*Test Results, Accuracies, and Uses of the Airborne Profile Recorder**

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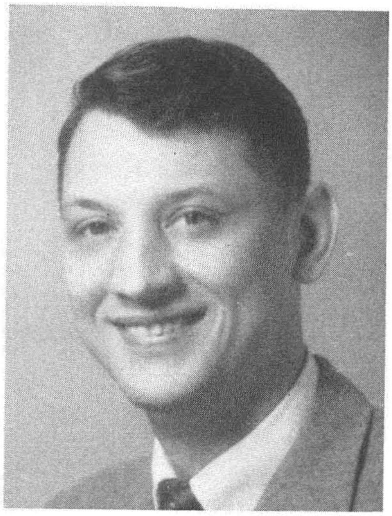
ABSTRACT: *The Canadian Applied Research Ltd., airborne profile recorder MK-5 was flighted by the 1370th Photo Mapping Group at West Palm Beach, Florida.*

Three different areas in the southern part of the United States were flown over and data collected. The three areas included several different types of terrain. The airborne profile recorder data were reduced by ERDL and the accuracies were found acceptable. The recorder under proper use, both in flying and data reduction, can be considered a first-order surveying tool to obtain vertical-control for mapping and charting.

At present the Air Force has no firm program for using the airborne profile recorder, but it is anticipated that the above tests will result in several new requirements for airborne profile recorder data in conjunction with vertical mapping photography, or a special airborne profile recorder mission from the Mapping and Charting Organizations of the Armed Services.

IN JANUARY, 1958, Lockheed Aircraft Corporation, under the supervision of the Aerial Reconnaissance Laboratory of Wright Air Development Center, completed modifying a Lockheed C-130A Hercules Aircraft, for research-and-development testing of a new Electronic Hiran Mapping sub-system. One of the new pieces of equipment to be tested, as part of the sub-system, was the Recording Set, Terrain Profile, AN/APQ-78 (XH-1). This is more commonly known as the Airborne Profile Recorder MK-5, and in this paper is referenced as the APR. Three APR's were procured from Canadian Applied Research Limited as commercial items, and were given the official Air Force nomenclature.



JOHN R. ANDERSON

The basic APR system consists of the following six units:

Console Assembly.—This assembly consists of an aluminum cabinet which contains, a dual-pen recorder, timing circuits, monitor circuit, power supply circuit, and the operator's controls.

Transmitter-receiver.—This unit includes a micro-wave hybrid duplexer, crystal detector, magnetron and hydrogen-thyra-

* Presented at the Society's 25th Annual Meeting, Hotel Shoreham, Washington, D. C. March 8 to 11, 1959. Official clearance action for publishing this paper has been taken.

tron pulse modulator, modulator driver stages, high-voltage power supply, and five-stage video amplifier.

Transmitter-receiver Mounting Tray.—This is a standard 4-point shock-mount assembly.

Inverter.—A Jack and Heintz F 16-4 inverter is used. It is capable of converting the aircraft's 28-v d-c supply to closely-regulated 400 cps 115-v alternating current which is used for the power supply and for the servo-motor excitation.

Hypsometer Head.—This is a cylindrical glass-lined container partly filled with toluene. It includes a thermistor, resistor, condenser, and electrical connectors for attaching the cables to the back panel of the console and to the static lines of the aircraft.

Antenna Assembly.—This assembly consists of a double dipole in a parabolic reflector. The antenna is fed from a Type RG-52/U wave-guide which terminates in a choke coupling.

The APR is an electronic device used for aerial surveying determining the relative heights of ground points along the flight path of the aircraft.

The APR contains two distinct measuring systems, namely a highly accurate radar-altimeter to measure terrain clearance, and a sensitive pressure-altimeter to measure variations from level flight. Both systems are combined in a single unit which is used to measure terrain-profile. Two simultaneous and continuous records are supplied on a paper-chart recorder by the APR, the first being terrain clearance as measured by the radar-altimeter, and the second being a terrain-profile as provided by the difference between the radar and pressure-altimeter readings. The clearance record is used to determine the photographic scale; the profile record provides vertical control for topographic purposes. The recorded data are correlated to geographic positions through using simultaneous vertical mapping photography.

Figure 1 is a block diagram of the APR and the camera system as installed in the C-130A test bed used for flight testing. Included with the diagram are the data that the APR operator was instructed to record manually on the chart paper. The mapping photography was obtained with a KC-1 Camera mounted in one of the Air Force's newly-developed torque-gyro-stabilized camera-mounts so as to hold the camera in a level position despite in-flight motions of the aircraft. The antenna of the APR unit was mounted in a stabilized A-28 Camera Mount which was slaved to the mount of the KC-1 Mapping Camera. In this way, the vertical axis of the mapping camera and the antenna of the APR are vertically coincident. The 70-mm. camera was not stabilized. Instead, it was rigidly attached to the frame of the aircraft.

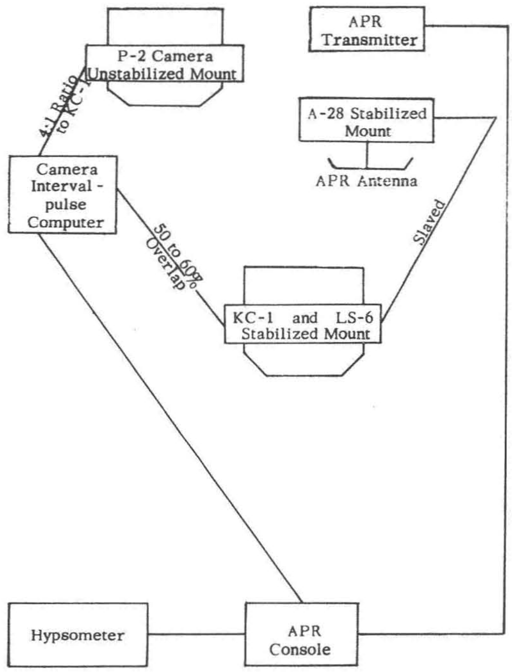


FIG. 1. Airborne Profile Recorder System as installed in C-130A test bed. 1. The following will be recorded on the Airborne Profile Recorder console chart paper by the Airborne Profile Recorder operator.

a. Latitude of flight-line, beginning and end of flight-line on east-west flights and as often as operationally possible on north-south flights.
b. True air speed beginning of flight-line and whenever true air speed varies over ±5 knots.
c. True heading beginning and end of flight-line.
d. Terrain Camera KC-1 frame number as often as convenient, at least beginning and end of flight-line.
e. Step-switch setting, as often as the switch changes.

FLIGHT TESTS

Flight tests of the APR were made by the 1370th Photo Mapping Group at West Palm Beach Air Force Base, Florida. Wright Air Development Center, in cooperation with the USAERDL at Ft. Belvoir, Virginia, and the

Air Proving Ground Command, prepared the flight test plan.

As originally planned, the flight testing was to be accomplished in five sorties. However, Sortie 2 was never flown because its original intent was accomplished by the four which were flown. The sortie numbers used in this paper are the numbers originally assigned.

Sortie 1.—This was flown at an altitude of 30,000 feet along the 37th parallel, from the Mississippi River to the Kentucky-Virginia State line. The terrain was both flat and mountainous.

Sorties 3 and 4.—These were flown at an altitude of 20,000 feet over a quadrilateral course which began at the airport in Atlanta, Georgia, continued to Greenville, South Carolina, thence to Knoxville and Chattanooga, Tennessee in turn, and ended at Atlanta. These sorties were flown in an attempt to see if there was any change in accuracies obtained on different days with different weather conditions.

Sortie 5.—This was flown along a short section of a road called Range Line Road; this had been surveyed and showed picture-point marks. The terrain camera was "fired" every half-mile, regardless of altitude and overlapping of the photographs. The attempt was to determine whether a half-mile distance between photographic exposures was enough, insufficient, or an excessive distance for the spotting camera. In addition, the flight was to show how the APR operated at different altitudes. Flights were made at 4,000, 8,000, 16,000, 20,000, and 28,000 feet.

Data Reduction

The data were reduced at USAERDL. Therefore, information on data reduction is based on Mr. J. M. Halsey's letter report "Evaluation of APR Data from the C-130 Test Aircraft."

The 1370th Photo Mapping Group supplied the following material to USAERDL:—original negatives of the mapping photography, prints of the mapping photography, the APR charts, and the original negatives of the 70-mm. photographs. Following receipt, USAERDL inspected all the items to determine their suitability for use in the reduction of data and to determine whether or not the Air Force should re-fly any of the sorties.

The sorties over flat terrain were evaluated without the aid of photogrammetric instruments. The others, which produced photography showing quite a lot of ground relief, were evaluated by using models set up in the Wild Stereo Plotter, Type A-7 (referenced hereafter as the Wild A-7). The ground-control was taken from topographic maps of 1:25,000 and 1:50,000 scale.

The isobaric surface was computed according to Henry's formula which is:

$$D = \frac{\sin L}{} \sin \alpha (TAS)(S_2 - S_1)(45.65)$$

where

L = latitude in degrees
g = gravitational constant in cm/sec.^{2}
α = drift angle in degrees
TAS = true air speed in knots
$(S^2 - S^1)$ = distance in nautical miles

Results of Tests

Sortie 5

Sortie 5 was the first one evaluated. Since the terrain elevation varied only a few feet along the entire flight-line, the terrain was considered flat; accordingly no photogrammetric instrument was used. The profiles were analyzed visually. The conclusions were as follows:

1. The equipment operated equally well at all altitudes.

2. Large random tilts occurred in both the mapping photography and APR antenna despite the stabilized mounts. These errors or tilts can be explained. The C-130, when carrying a load as light as the mapping and charting equipment, handles like a fighter aircraft. During Sortie 5, the pilot, in correcting his course, tilted the aircraft faster than the mounts could follow. This was shown by the fixed 70-mm. camera. It is obvious, therefore, that corrections must be slow-skid corrections when stabilized mounts are used, or, at least, must be slower than the C-130 can react if really "racked" over.

3. The 70-mm. photography was useless. It was meant to be used only for studying drift-angle. Certainly, we cannot call the effort successful.

4. The alignment of the mapping camera and the APR antenna axis was never determined by actual flights. However, even without test results, USAERDL was suspicious that the alignment was not as good as intended.

5. The annotation of the APR chart was not sufficiently good.

To summarize the results of Sortie 5, it can be said that the APR operated accurately at all altitudes up to 28,000 feet, that a definite procedure must be worked out for flying the APR, and that a different installation must be devised for using the APR in other Mapping and Charting aircraft.

SORTIE 1

Sortie 1 was the second to be evaluated. It covered a distance of approximately 350 miles. This flight-line, from the Mississippi River to the Kentucky-Virginia border, was over terrain which progressed from flat to rolling to mountainous terrain. The test data were evaluated visually and by photogrammetric analysis. Two groups of stereo models were set up in the Wild A-7. One was near the beginning of the flight-line and the other at the center. Twelve models were set up to spot elevations taken from large-scale maps. These were 10-foot Contour National Standard Accuracy Maps. They have spot elevations that should be accurate to ± 2.5 feet 90 per cent of the time.

A datum was established for each model and the elevations of approximately 10 points along the profile were determined. It was necessary to assume that the APR groundtrack was along the lines joining the principal points of the KC-1 photographs. The selected points were valley bottoms, hilltops, etc.

Stereo models were not set up in the mountainous area at the eastern end of the flight because only two or three usable APR points were available for each model. In the area of relatively flat terrain there were four models.

The APR points were compared with the elevation interpreted from the maps. The root mean square (RMS) error of the 120 points used in the 12 stereo models was 12.25 feet. The RMS error for the 10 points in the mountainous area was 36.7 feet. The APR datum established for each model indicated an isobaric surface slope of 230 feet over the complete flight-line of 350 miles. The slope of the isobaric surface could not be computed because there was no drift-angle data on this flight.

SORTIE 3

The results of Sortie 3 were evaluated visually and by photogrammetric analysis. The four legs of the flight were 130, 105, 95, and 100 miles long, respectively. Three stereo models at each end of each leg were set up in the Wild A-7 to map-control similar to that used for the 37th parallel flight. A total of 24 models was used; each model had from 4 to 13 APR points, depending on the number of suitable points available. The total number of points used was 204.

The terrain over which this flight was made varied from the fairly flat to the rolling type. The RMS errors were related directly to the amount of relief present. The isobaric surface was computed at several points around the quadrilateral flight-line and an adjustment was made back from the closure point. The difference between the computed datum and the adjusted datum was 29 feet. This small error in a 430-mile closed loop indicated that the formula for the isobaric surface is satisfactory.

SORTIE 4

Sortie 4 was checked and evaluated visually. Other than the quality of the photography taken when there was some cloud coverage, the flight results were approximately the same as those obtained during Sortie 3.

OVER-ALL TEST RESULTS

The over-all results of the flight tests showed that the airborne profile recorder data, when collected with sufficient auxiliary data and properly reduced, can give vertical-control for mapping and charting. However, the present installation of the APR and the camera system in the C-130 test bed aircraft are unsatisfactory. The ideal installation would be to mount the 70-mm. camera rigidly to the APR antenna. But this cannot be accomplished because we cannot photograph through the radome material. The next best solution to the problem would be to slave another mount and the APR antenna to the same vertical reference unit. This would require the following equipment being built and installed in the aircraft:

a. A stabilized mount to stabilize the pitch and roll of the P-2 Camera, the mount to be slaved from the vertical reference unit of the prime vertical camera mount.
b. A 250-foot magazine equipped with a frame counter and a clock for the P-2 Camera.
c. A camera frame counter to be positioned near the APR station so that correlation can be made with the paper chart. The ideal equipment installation would provide a stamp so that frame numbers could be marked on the chart automatically.

Potential Uses of APR

Plans are in process to properly install the APR system in the RC-130 Mapping and

Charting aircrafts. When the necessary changes have been completed, it is believed that the airborne profile recorder can be used on several different types of missions. The following four examples should indicate the APR's versatility.

1. The APR can be *operated in conjunction with Hiran Equipment on a Hiran-controlled photographic mission.* This type of mission will provide mapping photography for which the geodetic position of the camera at the instant of exposure of each photograph is determined by electronic measurements. This is accomplished by recording on film for each exposure of the mapping camera, the Hiran measurements from the aircraft to two Hiran ground stations of known positions. By proper use of auxiliary data (such as weather, altitude, etc.) recorded at the same time, the position of the exposure station can be established with sufficient accuracy for 1/50,000 scale mapping, and under optimum conditions for 1/25,000 scale mapping. This mission would enable the Air Force to record APR and Hiran data. Both horizontal and vertical control would be possible on the same mission.

2. The APR can be *operated on a regular Precision Aerial Mapping mission to obtain vertical-control.* The aircraft will have special navigational and camera equipment which will permit procuring precision mapping photography over long distances controlling the forward overlap and sidelap to a high degree of accuracy. It should be understood that on the missions mentioned in example 1 and in this example, vertical-control will be obtained only along the flight line.

3. A third potential use for the APR is on *Hiran line-crossing missions used in electronic aerial surveying.* This type of mission will determine accurately the distances between two points on the earth. In other words, electronic equipment aboard this aircraft can accurately measure by a process of trilateration, the distance between two widely separated ground stations (up to 500 miles) with first-order accuracy. To accomplish this, the aircraft flies a course roughly perpendicular to the line joining the two stations near its center. Distances from the aircraft to each ground station are continuously measured and are recorded on film, together with other auxiliary data. These slant range distances and auxiliary data are then reduced by means of a computer to a geodetic distance between the two stations. An entire network of accurately measured distances can be established and the longitude and latitude of each ground station can be determined. The APR has never been used on such a mission but there is no technical reason why such an application should not work and no reason is known why it should not improve the accuracies of the Hiran trilateration mission. On the Hiran missions, radar altitude and pressure altitude are both required, and the APR can record both altitudes. Also, by computing the isobaric surface, corrections can be made to the pressure altitude. No error-analysis of the method has been made to determine what improvement could be obtained, but the method should eliminate most of the errors caused by incorrect datum reference.

4. The use of the APR may be extremely *valuable for a vertical-control mission.* On this type of mission, the APR would be operated with its auxiliary data collecting equipments. The mission would be flown after the photographic mission had been accomplished. The flight line is laid out in the side-lap of the photographic mission. The APR mission would be flown along the line at an altitude from 6,000 to 10,000 feet. It is believed that the APR is most accurate at altitudes between 6,000 and 10,000 feet, because the isobaric surface is more stable within these altitudes. When the data from this type of mission have been reduced, vertical-control points along the side-lap flight line may be obtained. These control points may be used as picture points for stereo-mapping. Such a mission is especially important when ground surveying is impossible or impractical in areas which must be mapped.

Conclusions

The information in this paper should not be construed as a recommendation by the Air Force for the use of the APR for mapping and charting. However, on the basis of test results, it can be said that the APR is an accurate airborne surveying tool. The Air Force has procured five of the AN/APQ-78 Terrain Profile Recorders for use, as the occasion may demand, in any of their RC-130 Mapping and Charting aircraft now being delivered to the using Command.