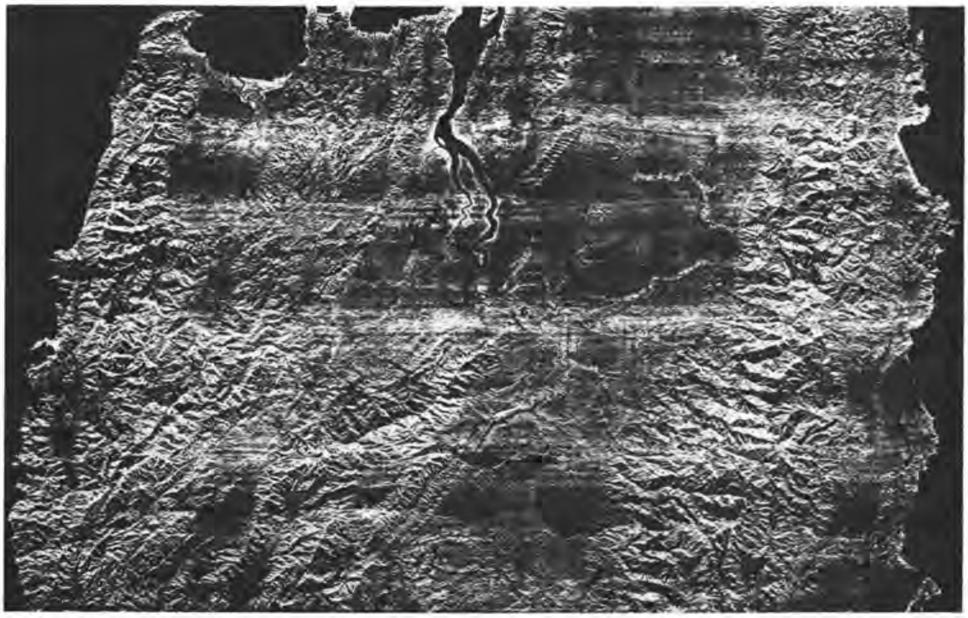

Frontispiece. Uncontrolled radar mosaic of Darien Province in the Republic of Panama, an area for which conventional aerial photographs have not been obtained because of continual cloud cover.

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Radar Mapping in Panama

Radar may offer the only practical means for mapping large areas of the earth that are continually covered by clouds.

(Abstract on next page)

THE DARIEN PROVINCE is the easternmost political division of the Republic of Panama (Figure 1). Along the natural barrier created by two large mountain ranges lies the border which separates Panama and Colombia. From some unidentified peak in this vast jungle domain Vasco Nunez de Balboa first view that part of the Pacific Ocean he named the Gulf of San Miguel. Yet 454 years later, the Darien remains virtually unchanged by civilization, a tribute to its impregnable swamp lands and mountainous jungle terrain.

More recently, part of this region has become known as the *Darien Gap* because it stands as an impassable barrier to the completion of approximately 300 miles of the Pan American Highway that otherwise reaches from Argentina to Alaska. The *Darien Gap* is an appropriate name because in the mapping field the Darien also creates another *gap*, a void in the photo coverage used to make topographic maps. This is not because of the jungle, but is due to the continuous cloud conditions that exist over this region.

Since 1947 the Army has tried to obtain suitable mapping photography of the Darien using conventional mapping techniques, always without success. In November 1965, the Topographic Sciences Division, Office of the Chief of Engineers, Headquarters, Department of the Army, made arrangements to fly

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the APQ-97 (XE-1) high-resolution radar over Southeast Panama and Northwest Colombia to:

- Determine the feasibility of producing topographic maps from high resolution side-looking radar presentations.
- Determine the performance characteristics of existing radar equipment in a near operational environment.
- Establish concepts and techniques for radar mapping data reduction and compilation.
- Obtain original mapping coverage over a geographic area with a known history of continually inclement weather.

ABSTRACT: *The APQ-97 side-looking radar system was used to produce a "radar mosaic" of a portion of Darien Province in the Republic of Panama, an area which is persistently covered by clouds so as to prevent successful aerial mapping photography. To serve as control points, 5-foot corner reflectors were placed at 13 locations in the 6,000 square-mile area through the use of helicopters. Six flight lines were successfully flown. The data reduction was handled by Raytheon/Autometric. The resulting uncontrolled radar mosaic was used for geologic and hydrologic purposes.*

As WITH ANY R & D program of this type, the problems at first seemed insurmountable. Funding, government and commercial coordination, engineering and political problems had to be considered. These were all eventually resolved and the success of the program is a credit to those individuals both commercial and government who combined their efforts to achieve the final goal.

The APQ-97 was developed by Westinghouse Electric Corporation for the U. S. Army Electronics Command (ECOM) as a surveillance and target location radar system. This system is contained in a YEA-3A twin engine jet with the antenna located in a pod beneath the aircraft (Figure 2). This pod is stabilized in roll, pitch and yaw. During its development period, the Army Engineer Topographic Laboratories, formerly the U. S. Army Engineer Geodesy, Intelligence Mapping Research and Development Agency (GIMRADA) at Fort Belvoir, Virginia monitored the program and performed tests which concluded that the system was capable of providing data from which 1:250,000 topographic maps could be produced.

Although the utilization of radar photography for purposes of making maps has been

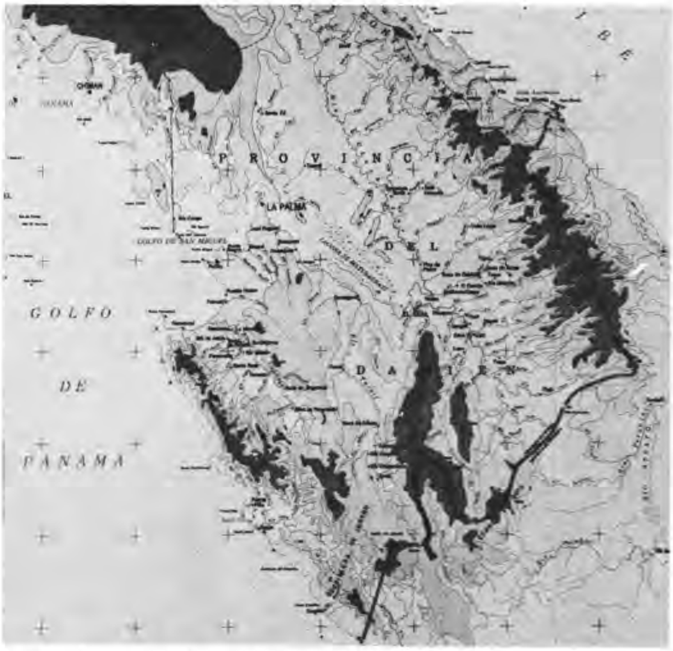

FIG. 1. A portion of an aeronautical chart showing Darien Province.

studied and tested for many years, Project RAMP is the first program ever conducted to obtain radar data for mapping purposes alone. It was considered that the APQ-97 radar most nearly met the performance characteristics required for mapping at 1:250,000 scale. The ideal side-looking airborne radar mapping system elements are as follows:

- A slant range presentation.
- A record of aircraft elevation above sea level.
- A record of aircraft elevation above terrain.
- Navigational positions of the aircraft in latitude and longitude.
- Film-speed correlated to aircraft ground speed (scale).
- Provision for altitude delay.
- Range and timing marks on the film.
- A large film format.

GENERALLY, RADAR presentations do not yield geometrically correct plan-position information suitable for planimetric mapping. The apparent distortion of the radar presentations is attributed to several factors, and it is necessary to correct these distortions before the information contained on the photography can be properly utilized. That is why a constant effort was made to obtain sufficient auxiliary data to control the radar photography.

Unfortunately, all these desirable system elements were not available on the APQ-97, namely, the ground speed and drift angle information. An effort was made to remedy the situation by installing a doppler navigator in the aircraft to provide the desired ground speed and drift angle information. This was to be used in conjunction with the antenna motions, aircraft heading and necessary timing information to relate the auxiliary data to the radar photography during the data reduction process. However, all efforts to make the doppler perform satisfactorily failed, although experts worked on the equipment until the date of deployment. Lack of the doppler data subsequently forced changes to the data reduction procedures and increased the time for delivery of the final end product.

Through the Inter American Geodetic Survey (IAGS) at Fort Clayton, Canal Zone, arrangements were made to obtain the support of the Panamanian and Colombian Governments in this mapping program. In addition, IAGS undertook the job of clearing and erecting radar reflectors on existing geodetic control stations located throughout the area to be mapped (Figure 3). This was a tremendous task because it involved clearing the jungle growth around each station to provide line-of-sight visibility to the aircraft.

Fig. 2. The YEA-3A twin engine jet aircraft with the radar antenna contained in the pod beneath the fusilage.

This task began in November and was completed the week that flying operations began in January 1967.

THE RADAR REFLECTORS measured 5½ feet square with crossed triangular panels 46.5 inches high; each weighed 150 pounds (Figure 4). For convenience they were cut into smaller sections which made them more convenient to carry, yet simple to assemble in the field. Angles between panels and between panels and the base were designed to be $90° \pm 0.25°$. The radar reflector, when assembled, contained a cluster of four corner reflectors. This assembly was designed for radar detection and identification 100 percent of the time when placed in dense foliage. Each reflector of the cluster gave coverage of 60 degrees in the azimuth plane, and from 15 degrees to 75 degrees in the elevation plane. During field installation, one edge of the reflector base was oriented to $318° \pm 3°$ to the true northerly direction and leveled on the ground to $0° \pm 2°$. Tree areas, surrounding each reflector, greater (in height) than 15 degrees line-of-sight were cleared. This meant that with tree heights of 25 feet, an area with a diameter of 360 feet was cleared. Trees much taller than this were generally encountered.

Original plans were to install between 30 and 40 stations to maintain density of control. This plan was quickly abandoned when the magnitude of the operation was surveyed during a visit to the Darien. Many of the stations could only be approached on foot after traveling the waterways by canoe. This entailed not only carrying the radar reflector but also the equipment for clearing and erecting the stations. Where possible, helicopters were used for this task (Figure 5). In all, 13 stations were finally erected.

Base of operations for the field control work

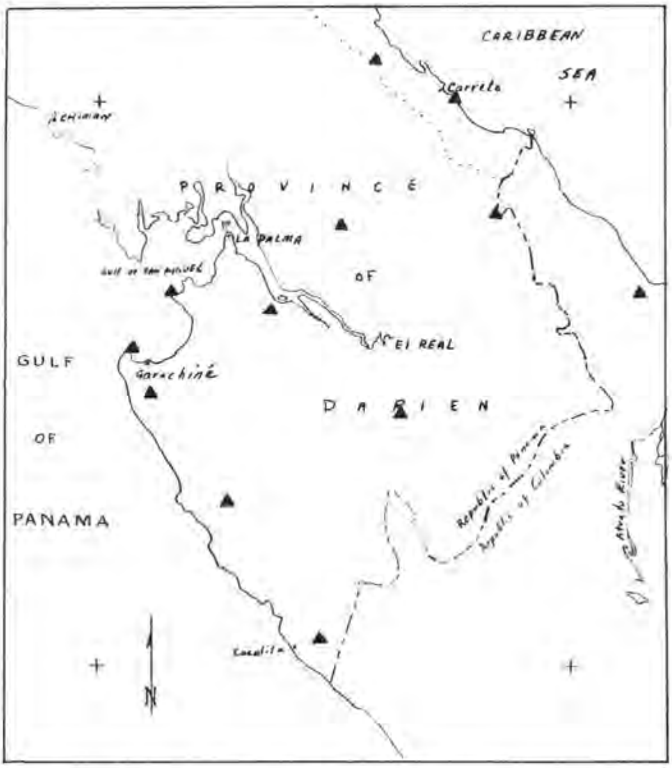

FIG. 3. Sketch of Darien Province showing the locations of the radar reflectors that served as control points.

was El Real which is located at the approximate geographic center of the Darien Province (Figure 6). Gasoline and supplies were shipped by boat to El Real from the Canal Zone. A short grass airstrip located near the town was used for the small Army aircraft and the contract helicopters (Figure 7). Flying conditions for these helicopters were extremely hazardous due to the ground fog and clouds that existed over some of the control stations.

In a region such as this the most critical problem for mapping, of course, is the control. In addition to the 13 geodetic control points, additional control was required, and any and all sources of information were investigated. The 1:50,000 scale class B maps bordering either side of the unmapped area, level lines along the proposed Pan American Highway, TACAN positional data and even radar tracking data provided by the FAA weather radar on Toboga Island were gratefully accepted as input information for the data reduction process. Of course, the overlapping flight lines and cross flights provided additional tie points and redundancy for controlling the compilation.

EIGHT FLIGHT LINES were laid out in a northeast-southwest direction covering an area of approximately 6,000 square miles from La Palma southeast to include the Colombia border and the area between from coast to coast (Figure 8). Each flight line was to overlap the adjacent one by approximately two miles. Due to the difficulty in entering each flight line precisely, it was not always possible to overlap the lines as planned. Consequently, at the conclusion of each flight an index was prepared to determine gap areas in preparation for the next flight. The total area could have been covered completely in one flight had the spacing been accurate. Malfunctions of magnetic tape recorders, air conditioning system, and burned out components in various electronic equipment were also cause for reflights. In all, six flights were made over the Darien before a ruptured fuel tank on the aircraft forced cancellation of the remaining two flights. Between each mapping run, which occurred every three to four days, the magnetic tapes were shipped to the Westinghouse plant in Baltimore for verification of the auxiliary data.

Meteorological observations and measure-

FIG. 4. A radar reflector consisted of a cluster of four corner reflectors measuring 5.5 feet on a side and 3.9 feet high and weighing 150 pounds; the unit was disassembled for convenience in carrying.

ments in the Darien Province are scarce (Figure 9). The most recent information is based on data recorded at El Real between June and August 1962 for the Transportation Research Command. The weather was overcast during the entire period and cloud cover of 100 percent was recorded for 65 percent of the time, about 80 to 90 percent for another 20 percent

FIG. 5. Helicopters were used to transport the radar reflectors to their sites.

FIG. 6. The "terminal" at the El Real landing strip.

FIG. 7. The air strip at El Real.

of the time, and 60 to 70 percent for the remaining 15 percent of the time during daylight. This is an average of 83 percent cloud cover 100 percent of the time. Cloud ceiling was under 4,500 feet generally and less than 1,500 feet 50 percent of the time. Although

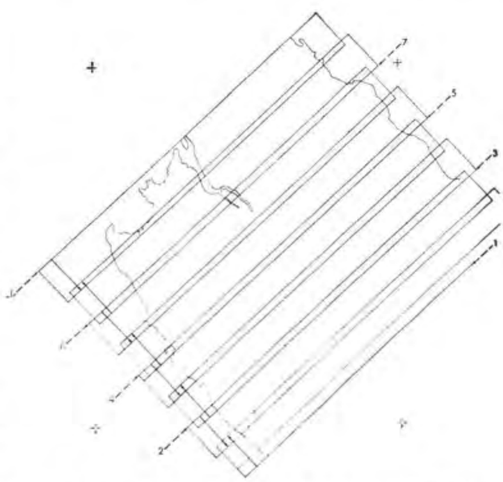

FIG. 8. Eight flight lines were laid covering about 6,000 square miles.

FIG. 9. The weather was overcast during the entire period, and cloud cover of 100 percent was recorded 65 percent of the time.

FIG. 10. Mensuration equipment used on Project RAMP included this Gilleland Point Coordinate Mensurator, a partly automated type of comparator.

the radar mapping program was conducted during the dry season, which runs from mid December to March, no apparent change was noted in cloud conditions from the rainy season although meteorological data was not obtained.

Data reduction is being handled by Raytheon/Autometric under contract to the Army Engineer Topographic Laboratories. The objective is to produce 1:250,000 scale topographic maps and semi-controlled mosaics.

BECAUSE THIS IS the first radar mapping program ever undertaken, the procedures for data reduction have not been definitely established. As with any R & D program, plans change with the situation. The original concept for map compilation was to determine the aircraft flight path using the inputs from the doppler navigator and measurements on the imagery. However, because the doppler was inoperative, an alternate plan was developed. The present procedure is to obtain a large number of measurements on the film for selected points in the overlap areas of adjacent strips of radar photography. These measurements will be adjusted in a least-square manner to provide the best fit to the controlled radar reflector positions. With this step completed the radar records will be put into an electronic sketching device and the planimetric imagery will be transferred to the base map projection. Vertical control information will be produced in a computer to provide dropline contour information. These dropline contours will be converted to regular line contours and fitted to the planimetric map. A color separation will then be made and the printing accomplished.

Although it has been nearly 30 years since the first photograph of an airborne radar scope was obtained, mapping from radar is still very much in its infancy. Project RAMP has gone a long way in proving the feasibility of mapping from radar presentations. Already the uncontrolled radar mosaic is being utilized for geologic and hydrologic purposes (Frontispiece). The hope is for continued advancement in the art of radar data collection and data reduction. The next step forward depends largely on the order of priority and urgency for its need in defense mapping.

For about four million square miles of the earth's surface, the weather conditions are such that little or no photographic mapping data can be obtained. These areas are generally in the tropic latitudes, and radar may be the only means by which complete mapping coverage of such places will be obtained.

The author is grateful to the Instituto Cartografico *Tommy Guardia*, Republic of Panama, the Ministry of National Defense, and Instituto Geographico *Augustin Codazzi*, Republic of Colombia for the assistance provided the Corps of Engineers in carrying out this radar mapping program and for their courteous cooperation in permitting the tests to be conducted over part of their territories.