A New Development Program for the Airborne Profile Recorder

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IN 1957 Mr. R. A. Stewart of the Department of Mines and Technical Surveys, Ottawa, presented a paper to the New York Region of this Society on the mapping of the Foxe Peninsula. At the start he referred to "necessity" and "improvisation" as being the two factors which came to the fore in carrying out this mapping project. Because of the existing ground and climatic conditions it was decided to utilize as much airborne equipment as practicable to supplement use of ground parties. Included in the group of airborne instruments was the Airborne Profile Recorder (APR) for vertical control.

This was one of the first major projects on which the Mark 5 APR system was used. Until 1955 the previous APR systems were for the most part modified wartime airborne radar systems. Although adequate for medium altitude operations the repair and maintenance of these systems were awkward due to the bulkiness of the chassis. During 1955 and 1956 the MK 5 system was developed. This Airborne Profile Recorder was designed for ease of maintenance while in flight, and the individual circuits were designed for reliability by current techniques at that time. On this first major project a great deal was learned about the problems of high altitude operations in remote areas, particularly those concerning the long-term use of the APR at high altitude. This was the first redevelopment program carried out on the APR system. Results of the Foxe Peninsula project indicated an average APR error of ± 10 feet, after adjustment, and at selected points the accuracy was from 6 to 8 feet. This accuracy was quite adequate for 1/50,000 mapping, although the project was for 1–250,000 scale.

As a result of this first project, modifications were made to the MK-5 APR system over the past five years to improve reliability and mean time to failure figures. It is only during the last year that there have been developed and placed on the market reliable components which will allow consideration to be given to a new major development program.

The purpose of this paper is to outline first, the principles of the present system; second, some of the MK-5 system shortcomings in the light of the present trend in airborne survey techniques; and third, the new developments required to keep in pace with the trend.

Please note that throughout the following text use will be made of the term "'System" meaning the Mark 5 Airborne Profile Recorder (commercial) and the Mark 6 Airborne Profile Recorder (military). Both systems are alike in size, weight, and operating characteristics.

Figure 1 illustrates the complete APR system as shipped for installation. Figure 2 is a block diagram of the System.

Briefly the system consists of two measuring devices:

(a) A pulsed radar system particularly designed for establishing the clearance height of the aircraft above the terrain. The radar portion consists of an antenna, a transmitter, a receiver, and the radar timing circuits. The output is fed into the blue channel of a two-pen chart recorder.

(b) An accurate pressure deviation measuring device (the hypsometer) capable of sensing the deviations of the aircraft from a chosen pressure surface. This portion consists of a pitot or static source, hypsometer head, and an electrical data converter (the hypsometer chassis). This output is fed through a mixer to the red channel of the recorder.

The radar output is fed to the mixer mentioned in (b) where it is combined with the pressure deviation data to produce the relative profile data in the red channel of the recorder.

The pulsed radar system employs a center reference time measuring system of a novel and simplified design which effects a sub-

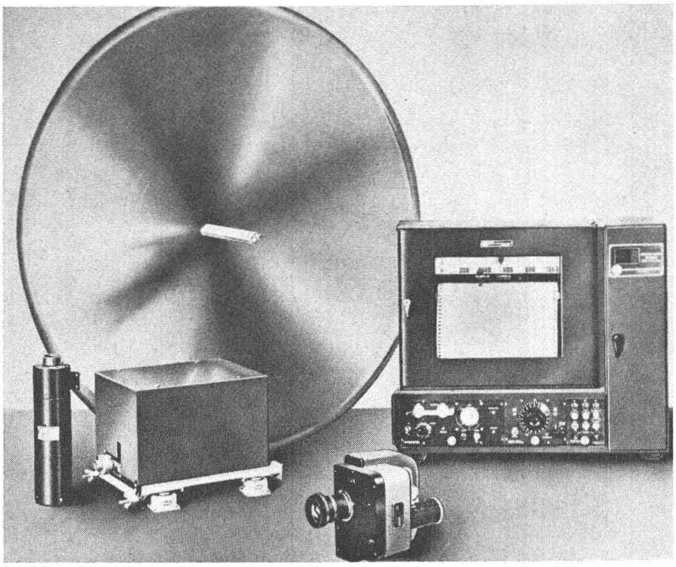

FIG. 1. APR 5 system as shipped for installation.

stantial saving in weight. The circuit design is also of such a nature that inaccuracies of the timing circuit and the recording devices, common to most radar systems, are for the most part compensated for.

The pressure measuring system employs the hyposometer principle, whereby pressure changes are sensed by electrically determining the saturated vapor temperature of a boiling fluid, when that fluid is in an atmospheric environment similar to that to be measured.

The hypsometer, illustrated in Figure 3, comprises a metal tube containing a fluid, a heating element, and a thermistor. The heavy metal portion at the top of the head forms the fluid condenser. The thermistor is placed above the fluid level in the area of the vapor formed by the boiling fluid. The thermistor is mounted on a heavy rod which is placed so as to conduct the condensate from the top of the tube down to and over the thermistor. The baffles, illustrated in the drawing, control the

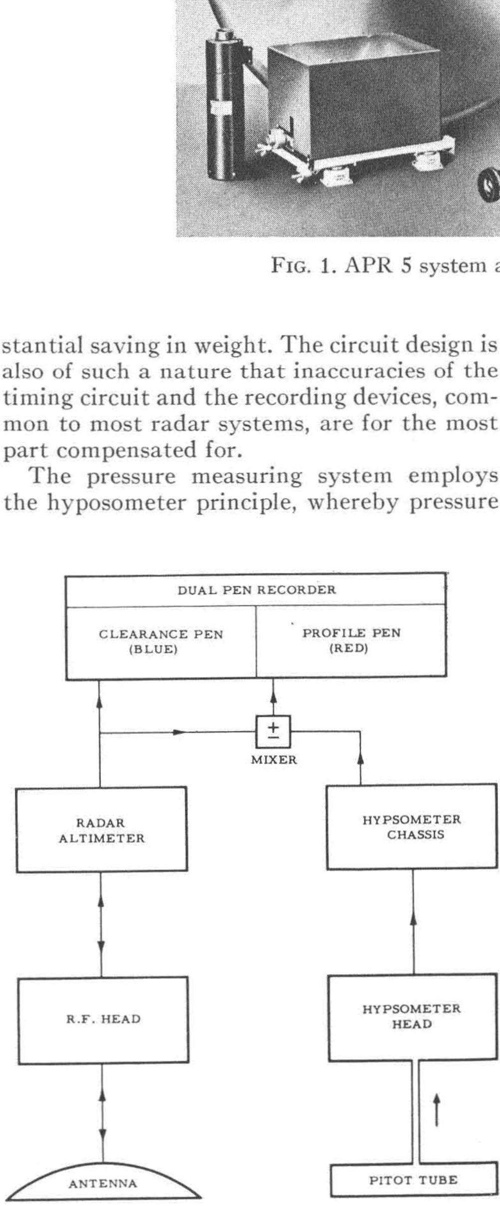

FIG. 2. Block Diagram of APR 5 system.

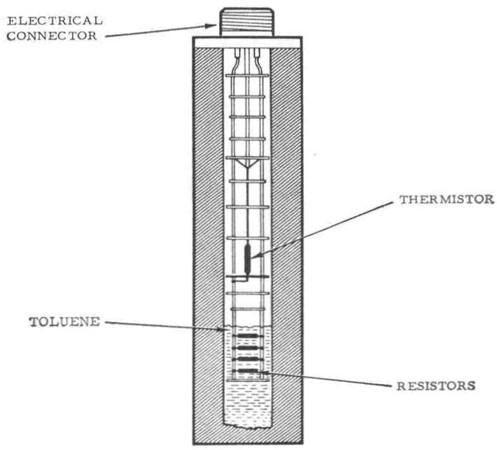

FIG. 3. Sectional view of Hypsometer Head.

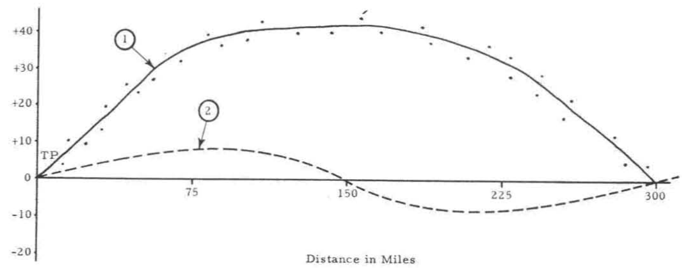

FIG. 4. Comparison of high-altitude photography error curves and those using APR system. (Note: Unit of measure on Vertical Scale is *feet*.)

vapor flow in the tube, thus preventing temperature errors due to convection.

A more detailed technical description of both the APR system and the circuitry involved is available from The Special Products & Applied Research Division of de Havilland Aircraft of Canada, Limited. The operational use of the APR System should also be briefly described for those who are not too familiar with the applications of the System.

Figure 4 illustrates the fundamental use of the APR System. Curve 1 represents a typical error curve for a long flight line for topographic mapping by high altitude photography. Curve 2 indicates the error curve when the same photography is flown simultaneously with the APR System, at the same altitude. By using selected APR points along the line the error is greatly reduced.

The terrain clearance information, being available as a part of the relative profile data, is recorded for vertical scale.

Figure 5 illustrates the common type of APR operation. Line (a) represents the chosen isobaric surface along which the aircraft is flown. Line (b) is the flight path of the aircraft. The hypsometer measures the deviation *Dx* and automatically compensates for this aircraft deviation over a range of ±250 feet. This means that the profile data are referenced to the isobaric surface which in turn can be referenced to sea level by determining *Bx*, the barimetric correction, by T. G. Henry's formula.

Now if (*i*) is a ground point of known elevation above sea level, the (*h*) at any unknown point *x* can be determined by the following:

$$H_x = h_i + C_i$$

and H_x is also equal to

$$C_x + h_x + D_x - B_x$$

Since D_x is automatically compensated for in the system to produce the red pen reading, then:

$$H_x = C_x + h_x - B_x$$
$$h_i + C_i = C_x + h_x - B_x$$

then

$$h_x = (h_i + C_i) - (C_x - B_x)$$

h_x is further adjusted, of course, by the application of a closure Q_x error. Therefore $h_x = (h_i + C_i) - (C_x - B_x) - Q_x$ where Q_x is the closure error at x. From this equation several methods can be devised for the application of the APR data. This equation is also used to evolve digital methods for the APR system data reduction.

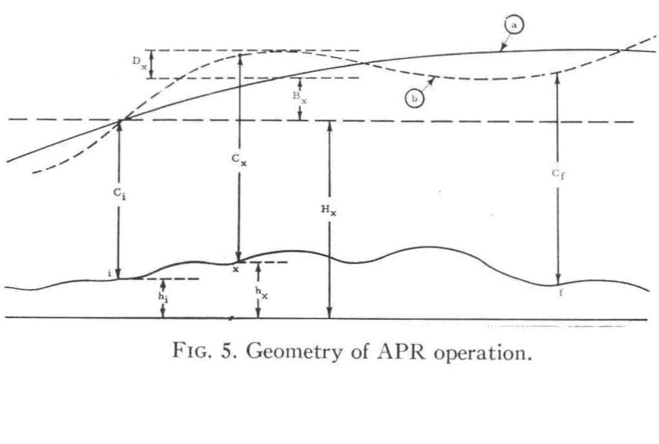

FIG. 5. Geometry of APR operation.

From a statistical analysis and experimental flying it was found that the APR system could be successfully flown over an altitude range of 1,500 to 30,000 feet and meet the required accuracy. This experimental work placed the Pulse Recurrence Frequency of the Transmitter at 2,000 pulses per second and the system time constant at $\frac{1}{4}$ second.

Recent flights have proved the APR system meets the same accuracy requirements at altitudes of 45,000 to 50,000 feet.

Figure 6 illustrates the theoretical approach to choosing Pulse Recurrence Frequency and System Time Constant. In combination these two factors determine the scanning rate of the radar system. In the present APR System $2,000/4=500$ pulses are theoretically used to produce a change in output data. In Figure 6 it is evident that if we consider each triangle as a pulse of RF energy and plot the average terrain height under the triangle, the more triangles we have, up to a point, the closer we come to having a plot of the true profile.

Table I shows some representative heights and illuminated areas. The present system beam-width is 1 degree. The diameter of the illuminated area is $h/57$. The illuminated area receives 2,000 pulses of energy per second and the recording pens are activated by the return of 500 of these pulses. Under these conditions any high peaks on the edge of the area are virtually eliminated, and a reading is obtained which is within 2 or 3 feet of the relative elevation of the area in the center of the beam.

A 100 to 150 millisecond transmitter pulse provides a fair vertical resolution, and it is tolerated because this pulse width is at the limit of the "X" band magnetron's power handling capabilities.

Other unique features of the APR system design serve to enhance the resultant data; however, these features do not have a direct bearing on the subject of this paper, and time will not be taken to delve into the technical aspects of the circuit design.

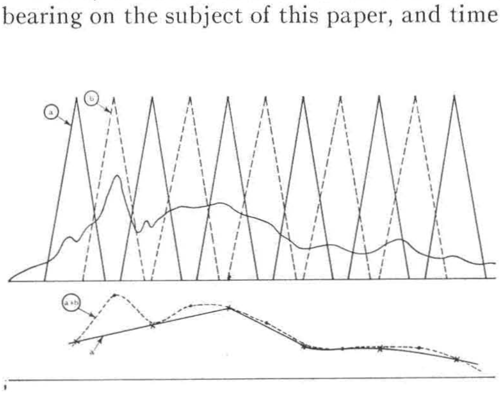

FIG. 6. Correlation of pulse recurrence frequency and systems time constant.

TABLE I

REPRESENTATIVE HEIGHTS AND CORRESPONDING ILLUMINATED AREA OF PRESENT SYSTEM

Altitude (*H*)	*Diameter of Illuminated Area*
5,000 feet	88 feet
10,000	176
15,000	264
20,000	352
25,000	440
30,000	528

The information presented up to this point is believed to be sufficient to permit an intelligent discussion of planned future developments.

The ever-increasing altitude and speed characteristics of modern aircraft tend to keep the airborne equipment designer in a constant program of redesign and new development. In the airborne survey field this is also true, more so perhaps, because of the recent advances made in the development of ground data processing methods and equipment. The use of the computer and the precise stereo plotter naturally require similar airborne equipment improvements to complement them.

In 1946 the APR System was flown at an altitude of 10,000 feet as the optimum operational height.

Around 1955, aircraft and cameras came into use which were suitable for 30,000-foot operation. The APR-5 was developed to meet this altitude requirement. Although 30,000 to 35,000 feet is still recognized to be the optimum mapping altitude, mainly for economic reasons, tests are now underway to prove the feasibility of operating at much higher altitudes. It will not be long before operating altitudes of 50,000 to 55,000 feet will be considered standard for reconnaissance mapping aircraft.

In our experience involving unpressurized or partially pressurized aircraft operating at 30,000 to 35,000 feet over the past years, we believe we can foresee the following areas which will require redesign:

(a) Above altitudes of 40,000 feet the partially pressurized aircraft environment will place physical and mental strains on the equipment operating personnel, which tend to affect them more

TABLE II
REPRESENTATIVE HEIGHTS AND CORRESPONDING ILLUMINATED AREA OF VARYING BEAM WIDTHS

Altitude	Diameter of Illuminated Area		
	Beamwidth 1°	$\frac{1}{2}°$	$\frac{1}{4}°$
Feet	*Feet*	*Feet*	*Feet*
5,000	88	44	22
10,000	176	88	44
15,000	264	132	66
20,000	352	176	88
25,000	440	220	110
30,000	528	264	132
35,000	616	308	154
40,000	704	352	176
45,000	792	396	198
50,000	880	440	220
55,000	968	484	242
60,000	1,056	528	264
65,000	1,144	572	286
70,000	1,232	616	308

than experienced flying personnel. Operating efficiency of the airborne survey systems will drop as a result and an automatic APR is required.

(b) Table II indicates the illuminated area diameter for various altitudes with three system beam-widths. The one degree beam-width is in use with the present APR System.

The second column in Table II indicates the diameter of the illuminated area with the present antenna system.

From test flight information it is known that the APR system will operate quite efficiently at altitudes of 35,000 to 42,000 feet. Therefore, we can assume that an illuminated area of 700 feet diameter would be suitable for good statistical averaging; however, there would be a very unusual increase in the vertical resolution of the output data, if this diameter were decreased to, say, 450 feet. This would result in acquiring output data from an APR system operative at 50,000 feet, comparable to that of the present APR System flown at 25,000 feet.

It should also be noted in Table II that an illuminated area diameter of 616 feet is obtainable at 70,000 feet with a one-quarter degree system beam-width. This is an acceptable area diameter and the one-half degree beam-width will be required for operation over 60,000 feet.

(c) Of lesser importance is the improvement of the vertical resolution by the use of a narrower transmitter pulse-width. This improvement is automatically possible with the requirements of (b) above.

These three areas—automatic operation, beam-width and pulse-width—have been in the paper planning stage for some time. Actually, the new transmitter is presently under construction and test flights are planned for later this year. All three areas involve state-of-the-art problems insofar as the electronics are concerned. The time involved in finding a solution to these problems will be the greatest single cause of delay in this program.

Automatic operation involves the use of high speed transistors capable of long term stability at extremely high operating frequencies. Such transistors are now listed as being available; however, we consider that the beam-width problem should be settled and a new transmitter placed in operation before we tackle the new automatic console problem.

The system beam-width is a direct function of the Transmitter Antenna Beam-width and the input characteristics of the Video Receiver.

For the parabolic reflector used: (Figure 7)
Transmitter Beam-width $B=58\lambda/D$

where

B = the transmitter wave-length in cm
D = the antenna diameter in cm.
58 = a constant dependent on the parameters of the parabolic reflector.

For the APR system

$$\beta = \frac{58 \times 32}{44 \times 2.54} = 1.65 \text{ degrees.}$$

Because of certain characteristics of the receiver input (50 D.B. attenuation), the actual system beam-width or receiver beam-width is 1 to 1.2 degrees. The variation of .2 degree is usually due to the position of the parabolic reflector in the radar well of the aircraft.

Now consider again the formula

$$\beta = \frac{58\lambda}{D}$$

To reduce the beam-width we must either enlarge the antenna diameter "D" or decrease the wave-length.

Since the present antenna is 44 inches in diameter we could not consider enlarging it. To reduce the wave-length, we must increase the frequency.

The formula $\beta=58\lambda/D$ indicates that if λ

is decreased by a factor of 2, i.e., 1.6 cm or 16 mm., then the beam-width β will be decreased by a factor of 2. However, it is not quite this easy. In microwave transmission, the transmitted energy is attenuated by the elements of the atmosphere. The principal elements causing this attenuation are water vapor and oxygen. The amount of attenuation caused by each of these elements is a function of the amount of gas molecules of each that are present and the wave-length of the transmitted signal.

In the microwave frequency spectrum the molecule of water vapor has an electric dipole moment which interacts with the electric field of the transmitted signal and has a resonance wave-length of 1.3 cm. Other resonance points occur at still smaller wave-lengths although the attenuation at these points is not as great in magnitude as the 1.3 cm point. It is also important to note that these resonant peaks tend to broaden at atmospheric pressure.

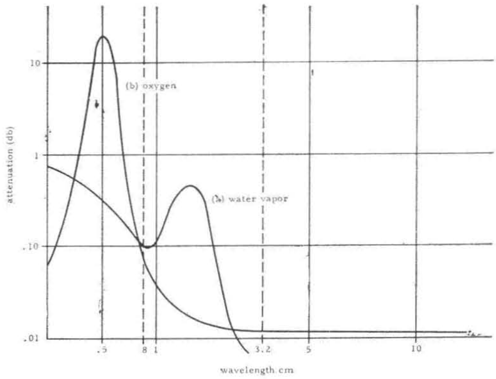

FIG. 8. Water Vapor and oxygen attenuation curves $B=58\lambda/D$.

Oxygen is paramagnetic and has a molecule with a magnetic dipole moment, which interacts with the magnetic field of the signal causing an attenuation to a lesser degree than water vapor.

Figure 8 is an illustration of the water vapor and oxygen attenuation curves. These curves indicate that water vapor is the most serious cause of signal attenuation in the area of interest. The two valleys, or windows as they are technically termed, in the curves are areas of low attenuation in the microwave spectrum. It can be seen that the two windows following the 3.2 cm. points occur at 12 and 8 mm. Twelve mm. equipment was operated by the Royal Canadian Air Force around 1948–50, but propagation difficulties above 25,000 feet limited the use of the equipment, and it eventually became obsolete when the R.C.A.F. ceased to perform photogrammetric operations.

The next, and probably the better, of the two windows occurs at 8 mm. (34.6 kilomegacycles). The low dips in the illustrated curves indicate this is probably an ideal choice.

During the past four years the Special Products & Applied Research Division has considered and researched the developmental problems which are allied with an 8 mm. transmitter program. I will not delve into the technical difficulties which have postponed a full scale development program on the transmitter. It is sufficient to say here that during 1961 we began to receive some encouraging reports on millimetric transmission studies which lead us to believe that an 8 mm. system is feasible for APR use. Accordingly, we are presently engaged in a development

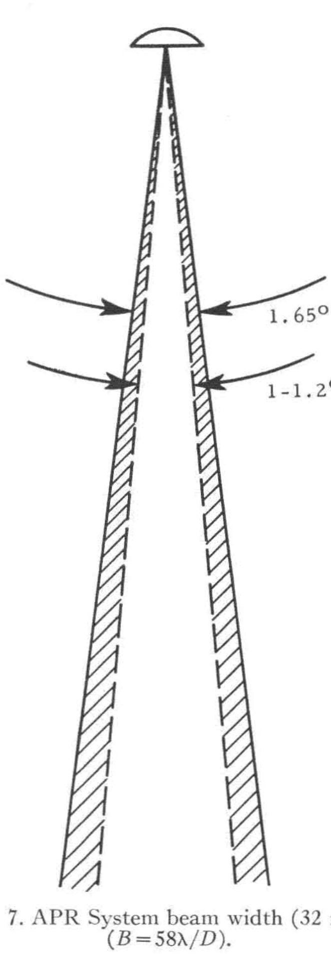

FIG. 7. APR System beam width (32 mm.) ($B=58\lambda/D$).

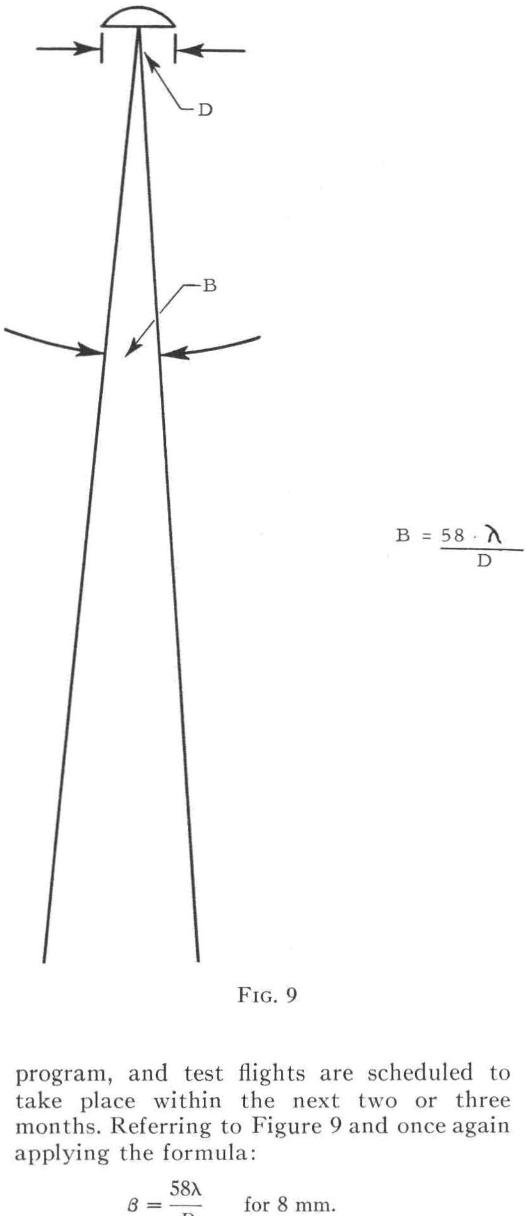

FIG. 9

program, and test flights are scheduled to take place within the next two or three months. Referring to Figure 9 and once again applying the formula:

$$\beta = \frac{58\lambda}{D} \quad \text{for 8 mm.}$$

$$\beta = \frac{58 \times 8}{44 \times 2.54} = .416 \text{ degree}$$

Therefore, replacing the transmitter of the present APR system would produce a .4 degree beam-width or reducing the antenna diameter to 22 inches would give a .8 degree beam-width. Both these situations are extremely useful.

It should be noted that transmitter and system beam-widths are not differentiated here. We will require a standard superheterodyne receiver when operating at a transmitter frequency of 34.86 Kmc. (8 mm.) and; therefore, the beam narrowing advantage of the crystal video receiver is lost.

The .4 degree beam-width will give an easy conversion for APR systems intended for use above 60,000 feet.

The smaller (22 inch) antenna, enabling the use of a smaller aircraft (Aerocommander, etc.), is of particular importance for two reasons.

(a) The Airborne Profile Recorder is becoming more widely accepted as a mapping tool. At the present time only the large aircraft operators are capable of using it, since a DC-3 or larger type vehicle is required for the installation. Bringing a transmitter into production which will operate with a 20 to 22 inch antenna reflector will enable many of the smaller aircraft operators to participate in APR controlled programs.

(b) Even more important is the use of smaller aircraft in South America today. Many available contracts are being turned down by Commercial Survey Companies due to the altitude and runway length conditions in some areas of the country; e.g., an airport at 15,000 feet altitude with a 600-foot runway.

The use of the smaller antenna is also of importance in the development of a new APR application technique; see Figure 10. We will touch on it briefly as food for some thought by those concerned with operational planning.

The Airborne Profile Recorder, in its present application, measures and records terrain profile data along the flight path of a survey aircraft. For a photographed area this means there are relative profile data available along the center of each flight strip. In most cases, the buildup of errors from the center of each

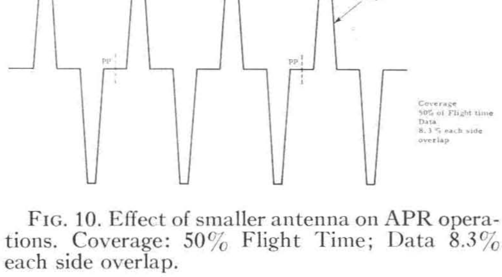

FIG. 10. Effect of smaller antenna on APR operations. Coverage: 50% Flight Time; Data 8.3% each side overlap.

strip to the center of the side overlap area is tolerated and is allowed for in calling up the mission accuracy requirements. In some cases, specifications are such that separate APR (spotting camera only) flights have to be made down the side overlap areas, so that relative profile data are available down the flight line of each strip and down each side overlap area. This represents a large increase in cost for a relatively small increase in overall model accuracy.

By using the smaller antenna we propose to scan periodically the side overlap areas between prime vertical frame times, and by continuously monitoring the antenna angle, automatically compute the slant range and correct for it. Essentially this system will be analogous to moving the aircraft over to the side overlap area at predetermined intervals.

Finally, the use of an 8 millimeter transmitter will allow the transmitter pulse width to be narrowed to 50 millimicroseconds pulse width, half the present pulse width. This will serve to improve the vertical resolution of the Airborne Profile Recorder.

The Program to develop an Automatic Airborne Profile Recorder is just getting under way. Essentially it means a complete redesign of the console unit.

Our development program for the Automatic Airborne Profile Recorder ideally fits into the pattern of present logic circuitry. The system output will be compatible with Airborne computers which are available, and those which are still in the product development stage. In conjunction with the Airborne Computer, automatic error detection and partial or complete processing of the APR data will be a part of the new design. Airborne processing of the raw data is a very desirable feature and we have a sufficient store of inflight factors to be able to program the APR for accurate airborne data reduction.

The initial planning of the Automatic Airborne Profile Recorder development program defined the use of transistors in all phases of the circuitry, eliminating completely the use of vacuum tubes. This was done principally to reduce both the mechanical size of the console and the input power requirements.

When we first considered the development program, transistors capable of reliable operation in the 100 to 200 megacycle range were not available to the specifications we required. Recently new developments (new silicon and mesa types) have placed on the market suitable transistors for our requirements and we can now proceed with the basic circuity for the new console.

Very shortly we hope to achieve a complete design for the Automatic Airborne Profile

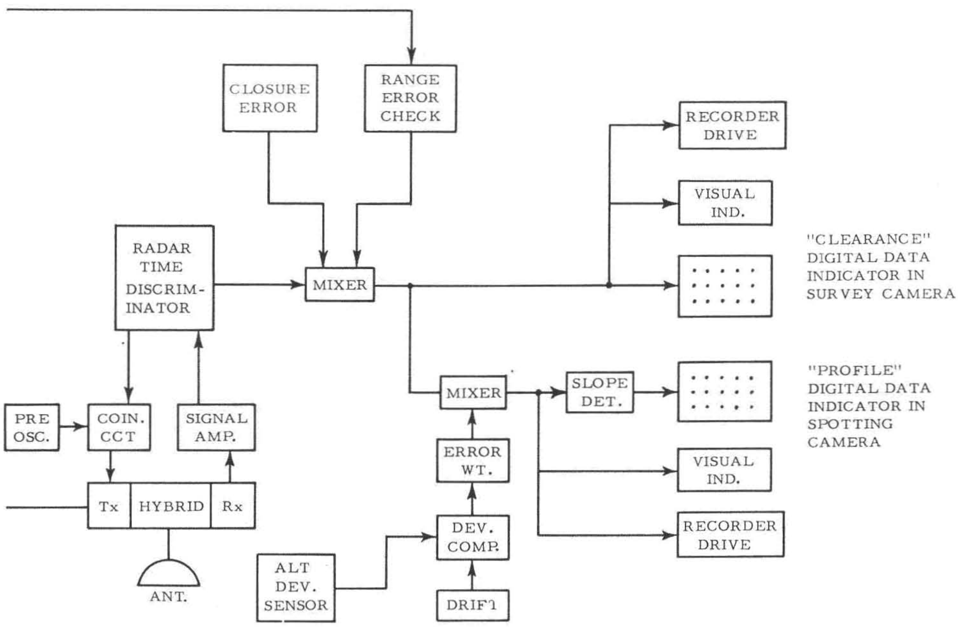

FIG. 11. Block diagram of a planned complete automatic airborne Profile Recorder.

Recorder which will include a form of data processing either partial or complete. Further information on this program will be published when test results are available.

It is interesting to see, in block diagram form, what we plan to produce as a complete Automatic Airborne Profile Recorder System. This is illustrated in Figure 11 which is a block diagram of the system which we envisage as the end result of the development program outlined in this paper. The components specified are available and we see no reason why selected profile points could not be resolved and printed on the appropriate frames of the spotting photography.

A study of Figure 11 shows that we must make some assumptions on the weighting of the barometric slope corrections and closure errors. We visualize these as mechanical inputs set according to the characteristics of the survey area, e.g., average type of winds, type of terrain, etc. This, of course, is done as a first approximation with present data reduction techniques. There will, of course, be areas where secondary checks will have to be done on the data at the ground installation.

We believe that such an Airborne Profile Recorder System as we have described will be a tremendous step forward in the mapping industry. We look forward to the publication of further reports as our development program proceeds.

*Photography and Imagery—A Clarification of Terms**

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THE increased use of pictorial displays of data in the fields of photogrammetry and photo interpretation has led to some confusion of terms, not so much by photogrammetrists as by users and interpreters of pictorial data. The terms "remote sensing" and "remote sensing of environment" are being used as general terms to describe "the measurement of some property of an object without having the measuring device physically in contact with the object" (Parker, 1962).

Measurements of size and shape by photogrammetric and optical means are common examples of remote sensing and therefore require no elaboration. Other techniques of remote sensing of electromagnetic radiation in and beyond the limits of the visible spectrum require some explanation and differentiation from the techniques used in the visible spectrum.

The following definitions of "photography" and "imagery" are proposed to clarify these two terms in hope that this will lead to more precise understanding and explanation of the processes.

PHOTOGRAPHY

The production of a permanent or ephemeral image of a subject on a medium which is directly exposed to electromagnetic radiation emitted or reflected from the subject, or transmitted through the subject, and is affected by the radiation in direct proportion to the emission, reflection, or transmission characteristics of the subject.

Examples of the process are ordinary photographic film that, after exposure to visible light, retains a latent image which prevents restoration of the emulsion to its original form and the evaporograph, which retains an image for a short time after the image-forming radiation is stopped.

IMAGERY

The pictorial representation of a subject produced by electromagnetic radiation emitted or reflected from a subject, or transmitted through the subject, and detected by a reversible-state physical or chemical transducer whose output is capable of providing an image.

A thermistor in a bolometer changes its resistance in response to incident infrared radiation. The resulting voltage change can be electronically manipulated to produce an image. The thermistor is a reversible-state transducer because the resistance produced

* Publication authorized by the Director, U. S. Geological Survey.