THE AIRBORNE PROFILE RECORDER*

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FOLLOWING the paper which Dr. Trorey read at the A.S.P. meeting in Washington last January, we received a large number of requests for further information on our Airborne Profile Recorder. It is indeed an opportunity to be permitted to describe the instrument to you so soon after that introduction of 9 months ago.

Ever since the aeroplane began carrying vertical cameras, surveyors have dreamed of the day when ground elevation control could be obtained by an airborne method.

Long-range high-speed aircraft have made possible the production of large quantities of planimetric maps. But the addition of topographic detail has presented a difficult, arduous task. In Canada at least 60% of the area is unmapped topographically. Facing this Mr. *B. M. Waugh*[1] of the Canadian Department of Mines and Technical Surveys initiated a research program to find an aerial method for procuring contour information. Exhaustive tests by his department in coöperation with the R.C.A.F. proved that standard military radio altimeters were inadequate. The National Research Council was asked to assist in the instrumentation, but it was not until 1946 that relief from wartime commitments made this possible. At that time Mr. *B. F. Cooper*, an Australian electronics expert employed by N.R.C., headed a group which developed a precision radar altimeter capable of accuracies of plus or minus 50 feet. The R.C.A.F. provided aircraft and personnel to carry out many months of intensive field operations and several eight-mile sheets were completely contoured.

By 1948 the Photographic Survey Corporation Limited had carried the development to the point where accuracies of plus or minus 20 feet were readily attained. By special flying routines, accuracies of plus or minus 10 feet could be realized.

The technique of surveying using the APR employs an aircraft flying at constant pressure height above sea level, while a narrow beam microwave radar instrument measures the terrain clearance below. (Figures 1–3) A four-foot parabolic reflector mounted in the belly directs the energy vertically downwards in a narrow beam 1.5° wide to illuminate as small an area as possible in order to preserve detail.

In the normal radar set the end result is usually a cathode ray tube display with a scale of some sort provided for estimating range. At best, these can give a readable accuracy of several yards. Due to the nature of the targets at which military radars are directed, the strength of the return signal can vary considerably. For that reason precise ranging is difficult. In altimetry, however, the signal strength is relatively constant. With water or ground as targets, the dispersion effects are much less. The increased signal strength, experienced when the radar is directed vertically at the ground in a very tight narrow beam, makes even a cathode ray tube display feasible from an accuracy standpoint. However the necessity for recording data for later examination implies a laborious photographic process. For this and other reasons, special circuits were en-

* Paper read at Semi-annual Meeting of the Society, Institute of Geographical Exploration, Cambridge, Mass., September 21 and 22, 1950.

[1] Mr. B. M. Waugh is now Surveyor General of Canada.

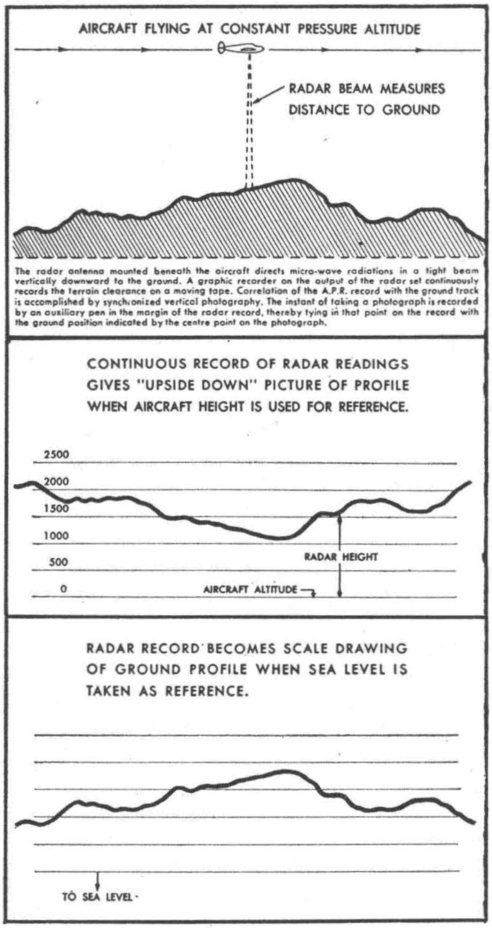

FIG. 1. Graphic representation of APR process.

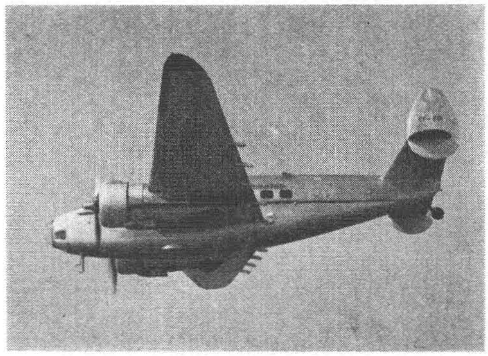

FIG. 2. APR aircraft in flight. Note 4-foot reflector in belly.

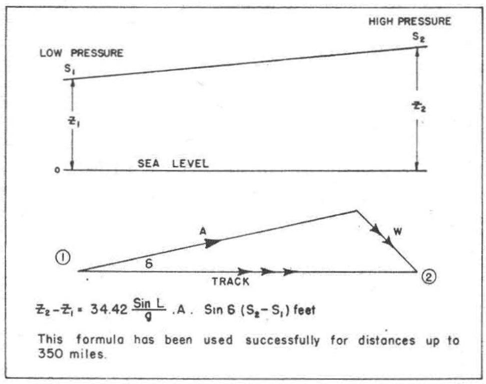

FIG. 4. The pressure gradient formula.

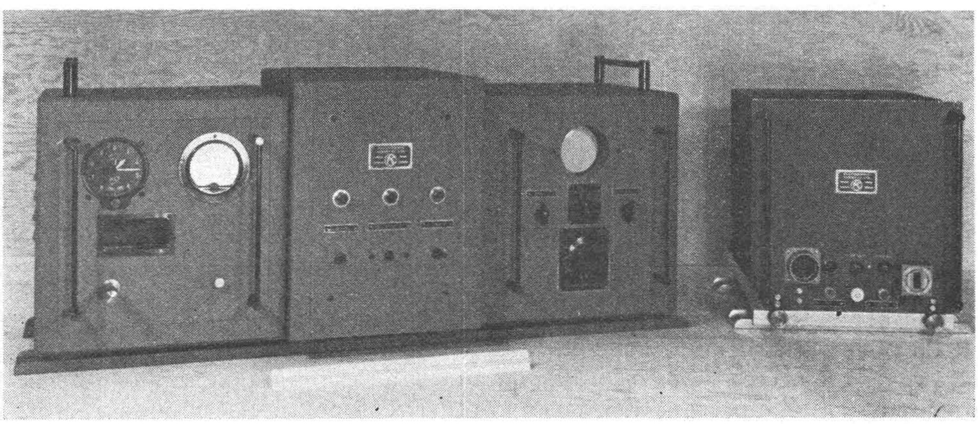

FIG. 3. The APR designed and built by the Photographic Survey Corporation Limited, Toronto, Canada

gineered to provide graphic recording of height information. The graphic instrument used is an Esterline Angus type using a five-inch wide strip, calibrated to give 2,500 feet full scale. In order to maintain a high readable accuracy, the recorder is designed to make measurements over a range of 2,500 feet, while the zero of the scale may be suppressed in 1,000 foot steps up to a total height of 30,000 feet. See Figure 5.

The heart of the measuring circuit is a crystal oscillator so that stability is inherently that of the crystal itself. This crystal controls the firing of the transmitter and initiates the timing cycle. A block functional diagram of the circuit is shown in Figure 6. Further technical details would cover several pages, and it is suggested that additional information be obtained from the manufacturer of the equipment.[2]

Airborne profile recording requires that the aircraft fly at constant height above sea level. However, it is impossible to maintain an exactly constant altitude over long periods, and some means of ironing out the variations is necessary. A standard altimeter contains too much inherent delay and therefore an auxiliary unit called a Datum Stabilizer has been developed. A small sensitive aneroid, which operates by virtue of changes in pressure with altitude, is used to produce an electric current proportional to height variations without mechanically loading the aneroid. This current is fed simultaneously with the radar signals to the same recording meter in a manner to correct for deviations from level flight. The result is an APR record which is a scale drawing of the terrain below.

Correlation between true flight path and APR record is achieved by vertical photography. At the instant of vertical exposure, a small solenoid-actuated pen places fiducial marks in the margin of the chart. Synchronized veeder counters in the camera and at the operator's table permit the margin marks to be numbered to correspond with the appropriate photographs.

There are many things which can affect adversely the precision of the APR. For best accuracy the system should have as narrow a beam as possible to provide fine detail. At present the beam width is $1\frac{1}{2}°$. Because of this, however, pitch and roll must be kept to a minimum, especially over rough terrain. Over water, the effect is not so serious provided that for at least a moment the beam is vertical. Over a water surface the correct elevation is the highest recorded point as a deviation from horizontal produces an error in one direction only.

Because a secondary reference datum which relies on a stable horizontal barometric air pressure is used, any gradients in this datum must be accounted for. If there are known elevations along a profile, the adjustments for gradient are simple. Lacking such convenient points, a formula involving a number of meterological factors may be used. See Figure 4. It can be shown that

$$h = \overset{(1)}{\frac{2\omega}{g}\int_{S_1}^{S_2} A \sin L \sin \delta ds} + \overset{(2)}{Z\frac{g_1 - g_2}{g}} + \overset{(3)}{\int_{t_1}^{t_2}\left(\frac{\partial z}{\partial t}\right)dt}$$

$$\overset{(4)}{-\frac{2\omega}{g}\int_{S_1}^{S_2} \sin L J_c dS}$$

where h = change in true height (slope of isobaric surface) $= h_2 - h_1$

[2] PSC Applied Research, The Photographic Survey Corporation Limited, 1450 O'Connor Drive, Toronto, Canada.

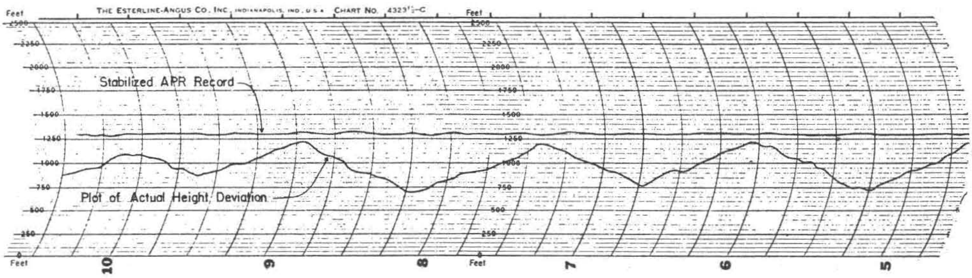

FIG. 5. Effect of Datum Stabilizer. The APR was flown over Lake Ontario executing vertical movements of 200 feet above and below the preselected datum—to simulate air bumps. 16 mm. photography recorded the actual excursions. The APR recorded the lake surface. The bumps were eliminated.

ω = angular velocity of earth's rotation
g = acceleration due to gravity
S = horizontal distance
$= S_1 - S_2$
A = true air speed
L = latitude
δ = drift angle
Z = geometric height
J_c = ageostrophic component of wind

For all practical purposes term (1) only is of importance and this reduces to

$$h = 0.035 \times \text{airspeed } MPH \times \sin \text{ drift angle} \times \text{distance in miles} \times \sin \text{ latitude}.$$

Table I shows results of experiments to test the formula.[3]

TABLE I

Obs.	Direction of Flight	Distance flown	Uncorrected Elevation from Profile	Correction from formula	Corrected Elevation	True Elevation	Discrepancy
1	Ref	0			Ref	664	
2	NE	49	599	−21	578	587	+ 9
3	NE	53	864	−23	841	855	+14
4	W	57	584	−20	564	587	+23
5	W	83	944	0	944	941	− 3
6	W	94	894	+ 9	903	900	− 3
7	W	121	794	+30	824	836	+12
8	W	134	839	+40	879	876	− 3
9	SW	169	764	+63	827	810	+17
10	E	214	719	+28	747	738	− 9
11	E	219	774	+24	798	800	+ 2
12	E	264	549	−11	538	520	−18
13	SW	306	624	+14	638	645	+ 7

It will be noted that the drift equation has been used for distances in excess of three hundred miles satisfactorily.

Other than their effect on the pressure gradient, atmospheric conditions (excepting of course rain and storms) have little effect on the APR. The

[3] Courtesy Department of Mines & Technical Surveys, Ottawa, Canada.

USAAF Shoran group carried out extensive measurements to determine the day to day changes in dielectric constant of the earth's atmosphere. At 30,000 feet, the difference in the height measurements taken on a very dry day and on a very moist day would amount to less than one foot. In heavily wooded areas, the heights of growth must be ascertained by inspection of the photography since the microwave radiations are reflected by the tree tops.

As a reconnaissance instrument, the APR has provided contour information

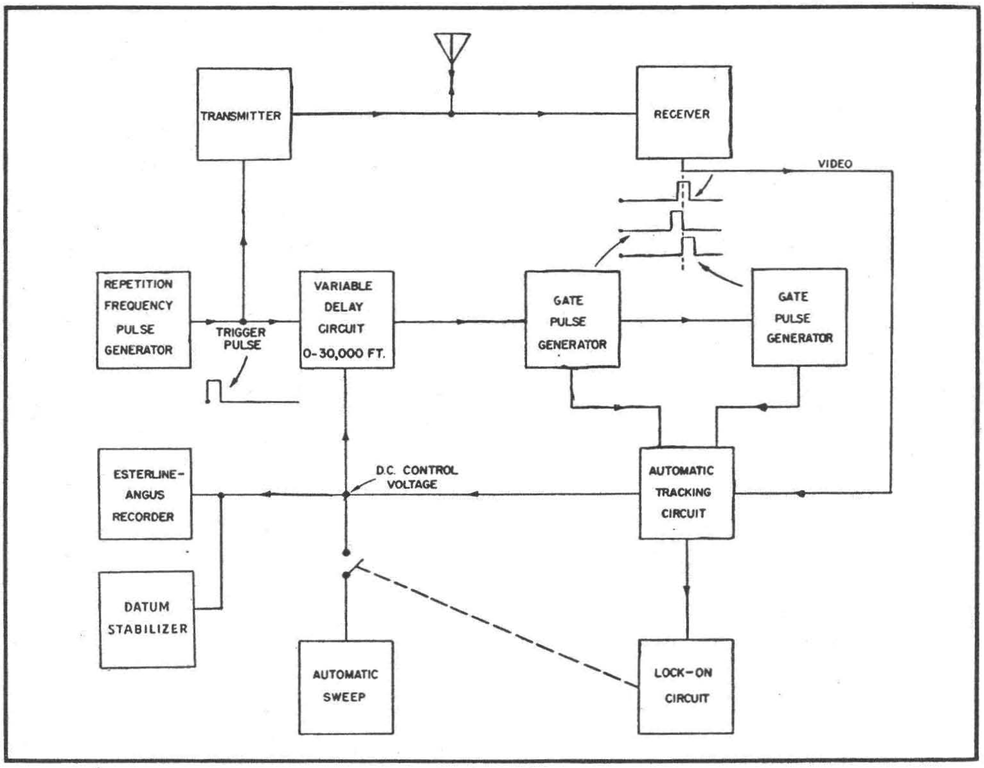

FIG. 6. Functional diagram showing circuitry of APR.

for aeronautical charts to fill a much needed requirement for the safety of expanding air services. The flight lines for such a survey are shown laid out on the map of Newfoundland. This survey was completed during 1950. (Figure 7)

By far the most useful application of APR is for control of machine mapping. By selecting lake and other water surfaces or flat ground and by adopting special flight routines, precision of the order of plus or minus 10 feet can be assured.

Several surveys for hydro and communication routes have been completed, resulting in tremendous economy to the clients. The ability to estimate the quantities of materials obviates costly delays which can result from inadequate supplies. The ability to select a route from the standpoint of accessibility and a minimum of constructional equipment offers other obvious advantages. Considerable saving is realized when exact volumes can be appraised before crews enter the field.

The television industry requires a speedy method for placing microwave link towers. The requirement is for line of sight communication up to distances of

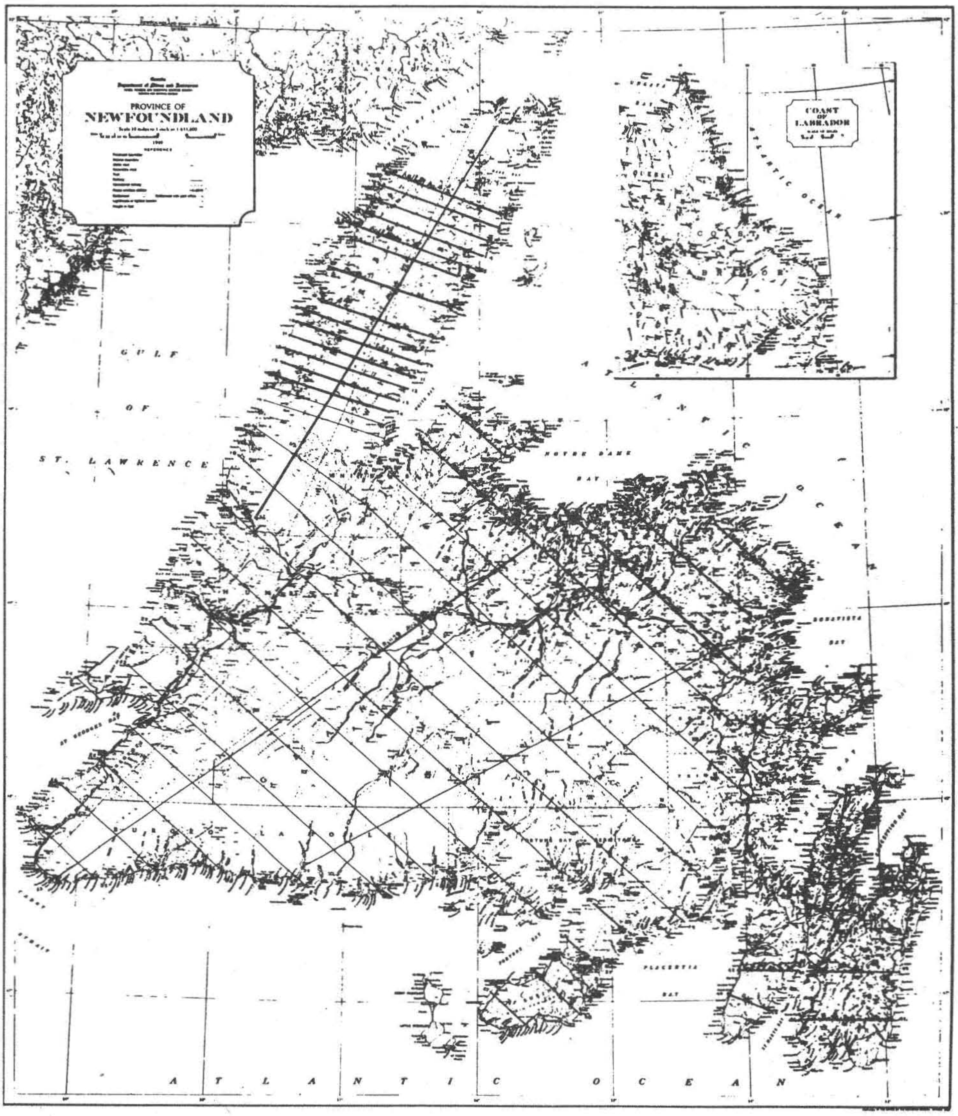

FIG. 7. Map of Newfoundland showing APR flight lines arranged to permit pressure gradient correction at sea level.

35 miles with a definite minimum vertical distance from a straight line joining two towers to the highest intermediate ground point. The prominent position of APR in this work must be evident. By plotting an APR profile of a proposed route on an earth's curvature basis the required tower heights are at once apparent (Figure 8)

Additional instances could be cited from experience gained during the past few years. However, in a paper such as this, one must choose between large amounts of detail on a few items, or scanty detail on many. The latter is probably the more interesting from the audience's standpoint because the chances of touching a familiar chord are greater.

In the last generation, the Western World has realized the necessity of improving the standard of living for the inhabitants of the backward and undeveloped places. This calls for, primarily, a complete inventory of natural resources. In the initial stages reconnaissance maps are of supreme importance; at a later period detail maps become essential. If we are to see the fruits of any planning in our own time, the production of maps must be accelerated by such instruments as APR.

The remarks which follow may suggest sharp contrast to the peace-promoting thoughts of the preceding paragraph. Much of what follows is a repetition of Dr. Trorey's ideas, as presented some months ago, with particular reference to APR's military usefulness.

Until the development of Shoran, it was impossible to apply sensible ground

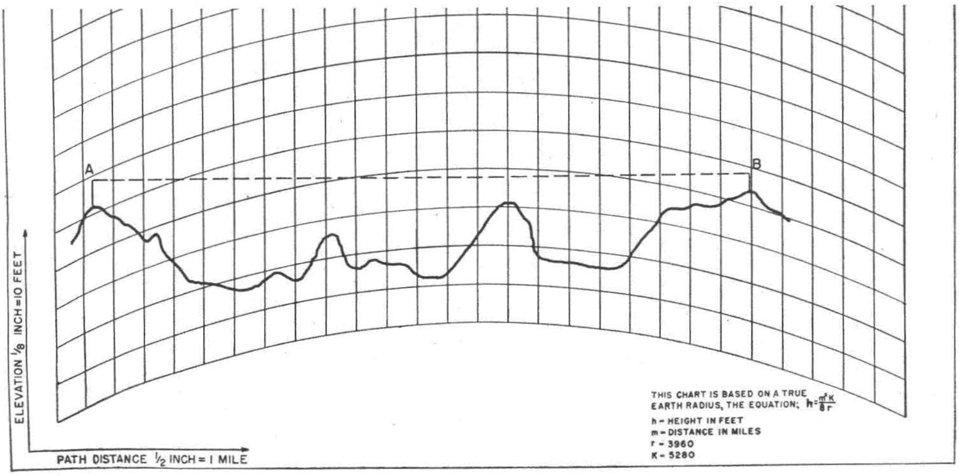

FIG. 8. Section of a recent television link survey showing true earth curvature plot for tower location.

scale to photography without the aid of ground parties. The use of Shoran still requires field parties to set up the ground stations. This brings us to the problem of mapping over territory where it is difficult or hazardous to send in field crews. This is especially true during a military operation. The ability to express accurately the location of a point in terms of latitude and longitude is one of the major problems facing reconnaissance over enemy territory. There are Intelligence methods for fixing a target including, of course, aerial photography. But unless the position of the target can be expressed geodetically, the possibility of attack by day is difficult, while attack by night is largely eliminated. During the past war the problem hardly existed, thanks to the ample geodetic information available throughout Europe from the various national maps. However, throughout Asia such information is not available. We are, therefore, reduced to such expedients as obtaining astro-fixations, once the reconnaissance aircraft passes beyond the range of Shoran.

While astro-fixation may be possible by day, it is more likely to be a night reconnaissance problem, combining night photography with astro observation. At best the accuracy of the "fix" will be one mile. In an important target area we are faced, then, with the prospect of having a few isolated astro-fixes containing large random errors. While this control can place a section of enemy teritory in approximately its correct position geodetically, it still does not provide means of controlling or "scaling" the air photography, such as is needed for *positioning* and mapping a whole target area. Some means of providing "horizontal control" for mapping is still needed.

Successive photographs taken with a suitable survey camera can be set up in an instrument, such as a Multiplex, so that each photo is placed correctly in relation to the next. By sensible study of drainage patterns, the resulting system of stereoscopic models can be rotated so that it is nearly level with the ground. Thus far the process involves merely angles. But to give the model scale, it has to date been necessary to know either the distance between at least two points on the ground, or the distance between two camera stations in the air. The one implies ground survey, the other radar fixation by Shoran. However, it is basically triangles with which we are dealing. The angles are known and it requires the measurement of but one side for complete solution. The answer can be effectively obtained by determining the vertical distance from the aircraft to the ground. (Figure 9)

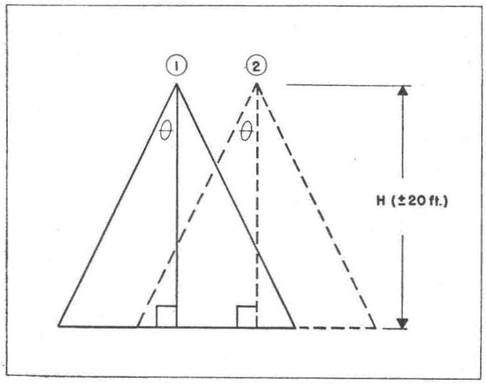

FIG. 9. Triangles show that horizontal scale may be obtained readily from a vertical measurement.

Let H=height of aircraft above ground as measured by APR in feet. (Figure 10)

h=height of projector exit node above the model in millimeters.

S=model scale in feet per inch.

then $S=25.4\sum h/\sum H$

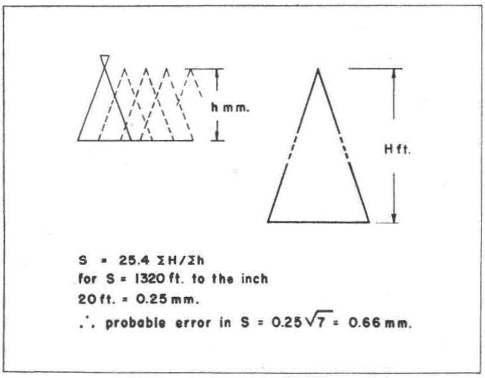

FIG. 10. Graphical representation of Dr. Trorey's calculations.

where h and H are the sums of several perpendiculars.

The big problem is, of course, the accuracy with which this scale is established. Assuming an accuracy of plus/minus 20 feet we then have the following situation:

e.g. At a model scale for mapping of 1,320′ to the inch, 20 feet equals 0.25 mm. Therefore, the probable scale error is $0.25\sqrt{7}=.66$ mm. for a seven bar projector, the error compensating.

The total error of 0.66 mm. is in the sum of the heights; i.e. $\sqrt{7}.250=2,520$ mm; hence error equals 0.66/2,520 or one part in 3,800.

While all that is theory, the APR has been giving accuracies as good as plus or minus 10 feet on water surface and 20 feet over land, at altitudes up to 10,000 feet. At greater heights the accuracy over water is not reduced, although over land discrepancies of 50 feet will occur, due to the area illuminated by the radar. The beam width of the APR radar is $1\frac{1}{2}°$. This means that the ground seen by the APR is a circle having a diameter of 28 feet for every 1,000 feet of terrain clearance. Over uneven ground, the elevation of the highest point in the circle is recorded, and unless careful inspection is made among the profile, the precision will suffer. This is not a serious matter since air photography is taken simultaneously, and it is possible to accept or reject points and to extract sufficient few points for map control.

For military purposes it will be necessary to map from higher altitudes than we have been using. To use APR at these altitudes a few refinements are necessary. These are gyro stabilization of the antenna and narrowing of the beam-width. Neither is an item of tremendous cost.

The APR has speeded up topographic contouring by a factor respresented by the speed of an aircraft relative to that of a ground party. It can do the same for planimetric and all mapping.

This paper would be incomplete were mention not made of the energy exerted by Mr. *S. Jowitt* of the Mines and Technical Surveys. Not only did he assist with this paper, but his efforts throughout the development of APR have lent unquestionably to its success.

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THE APPLICATION OF STATISTICS TO PHOTOGRAMMETRY*

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RECENT research, primarily that by Professor Matthews of New Hampshire, has indicated that we need more specific and more precise information on a number of elementary (I use the word in its generic sense) and combinational problems before we can expect to get the best results from the use of aerial photographs. Broad generalizations as to film and filter combinations have been accepted in the past, and may result in the correct combination to use for certain types of images and for some particular purpose of photo interpretation; but for other types of images and other purposes, some different combination may be superior. When fine points of difference present themselves, and when by occular observation alone it is no longer possible to positively identify the differences that may classify one set of values as superior or inferior to another set, it is desirable to resort to a statistical analysis of the results.

I should indicate that I am a forester and as such may be looking for effects on aerial photographs that may be considered by many as minute. This is only mentioned because I do not wish you to think that the problems about to be mentioned are necessarily common or pertinent to all who use aerial photographs. It is only my ignorance of the problems in other fields that prompt this statement.

* Paper read at Semi-annual Meeting of the Society, Institute of Geographical Exploration, Cambridge, Mass., September 21 and 22, 1950.