The Radar Profile and its Application to Photogrammetric Mapping

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In Canada, during the past few years, a technique has been developed which not only opens up new possibilities in the field of photogrammetry but which may also have considerable influence on the future development of photogrammetric methods, particularly as they relate to mapping at small and intermediate scales. This so-called airborne profile recorder method was first conceived during the war but its development and its adaptation to photogrammetric requirements is the result of work carried out since the last International Congress in 1948. Some of the details still require clarification but the actual method itself has already been established, the equipment has survived the rigors of early experiments, and the results of numerous tests are now available; moreover, considerable practical experience has been gained from the application of radar profiles to various cartographic problems encountered during the mapping of some 1 500 000 square kilometers (about 600 000 square miles). The results obtained are based mainly on Canadian terrain but data on some parts of Central and South America and Alaska are also available.

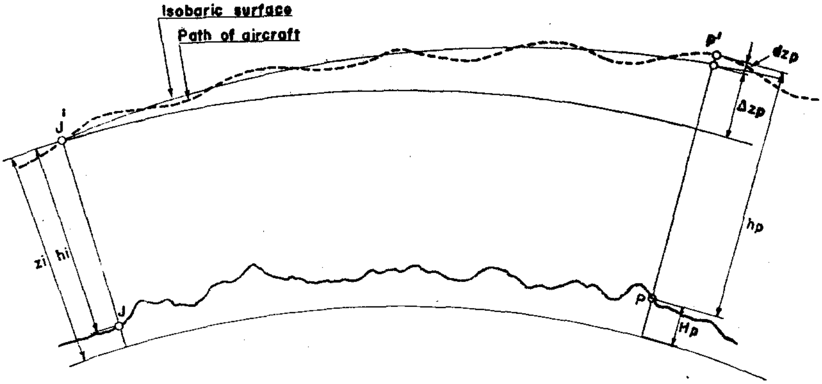

Fig. 1

In principle, the method is very simple. An aircraft carrying special radar equipment and a positioning camera flies over the terrain. Microwave impulses are continuously directed downward and the optical axis of the camera is aligned with the microwave beam. The aircraft should fly at a uniform altitude using the isobaric surface as a reference surface. After being reflected from the earth's surface, the electro-magnetic impulses are recorded, and since the speed at which the electro-magnetic waves are propagated is known and the time which elapses between the moment of emission of the impulse and its return is measured, the distance of the points on the surface of the earth from the position of the aircraft at any given time can be determined. If the aircraft is flying a course parallel to the geoid, the profile of the earth's surface along the line of flight can be reconstructed by plotting the position of the aircraft on the abscissa and the measured distance of the ground points from the plane on the ordinate. In actual practice, the line of flight deviates from the isobaric surface and the isobaric

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surface itself is not parallel to the geoid. The amount of deviation from the isobaric surface, however, can be measured with reasonable accuracy in the aircraft with a sensitive electronic aneroid. Similarly, the lack of parallelism between the isobaric surface and the geoid can be calculated by means of specially derived formula or by using known elevations on the ground.

A mechanical process has been evolved so that the profile of the terrain can be recorded on a strip of graph paper as the aircraft flies over the ground. Correlation with the actual ground features is obtained by a marginal pen which indicates the moment of exposure of the aerial camera. In this profile compensation has already been made for the deviations of the aircraft from the isobaric surface; before making further use of the profile data, it is therefore only necessary to correct the lack of parallelism between the isobaric surface and the geoid.

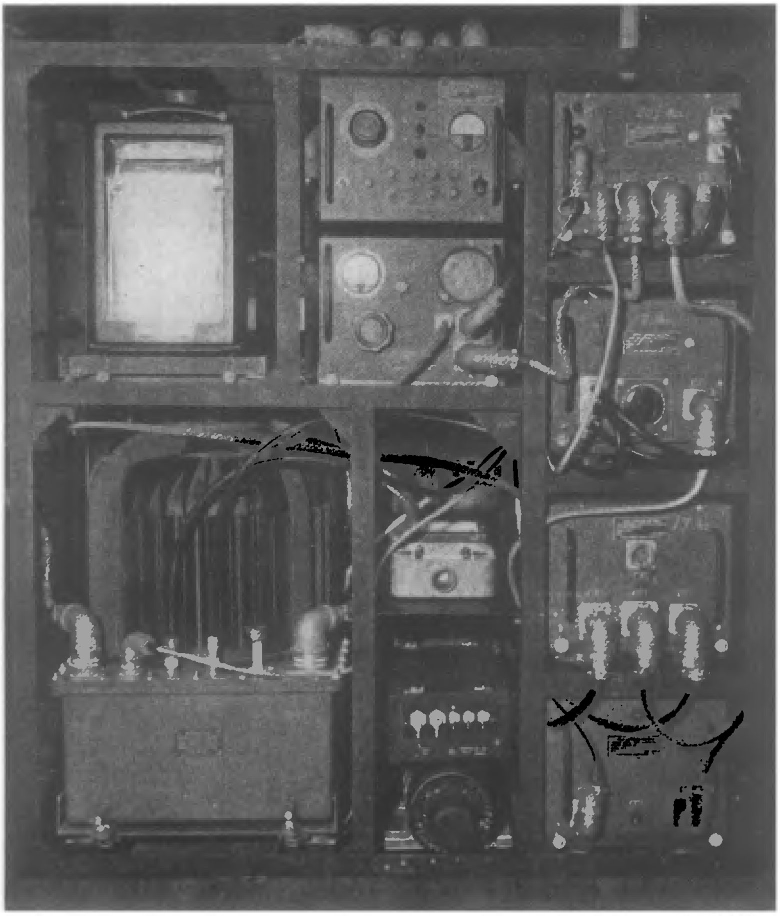

Fig. 2

As one can see, the absolute altitude H of any point in the profile depends on two independently determined quantities: the absolute elevation of the aircraft and the distance of the point in question from the aircraft.

$$H_p = z_l + (\pm \triangle z_p \pm \mathrm{d}z_p) - h_p$$

Before enlarging on the application of radar profile to photogrammetric mapping we would like to give a short description of the equipment used by the Department of Mines and Technical Surveys.

Fig. 2 shows the units of the radar equipment and the rack used in the installation in the Anson MK V aircraft.

The radar altimeter employs a microwave transmitter which feeds short pulses of energy to a parabolic antenna mounted under the aircraft. The energy is radiated in a narrow beam directed vertically downward from the aircraft when in normal flying attitude. The time taken for these pulses to travel to the ground and be reflected back to the aircraft is measured and automatically converted to distance. The velocity of propagation is assumed constant and chosen for average atmospheric conditions. From an investigation of the variation of dielectric constant of the atmosphere with height and atmospheric conditions by the United States Air Force Shoran group it can be shown that the maximum error incurred by this assumption in measuring 50 000 ft. would be less than 3 ft. (approx. 1 m) under extreme atmospheric conditions. The distance is presented on an Esterline Angus graphic recorder graduated in feet. The full scale deflection of the recorder covers a range of 2 500 ft. (approx. 762 m). The equipment is capable of measuring distances up to 50 000 ft. (approx 15 150 m) by means of a stepping switch which suppresses the zero of the meter up to 48.000 0ft. (approx 14 540 m) in 2 000 ft. (approx 610 m) steps. Fig. 3 shows a functional diagram of the circuit.

FUNCTIONAL CIRCUIT DIAGRAM OF THE RADAR ALTIMETER

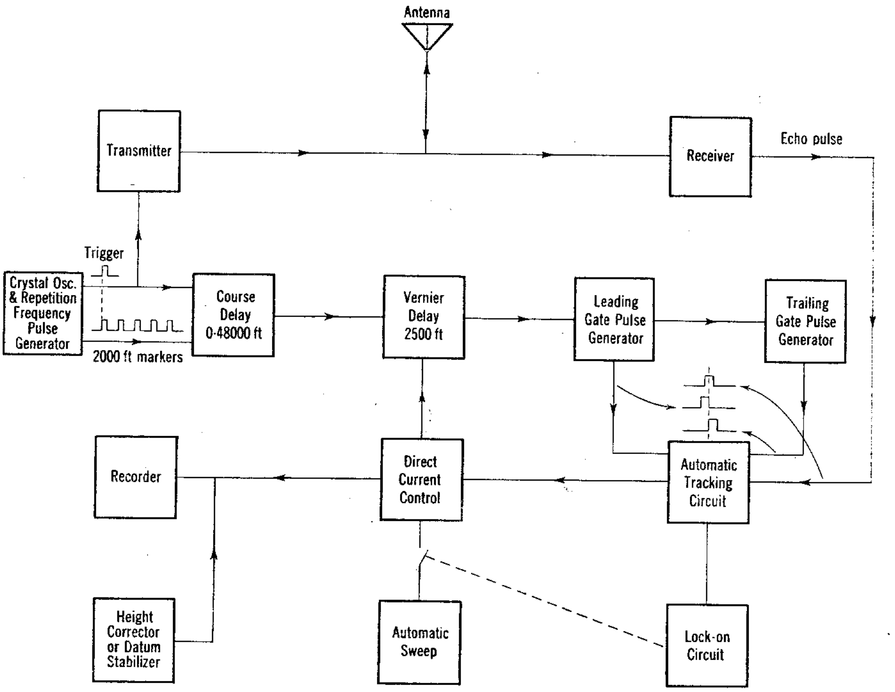

Fig. 3

The transmitter is a pulse modulated unit of conventional design. It employs a magnetron with a peak power input of about 35 KW at a wavelength of 1,25 cm. A pulse duration of ½ microsecond is used at a repetition frequency of 1 000 cycles per second.

The transmitter feeds the parabolic antenna shown in Fig. 4 mounted in the bomb bay of the Anson. This antenna is a horn fed parabolic reflector with focal point in the aperture plane. The reflector is 2 feet in diameter and confines the microwave energy to a conical beam whose effective vertex angle is about 1,5 degrees. By means of electronic switching the antenna is used for both transmitting and receiving.

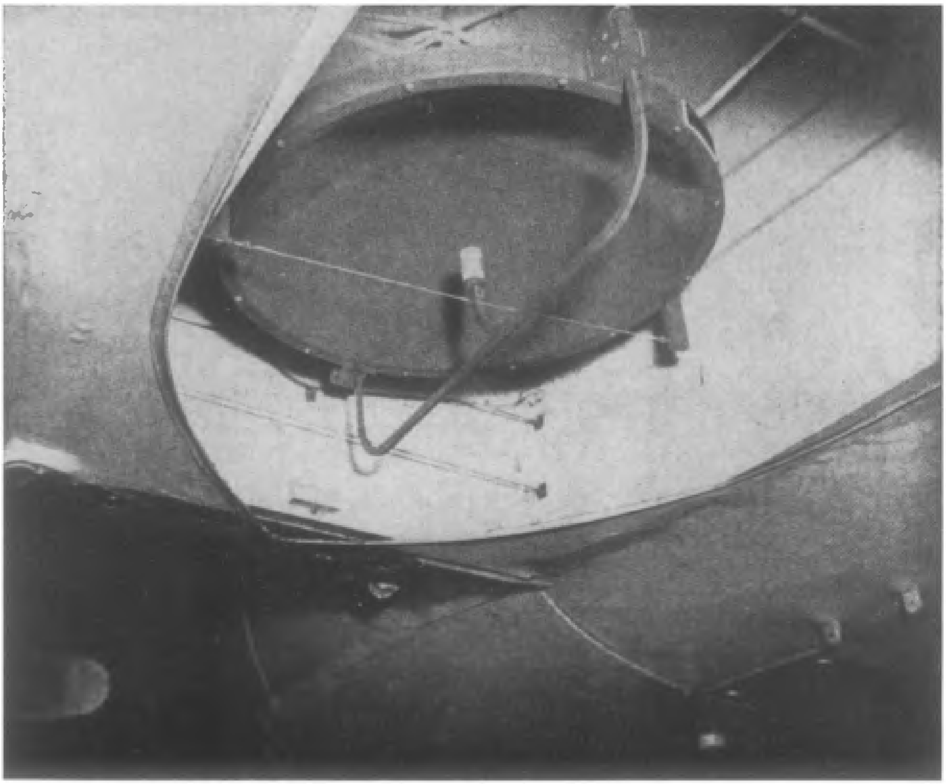

Fig. 4

The receiver used to amplify the echo pulse is also of conventional design.

The heart of the radar altimeter is a crystal controlled oscillator of frequency 245,85 ± 0,01% kilocycles per second. The period of this oscillator, 4,068 microseconds is equal to the time of travel of an electromagnetic wave to and fro over a distance of 2 000 ft. in a normal atmosphere. The output of the oscillator is used to provide highly accurate 2 000 ft. markers for the subsequent stages of the timing circuit.

A tolerance of 0,01% is specified for this circuit so that a maximum error of less than ± 5 ft. (approx 1,5 m) is incurred in measuring the complete range at 50 000 ft.

A counting down circuit of ratio of approximately 246 : 1 is then used to obtain the pulse repetition frequency of the transmitter. In this way a pulse is obtained, which is accurately locked to one of the 2 000 ft. markers, to fire the transmitter approximately a thousand times a second.

The automatic tracking and timing of the echo is achieved by producing a pair of gate pulses after a suitable delay so that they ride in a symmetrical fashion about the echo pulse. By making the delay in the production of these gate pulses proportional to a direct current the distance can be recorded on a milliameter. Since it is not practical to have the complete range of the altimeter presented on the scale of the milliameter this is accomplished in the following manner.

The course delay circuit provides a delay up to 48 000 ft. in 2 000 ft. increments. Due to the precision required a pip selector circuit is used which locks the delay to any one of the selected 2 000 ft. marker pips subsequent to the one which fires the transmitter. The desired delay is obtained by a manual switch which is adjusted in operation in accordance with the clearance between the aircraft and the terrain. After the selected delay has been reached the circuit then initiates the vernier delay.

The vernier delay circuit covers a range of 2 500 ft. and is the range which is presented on the graphic recorder. The delay of this circuit is controlled by the direct current plate voltage of the tube in whose plate circuit the Esterline Angus Milliameter is placed. This delay circuit initiates the generation of the two movable gate pulses which straddle the echo in a symmetrical fashion. If the time for the echo pulse to return alters due to change in the distance between the aircraft and the ground the gate pulses lose their symmetry about the echo. This loss of symmetry causes unbalance in the automatic tracking circuit, which changes the potential on the grid of the tube mentioned above. The resulting variations in plate current in this tube are recorded as height information on the recorder. The accompanying change in plate voltage alters the delay so that the gate pulses are again produced in a symmetrical fashion about the echo.

In a flight where the clearance between the aircraft and ground is 7 000 ft. the course delay switch would be set to the third position marked 6 000 ft. The Esterline Angus meter should then read approximately 1 000 ft. The set will then record variations of elevation up to 1 250 ft. in either direction. If the change in elevation exceeds this the course delay switch must be moved in the appropriate direction to bring the record back on the scale of the milliameter.

An automatic sweep circuit is provided so that the movable gate pulses will search for the echo if for any reason the tracking circuit should lose it. The gate pulses are made to travel over the range of the vernier delay until the echo pulse is encountered. When the echo is found they adapt the symmetrical position about it and the lock-on circuit cuts out the sweeping action.

The height corrector or datum stabilizer which correct the radar measurements to a constant pressure level when the aircraft fails to maintain that level, is controlled by a sensitive aneroid capsule. By linking the aneroid directly to a parallel plate condenser * a change in capacitance is obtained with any up or down motion of the aircraft. This variable capacitance is then used in an oscillator-discriminator circuit to obtain a direct current which is proportional to the pressure change. Due to the limitations of the electronic circuit and aneroid, one plate of the parallel plate condenser is mounted on a micrometer screw. In operation a flight altitude is chosen, the output of the circuit is then adjusted to zero at this altitude by moving the plate attached to the micrometer screw. Any variation from this altitude then causes the aneroid to expand or contract moving the other plate, and produce a current proportional to the movements. The circuit will compensate for changes of altitude of ± 200 ft. from the chosen flight altitude. The output of the circuit is directly connected to the Esterline Angus meter so

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* This electronic type pickup does not mechanically load the aneroid capsule and has been found to be much more sensitive and have a faster response than conventional aneroid barometers.

that it corrects the radar readings automatically to the constant pressure level chosen.

If the absolute altitude of the aircraft is desired the unit may be disconnected, or a separate graphic recorder may be inserted to record its output.

A monitor oscilloscope not shown in Fig. 2 is usually used in operation of the equipment. The oscilloscope is not a functional part of the set but by connecting it so that it will display various wave forms of the circuit it provides the operator with a convenient method of checking the operation of the various units.

This radar altimeter was built for the Royal Canadian Air Force by Electronic Associates, Limited, of Toronto, and is basically the same as the prototype altimeter designed by Mr. B. F. Cooper of the National Research Council of Canada. A more complete description may be found in his report (1) or in the R.C.A.F. Maintenance Manual (7).

As far as the errors which may be found in radar profiles are concerned, a definite distinction may be made between errors in the barometric determination of the differences in absolute aircraft height and errors arising from the use of electronics in measuring distance. In order to give a clearer picture of the method itself, we will enumerate the most important errors of these two groups.

To the first group belong:

1) the error in determining the differences in aircraft altitude with reference to the isobaric surface. This error probably amounts to 1 meter (3 ft.).

2) local anomalies and lack of parallelism between the isobaric surface changeable with time and the geoid. By choosing a suitable flying altitude the effect of local atmospheric disturbances, which are concentrated in relatively limited areas above the earth's surface, are almost eliminated. The minimum flying altitude is therefore 700—1300 meters (about 2 000—4 000 ft.), depending on the nature of the terrain. The fact that the elevation is measured by means of a barometer at a certain altitude in the atmosphere is one of the most important characteristics of the radar profile method.

As mentioned previously, compensation of the errors listed in point 2 can be carried out as follows:

a) applying the formula derived in connection with the development of the radar profile method, with which it is possible to calculate the gradient of the barometric air pressure during flight as a function of the angle of drift and other known factors, and

b) making, if possible, corrections after comparing the profile with actual spot heights on the ground.

The formula * used in calculating the air pressure gradients, in its abbreviated form, is:

$$h_{\text{feet}} = 0.035 \, . \, v \, . \, d \, . \, \sin\alpha \, . \, \sin\varphi$$

in which

v is the air speed in m.p.h.,
d is the distance from the initial point in miles,
α is the angle of drift, and
φ is the latitude (approx.).

To the second group belong various sources of error of an instrumental or more general nature which are inherent in the physical process of electronically measuring the distances between an aircraft and corresponding profile points. We shall mention only a few of them here. Because of the dimensions of the electro-magnetic beam (a cone with a vertex angle of 1.5 g.) a fairly wide area, rather than one specific

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* This formula was evolved by T. J. G. Henry of the Meteorological Branch of the Department of Transport:

point, is involved in the measurement of the distance. For example, at an altitude of 2 000 meters (6 500 feet), the area involved would be equivalent to that of a circle having a radius of about 26 meters (about 85 ft.). It must also be borne in mind that the radiation is generally not exactly vertical so that the identification of the profile in the field is not entirely without ambiguity. Gyro stabilization of the beam and the 35 mm. camera plotting the course of the profile in the field, which was introduced by the Photographic Survey Corporation of Toronto, represents a step forward in this respect. Further errors may be the result of variations in the strength of the energy reflected from the earth (e.g. variations between the energy reflected from water surfaces and that from dry land), of partial penetration of the tree-tops, or of the limited resolving power of the radar profile, etc.

In addition to the sources of error mentioned above, we might mention identification errors which may lead to incorrect correlation of the radar profile with a corresponding point on the ground.

Thus, with this method of measurement, as with any other, we are apt to encounter a number of accidental and systematic errors and one of the problems involved in the application of the radar profile method to photogrammetry is the necessity of eliminating as many of these errors as possible from the mapping process.

With this brief outline, we now turn to the application of the radar profile to photogrammetric mapping and to the results obtained thus far.

One of the first occassions on which the radar profile method was applied on a large scale was in connection with an extensive mapping project undertaken by the Aeronautical Charts Division of the Canadian Department of Mines and Technical Surveys. The procedure used may be outlined as follows. The region to be mapped is generally covered with Tri-Metrogon photographs, from which the planimetry is charted. The mapping scale is 8 miles to the inch or about 1 : 500 000, and the contour interval is 500 feet or about 150 meters. In order to complete the topographical detail, the entire area is covered by parallel radar profiles at 16-mile (26 kilometer) intervals. Vertical photographs are made at the same time as the radar profiles so that the position of the profile on the ground might be identified.

After making the correction in the profile for the gradient of the barometric pressure and any further corrections which can be made with the aid of existing fixed points, well-defined and reliable points characteristic of the terrain are chosen and recorded in the appropriate position. The contours are plotted by interpolation between the given points; at this stage, of course, use is made of the preliminary aerial photographs and the stereoscope. If significant elevations appear between the individual profiles, secondary spot heights can be reconstructed with the aid of the Tri-Metrogon photographs.

This method has proved to be very rapid and convenient for the purpose in question and in the past three years it has been possible to map vast, almost inaccessible areas of Canada.

At the same time as this work was being done on the production of aeronautical maps, the Aeronautical Charts Division in collaboration with the National Research Council, on the one hand, and the Photographic Survey Corporation, on the other, were carrying out a number of experiments in an effort to solve various problems encountered in the instruments used and in the general application of the method. Several thousand miles of profiles were made and analyzed. Of these preliminary tests, we would like to cite here the results obtained from a profile of about 500 km (306 miles) in length. This test is of particular interest because the only elevation known in this profile was that of the initial point; moreover, the course of the aircraft was changed several times. The corrections in elevation were therefore calculated only on the basis of the formula mentioned above an the absolute elevations of various water surfaces, as deduced from the profile, were compared with the actual elevations. The results are shown in Table 1.

Point	Direction of Flight	Distance Flown		Elevation Profile from A.P.R.	True Elevation	Error	
		Miles	Km			Feet	Meters
1		0	0		664		
2	NE	49	78	578	587	— 9	—2.7
3	NE	53	85	841	855	—14	—4.3
4	W	57	91	564	587	—23	—7.0
5	W	83	133	944	941	+ 3	+1.0
6	W	94	150	903	900	+ 3	+1.0
7	W	121	193	824	836	—12	—3.7
8	W	134	214	879	876	+ 3	+1.0
9	SW	169	270	827	810	—17	—5.2
10	E	214	342	747	738	+ 9	+2.7
11	E	219	350	798	800	— 2	—0.6
12	E	264	422	538	520	+18	+5.5
13	SW	306	489	638	645	— 7	—2.1

Table I

The mean square elevation error, which amounts to only ± 3.7 meters (± 12 ft.), and which appears to bear no relation to the distance between the point measured and the initial point, speaks for itself; at the same time it shows clearly that an isobaric surface at a certain elevation above ground-level is incomparably better as a reference surface than is the case in the classical barometric measurements in the field.

A similar test made more recently over mountainous country in Alaska by the Photographic Survey Corporation of Toronto for the Geological Survey in Washington gave results which are no less interesting. In this test, a complete profile of about 500 km (300 miles) in length was made three times, and the absolute elevations of several water surfaces were compared with the elevations as determined by actual surveys in the field. Although each of the three flights was made on a different day, comparison showed an astonishing reproducibility of results and the mean square elevation error in the triple determination of the elevation of any one point amounted to only ± 3 meters (± 10 ft.). It is possible, however, that the maximum error in point 5 can be attributed to a coincidental orographic effect or to incorrect reference elevation; if this is actually the case, then disregarding point 5 the mean square error in the triple determination of the elevation might be reduced to about ± 2.0 meters (± 6.5 ft.), which would correspond almost exactly to the mean square error in single determinations of elevation established as a result of tests carried out by the Aeronautical Charts Division and the National Research Council. Table II (page 25) gives the results of the Alaska test.

The results shown in Tables I and II are possibly already known. In presenting them again, we wish to stress not the absolute value of the errors, which is so surprisingly low, but rather the very interesting conditions under which the experiments were made. The first experiment shows how reliable can be the flight altitudes determined barometrically without reference to fixed points other than the initial one. The second experiment shows an astonishingly high degree of reproducibility under difficult conditions and when very rigidly controlled.

The results obtained in the determination of the elevations of water surfaces on further flights executed by the Aeronautical Charts Division are compiled in Table III. The only errors amounting to a more than 20 feet were due to local sleet storms and may therefore be ignored.

Point	Distance from initial point		Error, in ft.			Maximum Spread		Mean Error	
	Miles	Km	Loop 1	Loop 2	Loop 3	Ft.	Meters	Ft.	Meters
1	40	64	— 9	— 7	— 6	3	1.0	— 7	—2.1
2	50	80	— 8	— 6	—16	10	3.0	—10	—3.0
3	74	118	+ 2	+15	— 1	16	4.9	+ 5	+1.5
4	96	153	— 3	— 6	— 8	5	1.5	— 6	—1.8
5	114	182	+20	+34	+15	19	5.8	+23	+7.0
6	141	226	— 8	— 2	— 9	7	2.1	— 6	—1.8
7	148	237	+ 9	0	— 3	12	3.7	+ 2	+0.6
8	70	112	— 7	— 6	+ 1	8	2.5	— 4	—1.2
9	48	78	+ 5	+12	+12	7	2.1	+10	+3.0

Table II

Range of discrepancy		Details re 117 elevations checked								
50%	0 + 5	11	3	3	3	4	4	1	2	58
	0 — 5	6	5	4	4	2	3	1	2	
79%	6 + 10	9	1	7	1			1		33
	— 6 — 10	4		1	7				2	
96%	11 + 15	2		3				3		18
	— 11 — 15	1	3		4	1			1	
100%	16 + 20			1						5
	— 16 — 20	1	1	1	1					
	21 + 25									1*
	— 21 — 25		1							
	over ± 25		2							2*
Flight No.		1	2	3	4	5	6	7	8	117 total
Mileage between reference elevations		440	300	300	300	50	50	150	120	
Flight altitude in feet		5000	6000	6000	6000	4300	4300	10000	20000	

* Not considered because of sleet storm.

Table III

The results given in these three tables refer to errors in determining the elevations of water surfaces. Water surfaces are particularly suitable as vertical control in radar profiles not only because of their geometric quality, but also because of their homogeneous physical properties. A profile of dry land, however, may also give useful results provided that the data derived from the profile is correctly interpreted. Above all, it must be borne in mind that the radar beam covers a definite area and should therefore be related to "elevation areas" — as in the case of water surfaces — rather than to "elevation points". It has been established that the representation of some areas in the radar profile, while not exactly distorted, is nevertheless probably not as accurate as that of other more suitable areas. For this reason the choice of any specific point in the profile as an elevation point for further mapping can be made only after careful interpretation of the terrain using aerial photographs and a stereoscope. In this connection, it has been found in practice that it is advisable to leave the choice of the elevation in the profile to the discretion of the photogrammetrist who will later use the same elevation while working on the plotting machines. If it happens that more elevations are chosen from the radar profile for one pair of photographs than are necessary for the absolute orientation of this stereogram, then certain adjustments in the profile data can be made during the plotting. As an illustration of the degree of accuracy which can be achieved in this way, the control results of a project carried out by the Photographic Survey Corporation are given in Table IV. Some of the terrain mapped by the radar profile method had a sufficiently large number of elevation points to permit the absolute orientation on the Multiplex of several pairs of photographs independently. It was therefore possible to compare the spot heights established by radar with the Multiplex readings. The total length of the radar profile from which the figures in Table IV are derived amount to about 3.200 km (2 000 miles) with the average distance between control elevation 48 km (30 miles).

In the projects carried out by the National Research Council, the radar elevations are chosen in a somewhat different way. We try not to single out specific points, but rather to establish a "reference horizon" for a stereoscopic pair or preferably for a longer profile section. There is no doubt that the ground profile of a stereogram constructed on a plotting machine reproduces the details of the terrain much more exactly than the radar profile. Thus, if we were able to orient the instrument profile absolutely, individual points could be singled out for use as elevation points with a relatively high degree of accuracy. We are, therefore, undertaking the absolute orientation of the instrument profile with the help of the radar profiles, by superimposing the profile graphs and adjusting them until they coincide as much as possible. The elevations of the characteristic points in the instrument profile, which may be marked in advance, are then read on the scale of the radar profile; in this way the reference horizon can be established for the profile section in question. Since the "reference horizons", rather than specific points, are derived from the radar profile by this method, the purely local errors in the profile are eliminated and a reading can be taken of any point in the corresponding portion of the profile with almost equal accuracy. The method seems to be particularly useful in the case of rolling country with small

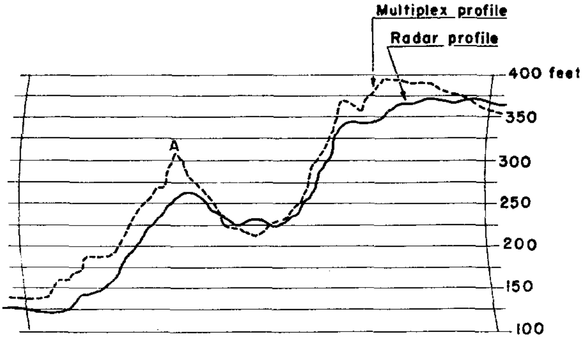

Fig. 5

COMPARISON OF A. P. R. AND MULTIPLEX ELEVATIONS

Multiplex Referenced to Ground Control

Description of feature	Discrepancy in feet — A. P. R. Elevation relative to Multiplex Elevation																									Total number of points
	0	5		10		15		20		25		30		35		40		45		50		55		60		
		+	—	+	—	+	—	+	—	+	—	+	—	+	—	+	—	+	—	+	—	+	—	+	—	
	Number of points																									
Lake	114	13	10	9	10	12	6	12	6	6	5	3	4	5	4	1		1						1		222
Valley	86	9	5	2	7	7	3	3	4	1	7	2	3	2		1		1				1				144
River	50	17	8	3	14	11	1		5	1	2	3	1	1			2	2		1				1		123
Creek	7	10	8	5	13	3	3	1	2	1						1										54
Road	25	3	1	3	5		5	2		2		1			1	1	1	1								51
Flat Field	12	2	2	2	2	1	2	3		2			2				1		1							32
Marsh	8	2							1					1												12
Water	1	2		2				1	1	1				1												9
Railway	1	1		1	1		1	1	2																	9
Hill	2	1									2		2		1											8
Clearing	3		1		1	1																				6
Pond		1																								1
Total number of Points	309	61	35	27	53	35	21	23	21	14	16	11	10	10	6	4	4	6	1	1		1		2		671

Percentage Distribution of Discrepancies

←46%→

←60%→

←72%→

←81%→

←87%→

From operation conducted during 1950—51 using P. S. C. — A. P. R. — Mk. 1 with fixed reflector and curvilinear recorder sharp lands forms, since radar profiles generally tend to round off the actual form of the terrain to some extent, as can easily be seen from Fig. 5.

In addition to showing the differences between an accurately reconstructed Multiplex profile and a radar profile, this Figure also shows an identification error in the profile at point A, due to the fact that the Multiplex profile was shifted slightly in relation to the radar profile and therefore shows the peak of the hill while the radar profile shows only the terrace below the peak. The location of the profile on the ground was defined by relatively few photographs which were taken at 1-mile intervals. One can also observe from this Figure the differences in the horizontal scale of the two profiles as well as a characteristic "lag" (a horizontal shift) of the radar profile.

To illustrate the reference horizon method which has just been described, the results of a 250-kilometer (150-mile) profile might be noted. In this case, it was possible to orient absolutely several stereograms with the aid of the field control and to compare the radar profile with the corresponding Multiplex profile. We did not know the values required to calculate the gradient of the atmospheric pressure and, therefore, only a linear correction was made, using a known point at the beginning and one at the end of the strip. The results are summarized below.

Distance from Initial Point (Miles)	Errors in Reference Horizons (feet)		$\frac{I + II}{2}$	
	Operator I	Operator II	Feet	Meters
6- 7	— 5	— 4	— 4.5	— 1.4
26- 27	+ 12	+ 13	+ 12.5	+ 3.8
30- 31	— 19	— 22	— 20.5	— 6.2
57- 58	— 12	— 12	— 12.0	— 3.7
70- 71- 72	— 5	— 5	— 5.0	— 1.5
73- 74	— 7	0	— 3.5	— 1.1
81- 82- 83	— 12	— 10	— 11.0	— 3.4
88- 89	0	+ 5	+ 2.5	+ 0.7
100-101-102	+ 5	+ 10	+ 7.5	+ 2.3
115-116-117	— 12	— 12	— 12.0	— 3.7
135-136-137	— 10	— 6	— 8.0	— 2.4
		$\frac{\Sigma}{\eta} =$	$\frac{98}{11} = \pm 9.0$	$\frac{30}{11} = \pm 2.7$

Table V

Even using the reference horizon method, it is very important that the profile be carefully interpreted because certain portions of the profile may necessarily be disposed of as less accurate.

Another even more important problem is that of correlating the profile data with the purely photogrammetric method in order to achieve a procedure which is not only as economical but also as accurate as possible. The solution to this problem is connected with the general arrangement of the radar profiles and the following cases may be noted:

In the first case, the profiles run parallel to the edges of the strip of photographs, within the limits of the common lateral overlap, as shown schematically in Fig 6. After a suitable number of elevation points has been chosen for each pair of photographs in accordance with one of the methods indicated, the contour map of any of the stereograms can immediately be made.

If aerial photographs are made simultaneously with the profile then the horizontal scale of plotting can be established with the aid of the radar profile method. If difficulties are encountered in levelling individual models, the stereogram should be positioned so that the best correlation with models which have already been plotted is achieved and the deviations are distributed as evenly as possible over all the radar elevation points. This method has the advantage of being very fast since the mapping is based directly on the radar profile and all the intermediate steps are eliminated. Such a method will, of course, also be used in all those cases when the topography of narrow strips of territory is involved, as, for example, in the laying out of roads, power lines, piple-lines, etc. It might be noted here that with this method the axial part of the strip is generally more accurately reproduced, because the effect of errors in the spot heights will diminish towards the axial portion of the strip.

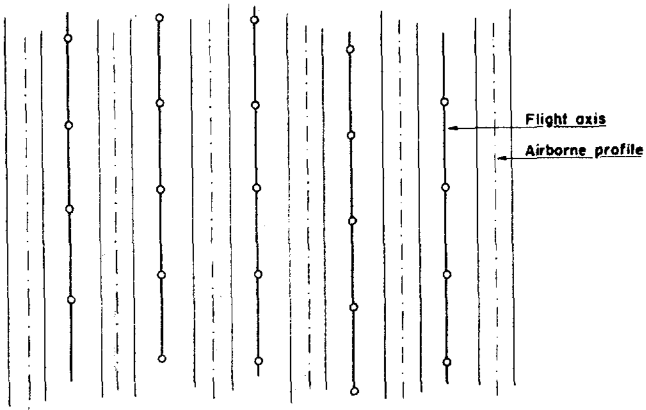

Fig. 6

Another method consists of laying the radar profile at right angles to the strip of photographs. The distance between them is determined by the length of the aerotriangulation strip concerned. In this case, the radar profiles do not eliminate the photogrammetry by making it an integral part of the aerotriagulation method. When working on the plotting machines, use would therefore be made of the data contained in the radar profile, such as the differences in the altitude of the aircraft above the ground; the elevations deduced from the radar profile will also be used later as a basis of adjustment. In comparing the radar profile with the aerotriangulation, the following difference necessity of aerotriagulation; on the contrary they form the basis of it.

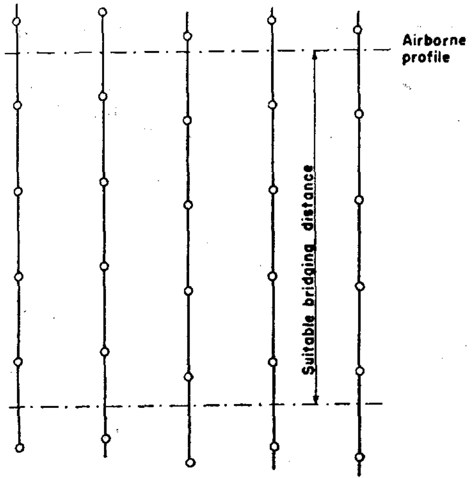

Fig. 7

In comparison with the first method, such an arrangement of the radar profiles reduces their number considerably, although it does not reduce the amount of work which must be done on the plotting machines, since the data necessary for a detailed plotting must first be obtained by aerotriangulation. There are cases, however, such as when the type of terrain makes precise navigation impossible, when this is the only practical method.

If there are only a few widely spaced fixed points in the area, a system of nodal points adds considerable strength to the established network of vertical controls.

And finally there is the third possibility of applying the radar profile to becomes obvious: although aerotriangulation itself may have great inner accuracy, various types of systematic and pseudo-systematic errors and the occurence of "breaks" due, for instance, to some kind of irregularity in a photograph, lead to a rapid increase in the values of the absolute error, thus reducing the accuracy and efficiency of the method. In contrast to this, the radar profile possesses a high degree of "general" accuracy within wide climatological limits, but a limited "inner" accuracy in the representation of neighbouring points of the profile. By integrating the inner accuracy of aerotriangulation with the general accuracy of the radar profile, a favourable combination of the two methods for the purpose of increasing the efficiency in bridging long distances would be achieved. In order to control the cross tilt of the aerotriangulation strips, short transverse aerotriangulation strips, based on the radar profiles, of three or four models might be cut in at certain intervals. In this way, it would be possible to determine the lateral tilt (not the absolute elevation!) of the terrain with a sufficiently high degree of accuracy.

On the other hand, the possibility of using the radar method as an accurate control of the scale represents a new approach to the aerotriangulation method, and the results of our preliminary experiments in this connection indicate that it has considerable merit. Unfortunately we have not yet had the opportunity of carrying out, with first-order autographs, the experiments which are necessary for a full investigation of the possibilities offered by the radar profile.

Of the three factors which determine the position of a point in space, two — the distance from the initial point and the elevation above the reference surface — can quickly be ascertained by the radar profile method with a relatively high degree of accuracy an at a great distance. Only the third factor, the azimuth, eludes our grasp to some extent, but even in this case the solution of the problem will probably be found in radar navigation.

It is obvious that the radar profile method for photogrammetric mapping is very significant. Above all, the radar profile represents a substantial economy of time. Within a few days it is possible to obtain data which would otherwise be available only after long painstaking and expensive work in the field.

Its application offers a possible solution to the problem of mapping on small and intermediate scales and particularly to the problem of mapping inaccessible areas having insufficient geodetic data to overcome the difficulties encountered. Particularly in cases where the mapping is based on only a few vertical controls or on points determined barometrically in the field, the use of the radar profile not only speeds up the mapping process, thus reducing the cost, but also increases the general accuracy.

If we may make a statement on the basis of results obtained thus far, it seems no exaggeration to say that the degree of accuracy achieved in determining elevations with the radar profile is only slightly less than the accuracy of aero-levelling at distances as great as 100 kilometers (60 miles), assuming of course that the most accurate type of plotting machine and a more elaborate method is used. The ratio of the distances bridged, however, would be 2—4 : 1, depending on local conditions. If only second-order apparatus is used in aero-levelling (as is very often the rule) the ratio is even more favourable to the radar profile method.

The new method however, offers new opportunities not only for obtaining the elevation data required for mapping but also for charting the planimetry and determining the scale. This very significant fact also opens up new possibilities for aerotriangulation and it would appear that the synthesis of the aerotriangulation method and the radar profile method might provide the long sought solution to the problem of the provision of control points for detailed mapping on a small or intermediate scale.

Obviously the radar profile offers an immediate solution to a great many of the technical problems connected with topography and it is unfortunate that they cannot all be dealt with in this brief outline.

A further significant fact about the airborne profile recorder method is that it permits in actual operation a very elastic relationship between the altitude at which the photographs are taken and the profile flights flown, thus achieving a high degree of economy in phogrammetric mapping.

As we mentioned earlier, the radar profile method has already developed beyond the initial stages and is now being used, as well as other methods, to overcome many of the problems encountered in map production. This does not mean, however, that its development is by any means complete. On the contrary, a number of projects now in hand are aimed at the improvement and perfection both of the instruments used and the procedures followed.

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