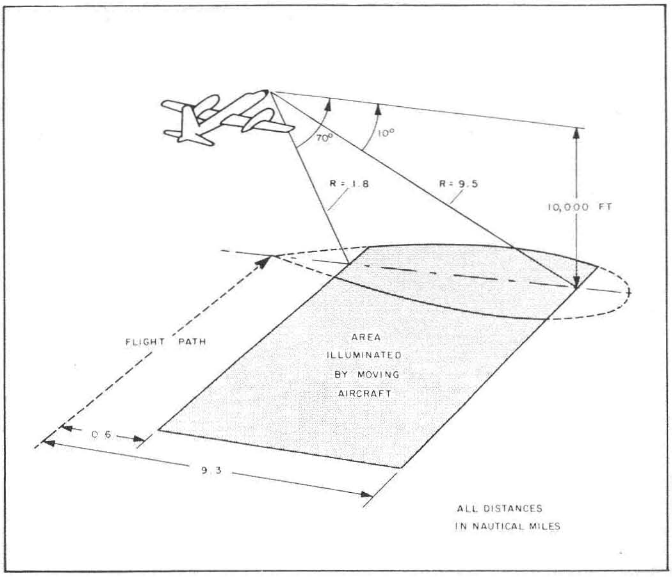


FIG. 1. Radar antenna coverage.

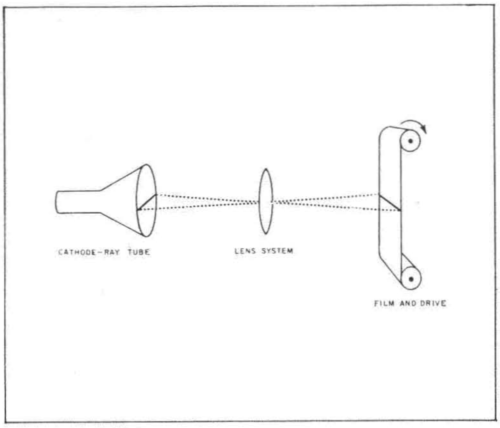


FIG. 2. Formation of radar strip map.

beam and, hence, appear brighter. The black areas on the map represent plowed or fallow fields.

Figure 5 shows a radar photograph of a mountain range in southwestern Arizona and part of a photo-index mosaic of the same area. Note the general conformity between them.

Figure 6 is a radar map together with a topographic map of lakes and forests northwest of Duluth, Minnesota. Identification of specific lakes is relatively easy. When large-scale topographic maps are used for comparison, forests and open areas can be identified on the radar maps.

FIG. 3. Radar map of New York City.

Figure 7 shows a radar map and a nautical chart of the Florida Keys area. Note how the causeway connecting the various keys is sharply defined on the radar map.

In the photographic and photogrammetric work for the Goodyear research program, a Maurer 70 mm. format camera with a 38 mm. lens was used. It was vertically mounted in a Steinheil gyro-stabilized camera mount. An exposure was made every 20 seconds—about once every nautical mile, assuming an aircraft speed of about 180 knots. The pulse that triggered the camera placed a reference

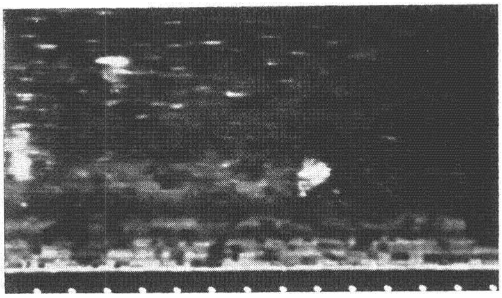


FIG. 4. Radar map of cotton fields in central Arizona.

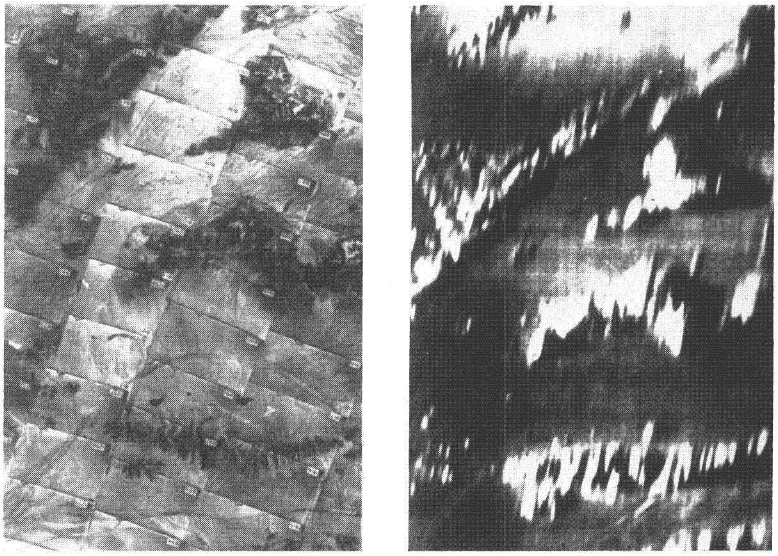


FIG. 5. Radar map and photo index of mountains in southwestern Arizona.

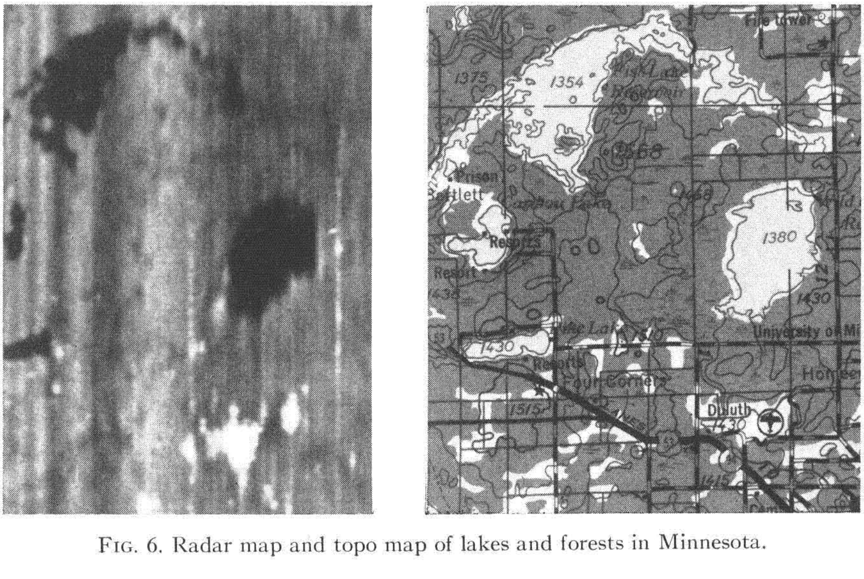


FIG. 6. Radar map and topo map of lakes and forests in Minnesota.

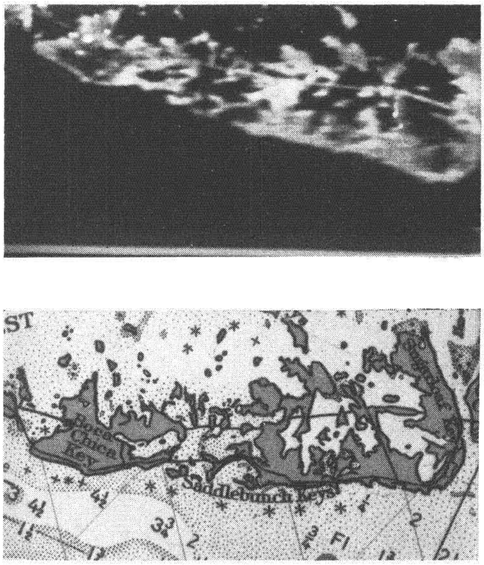


FIG. 7. Radar map and nautical chart of Florida Keys.

mark on the radar map and the other data-recording systems that were part of the entire installation.

To obtain the flight path of the aircraft, the principal points of the photographs were plotted on large-scale topographic maps. Since the gyro-stabilized camera mount kept the camera to within ±0.5 degree of arc of the vertical, the use of the principal points proved to be a sufficiently accurate method for locating the flight path.

The altitude of each exposure was computed; then it was possible to plot the exact limits of radar coverage on the topographic maps, since these limits were directly dependent on the altitude of the plane. Also, at each exposure station a profile was prepared of the ground covered by the radar beam. Where necessary, profiles were prepared at intermediate points. On occasion, a profile running the length of the radar map at a specified range from the aircraft was prepared to determine the exact ground elevation of the target and, thus, the exact depression-angle, as this angle is a function of ground range to the target and the height of the antenna above the target (see Figure 1).

While these operations were being performed, 20× enlargements of the radar maps were prepared for use in target identification. The identification was accomplished by map study, stereo study of conventional photographs, and field trips. On the field trips, an actual field check was performed; on a radar map were marked such things as type of crop, direction of planting, height of vegetation, whether the vegetation was narrow- or broad-leafed, size and orientation of farm buildings, type and height of trees, whether the trees were deciduous or coniferous, and the size of meadows or clearings.

As many ground photos were taken of these features as seemed necessary. For example, on a four-day trip to Minnesota in August 1958, the author took about 90 photographs, half of which were in color.

All data-recording systems of the complete installation were then subjected to a comprehensive electronic and mathematical analysis. The data obtained by photogrammetric and cartographic methods—antenna altitude, range from antenna to target, ground elevation of target, and target identification—were included in the analysis. The validity and accuracy of these photogrammetric operations influenced the accuracy of the interpretation of the final results. For instance, the signal return from a cotton field will vary with its depression-angle, and photogrammetric computations were necessary as part of the systems analysis resolving this and other parameters.

Photogrammetry is proving to be a valuable tool in radar research; at the same time radar, because of its varied needs, is expanding the potential of photogrammetry. These present contacts will benefit both technologies and will provide the stimulus for increasingly more fruitful contacts in the future