avoided if another project were undertaken while some others could not. One time-saving device highly desirable would be a printing counter for machine coordinates, now standard on the newer first-order instruments. Experience gained by personnel would permit greater efficiency in a similar undertaking. As was pointed out at first, it will probably be difficult to find another area with so many factors favorable to photogrammetry. The expense of going into the area twice and setting up a camp is a disadvantage of this method. A complete survey would permit a comparison more favorable to photogrammetry than the skeleton survey described here. One conclusion seems certain, the method is not adapted to a survey of a small area. The extent to which it will be used for other original surveys is a matter for further study.

This project is an example of one of a number of techniques under consideration by the Bureau of Land Management as an aid in speeding up surveys in Alaska and the unsurveyed lands in the other States of the West.

*The Use of Doppler Radar in Present and Future Mapping Operations**

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ABSTRACT—*The removal of the military security restrictions on the Doppler Radar Navigation System has made possible adding a new tool to the commercially available electronic distance-measuring devices.*

The purpose of this paper is to explore the possibilities which this new instrument offers to the surveying and mapping profession. Since only a very limited amount of practical experience exists in this new application of Doppler, the ideas presented herewith should be considered as suggestions for studies to obtain the necessary statistical data to verify and prove our fondest hopes.

AT PRESENT, our position is the same as that of enthusiastic and optimistic pioneers after the Second World War, when Shoran was a navigation instrument and its development as a geodetic measuring instrument was proposed. The theory and instrumentation of the Doppler system which measures ground speed and drift angle by means of radar signals emitted from the aircraft and reflected from the terrain is assumed to be known. However, a short description of the Doppler principle seems to be in order.

Figure 1 shows an aircraft emitting two pencils of radiation downward and which are reflected back to the aircraft. The difference between the emitted signal-frequency and the received signal-frequency from a forward and backward-looking pair of radiation beams is measured. This difference is proportional to the aircraft's ground speed. If we use four beams radiating symmetrically to the aircraft axis, covering the ground in an x-shaped pattern, the drift-angle of the aircraft can be measured. The Doppler echo frequency-shifts from the two diagonal pairs of pencils are compared. If they differ, the antenna is not aligned with the actual path being flown, and the aircraft is drifting. The frequency difference actuates a servo mechanism, which rotates the antenna, aligning the beams with the actual path flown. The angle through

* Presented at the 25th Society's Annual Meeting, Hotel Shoreham, Washington, D. C. March 8 to 11, 1959.

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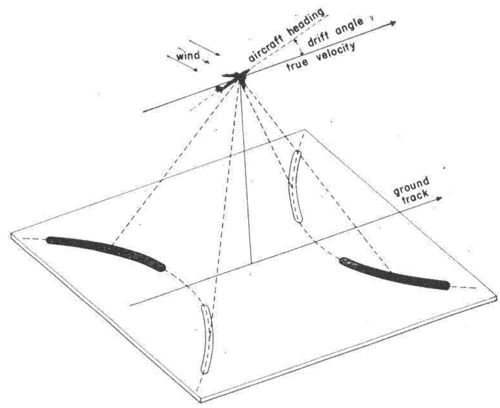

FIG. 2

which the antenna was rotated is the drift-angle.

Figure 2 shows the four-beam principle. The important advantage of Doppler is the fact that all measurements are made in the aircraft without any assistance from ground stations. This short explanation of the Doppler principle will be considered sufficient, since we are concerned here only with the application of the system to photogrammetric and surveying problems.

Aero Service Corporation owns and operates Radan, a commercial version of the military model, which is installed in a DC-3 for magnetometer survey navigation. This Doppler system consists of transmitter, antenna, receiver, gyrocompass and a special computer which determines continuously the distance traveled as well as the lateral deviation from the pre-selected track. All this information is available in digital form to the pilot and the data compiler. Since it is quite evident that these data are exactly what is needed for photogrammetric purposes, the only question which must be answered satisfactorily is: "What is the accuracy?" As of now, we have only the word of the manufacturer and the enthusiastic reports from pilots, Lacking are statistics substantiating these astonishing claims.

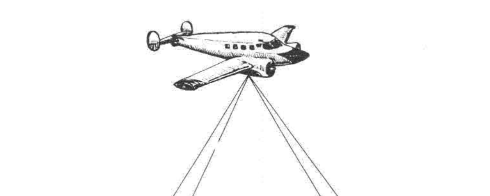

FIG. 1

It appears that distance accuracies of 0.2% or better can be obtained. This error magnitude is within the realm of photogrammetric applications.

A test flight was made with Aero Service's Radan along a straight railroad track where the 9″×9″ mapping camera was triggered by the Doppler computer at equidistant intervals. The actual exposure intervals were then checked by photogrammetrically measuring the ground distance between the nadir points of the photos. The maximum error was 9 feet for a 1,500-foot base.

Let us look into the future and see how we would use the Doppler information.

1. The system can be used immediately in connection with the airborne profile recorder (APR) to determine the slope of the isobaric surface, which is usually given by the formula:

$$\Delta h = 0.0351 \times \sin\phi \times s \times V_A \times \sin\delta$$

where

- $\sin\phi$ is a constant for a certain flight-line
- V_A is the true air-speed
- $\sin\delta$ is the sine of the drift-angle, and
- s is the distance between exposure stations.

The Doppler computer determines continuously the true air-speed, the sine of the

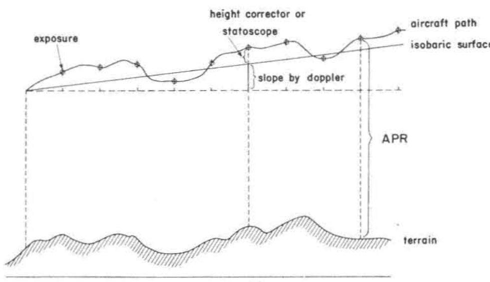

FIG. 3

drift-angle and the distance along the track. It is, therefore, possible to determine automatically the elevation difference of successive exposure stations. It might be pointed out that only the height corrector of the APR or a statoscope is necessary for this procedure.

Since the drift angle is the most critical quantity in the above equation, its *continuous* and more accurate determination by Doppler will increase the slope accuracy considerably over the present method of measuring the drift angle with a driftmeter at relatively large distance intervals.

2. A photo mission flown with a Doppler-equipped aircraft allows keeping the sidelap to a minimum, reducing the number of stereomodels. Gaps in the photography due to poor navigation can be completely eliminated, reducing the amount of costly reflights.

3. If further tests prove sufficiently accurate for determining also the distance between exposure stations, aerial bridging will be greatly facilitated. Combined with the height-difference information explained before, we would have an excellent system for photogrammetric control-extension. The test flight along the railroad track, which we have mentioned earlier, indicates that this procedure is well within the capability of the Doppler system.

Going a step further, we visualize the use of Doppler in connection with Shoran or Hiran surveys. The tri-lateration network will furnish the basic horizontal control to which the *Doppler controlled* photos are adjusted. The selection of Shoran stations is then divorced from the photo aspect, and they can be placed on easily accessible points without the present restrictions imposed on them by station angle limitation. The occupation period of the ground station will be much shorter, since they are not needed for the aerial photo work, thus reducing the problems of logistics considerably.

Cumbersome reconnaissance trips to the highest points in the survey area, to determine the horizon profiles, necessary for present Shoran controlled photography work, are reduced to trips to more accessible locations, since complete horizon profiles are not required for tri-lateration flying.

Shoran equipment maintenance will be easier, since it can be returned to base after a relatively short station occupation, thus reducing also the length of time between equipment calibrations.

Selected Doppler flight lines can be checked with Shoran, providing an excellent means for calibration of the Doppler system.

In order to strengthen the Doppler controlled photography, more Shoran tri-latera

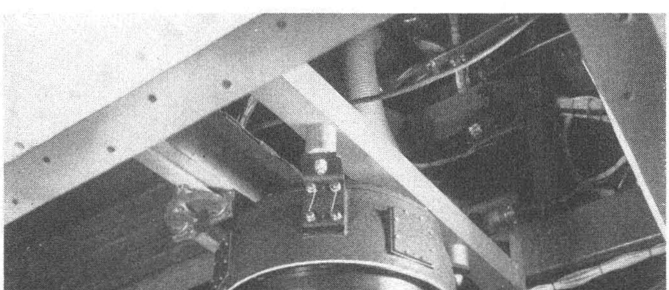

FIG. 4. Antenna of self-contained Doppler navigation system mounted flush in belly of Aero's DC-3.

tion stations will be needed than in regular Shoran controlled surveys. This, however, need not be a disadvantage, because the restrictions imposed on present Shoran station locations are greatly reduced. The tri-lateration network obtained in this manner will be used in all future survey projects which will certainly follow a small-scale Doppler controlled mapping program.

Pure Doppler flights can be used to determine the geographic positions of flight-line intersections within an accuracy obtainable by usual astro field methods. This procedure was used by Aero Service on a recent magnetometer survey over the Libyan Desert. The flight path was photographed on strip film from 1,500 feet above ground. At 4 km. intervals, a fiducial mark was exposed on the film triggered by the Doppler computer. Flight-line intersections were then determined from the strip film interpolating the interval for distance. The strip film intersections were then transferred onto existing 9″×9″ photographs and a radial photo templet-laydown was made, using the astro positions as basic control. The Doppler distances were compared with the astro controlled templet distances resulting in an average distance error of 0.22%. However, this test cannot be considered as conclusive for the attainable accuracy. The distance comparison is based on astros in an area which is known to have large deflections of the vertical and is lacking ideal identifiable terrain features. This leaves too much to unaccountable facts.

It would be highly desirable to perform a test over well-mapped territory with the Doppler lines flown in such a manner that enough redundant measurements are available, and where errors due to the insufficient reference data are eliminated.

Since the azimuth of the flight line is determined by reference to a compass aboard the aircraft, the accuracy and dependability of this compass become matters of great importance. We use a Kearfott J-4 compass, either as a high-precision magnetic compass, or in free mode, as a low-drift inertial reference. Its operation has been satisfactory, but the magnetic compensation of the aircraft has not yet been carried out to the limit we desire.

We realize that the feasibility of the ideas presented here depend on further investigation of the capability of the Doppler system for photogrammetric purposes. It has proven its value as a navigation device, and it seems to us, based on the short experience gained with the instrument, that its use for small-scale mapping is well within its range. At present there are at least four different Doppler systems commercially available: the Decca, the Marconi, the Laboratory for Electronics and the Radan. Each of these makes has different characteristics, advantages and disadvantages.

Aero Service will welcome the opportunity of keeping the Society advised of future experience gained by the Company with its Radan equipment.

*ACIC Objectives for Photographic Quality Control**

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(*Abstract is on next page*)

A RECENT magazine article stated that science and technology have been expanding at an annual rate of 5 to 7 per cent. Such a rate of expansion means a doubling in about 15 years.[1] How the photographic industry would rate under such a system is not definitely known, but from a user standpoint the author would be inclined to place it at or near the top.

A part of the mission of the Aeronautical

* Presented at the Society's 25th Annual Meeting, Hotel Shoreham, Washington, D. C., March 8 to 11, 1950.

[1] Foote, P. D., Industrial and Engineering Chemistry, Vol. 51, No. 2, p. 91A (1959).