PLOTTING THE VERTICAL PHOTOGRAPHS OF THE SECOND MOUNT EVEREST FLIGHT: *A paper read at the Afternoon Meeting of the Society on 11 December 1933, by*

LIEUT. J. S. A. SALT, R.E.

THE immediate neighbourhood of Mount Everest falls at the junction point of four sheets of the $\frac{1}{4}$-inch-to-the-mile series published by the Survey of India (71.L, 71.P, 72.I, 72.M). A special sheet, "Mount Everest and Environs," is also published on a scale of $\frac{1}{2}$ inch to the mile. On all these sheets the area lying to the north of the general boundary between Tibet and Nepal has been depicted according to the plane-table survey of Major Wheeler in 1921, as amplified by the work of the expedition of 1924. Most of Nepal has been surveyed by the Survey of India, but in the immediate neighbourhood of the Tibetan border, owing to the wild and uninhabited nature of the country, the work is not to be regarded as of the same order of accuracy as elsewhere. Many peaks however have been included by intersection in the general triangulation, and their positions are shown by means of black dots accompanied by spot-heights.

When the project for a flight over Mount Everest was first discussed, it was obvious that to achieve the maximum amount of scientific record in the short time of a single flight it would be necessary to carry out a photographic survey. There have been many methods devised for transferring the data contained on an air photograph to an ordinary map sheet. The choice of method normally depends on the nature of the country and the purpose to which the resulting map is to be put, and the vital factor which then conditions all operations is the amount of ground control it is possible or necessary to provide. Air photographs by themselves record the physical features of small areas of country but not the actual positions of these areas upon the surface of the Earth. The positions of some of the points appearing on the photographs must therefore be known, in order that the data as a whole may be tied in to an accurate framework. In most cases a considerable amount of such ground control is necessary, but since on the Mount Everest flight there was no possibility of providing any more than could be obtained from the existing maps, the method offering the greatest freedom in this respect was much to be preferred. It was decided therefore to use the method known as the "Arundel" method, which has been developed at the War Office and used with considerable success in many parts of the world.

An air photograph taken absolutely vertically over flat country would be a true plan to some definite scale depending on the focal length of the lens and the height of the aircraft above the ground. On a similar photograph of hilly country the result would no longer be a true plan, since the higher ground would now be nearer to the camera and therefore photographed at a larger scale than the low ground. The distortions involved in this all take place radially from the centre of the photograph, so that a tall chimney near one of the margins would appear as a short straight line pointing away from the centre of the picture. In practice it is impossible to ensure that the camera is pointing in a truly vertical direction at exposure, and under these conditions

the point from which height distortions are radial is no longer the centre of the picture (principal point) but the plumb point, *i.e.* the point where the plumb line from the perspective centre of the lens cuts the plane of the photograph. There is a further effect of this tilt: such a photograph, even of flat country, is distorted in that the image on that side of the negative tilted nearer to the ground is at a smaller scale than that on the other side. It can be easily shown that this distortion takes place radially from a point known as the isocentre, situated roughly halfway between the principal point and the plumb point. There are therefore two sets of distortions, each set taking place radially from a different point, whose positions we can only discover if we know the magnitude and direction of the tilt. These quantities however cannot be readily obtained, as a spirit-level, or similar contrivance, is unable to distinguish between gravity and acceleration. But for small tilts the two points lie quite close to the principal point, whose position is always available from the calibration data, and the question arises as to what kind of error would result from the assumption that all distortions take place radially from the principal point. We wish to assume, that is, that angles subtended at the principal point by points of photographic detail are equal to the angles that would be measured to the corresponding points by a theodolite situated at the point corresponding to the principal point on the ground. It can be shown theoretically, and is borne out practically, that the errors resulting from this assumption can be tolerated on the ordinary scales of plotting provided that the tilts are kept below about 2° and the variation of ground height does not exceed 10 per cent. of the altitude of flight. These conditions are normal, and such photographs may then be considered as records of true angles measured from the principal point. If therefore a strip of vertical photographs is taken in such a way that each one overlaps its neighbour by rather more than 50 per cent., there will be a small area of ground common to every three successive pictures. The above radial assumption therefore enables us to construct a graphical triangulation in which a traverse containing the principal points is connected up by means of three-ray intersections to points on either side. Its scale and orientation are as yet unknown, but may be obtained from any two known points situated within it. If several such strips are flown alongside with a small lateral overlap their graphical plots may be joined up by means of points in the common overlaps. Together they thus form a block, to which the two-point condition still applies. Finally, the detail may be plotted by intersections and tracing from the photographs.

A further possibility is opened up by the fact that since the overlap between successive pictures is at least 50 per cent. every point on the ground is photographed from two points of view. If now we so arrange matters that when two neighbouring photographs are placed side by side the observer's right eye sees the right-hand picture and *vice versa*, he will get the same impression of the ground that would have been obtained by a giant with an inter-ocular distance so large that his eyes were situated at the original positions of exposure. In the same way that the giant would see the landscape in the solid, the human observer can connect up the two photographic images to form a fused impression of the landscape in stereoscopic relief. In ordinary vision

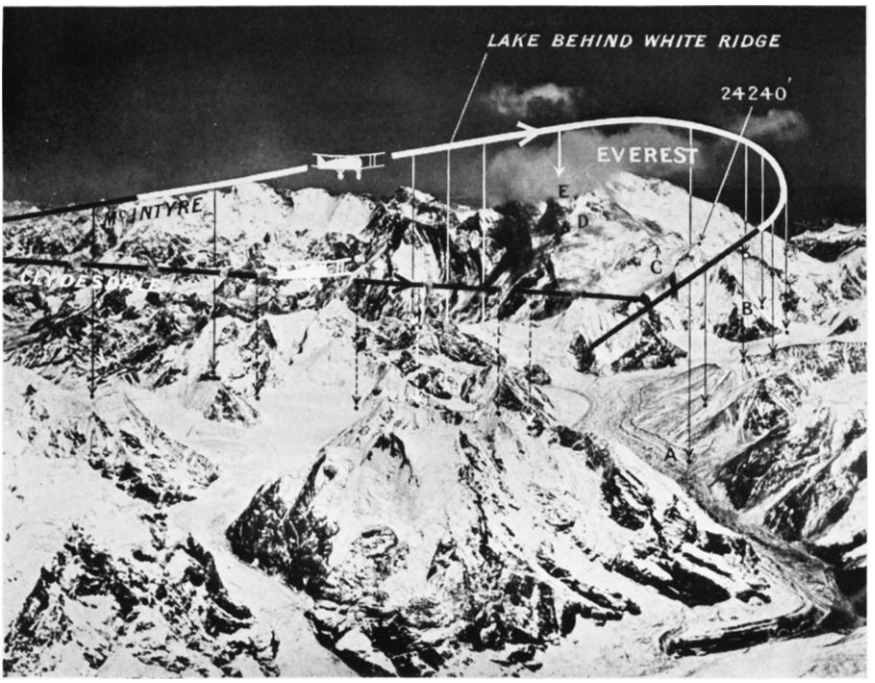


Plate 1. Area between Makalu and Everest

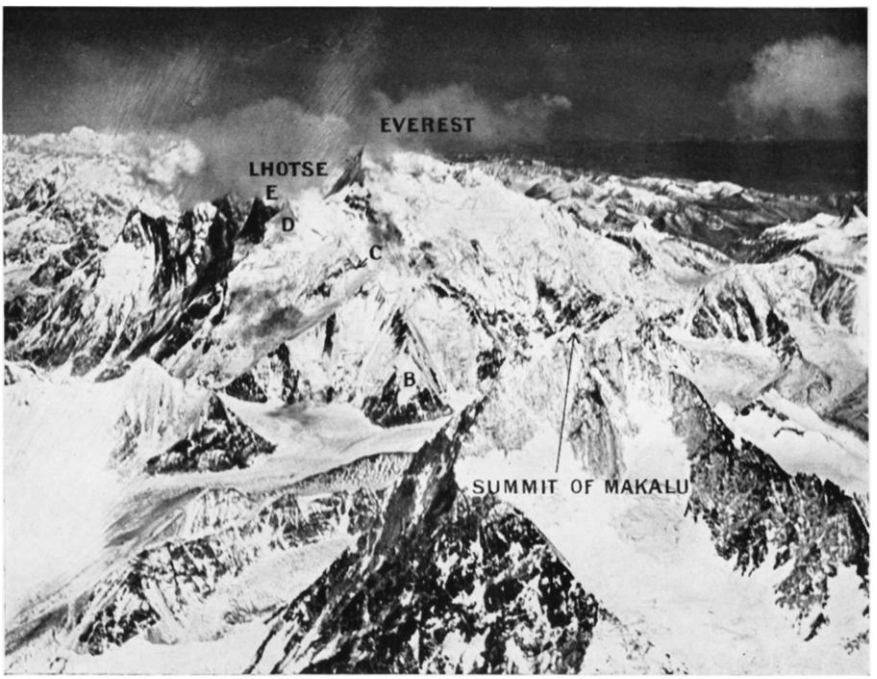


Plate 2. Mount Everest from south-east of Makalu

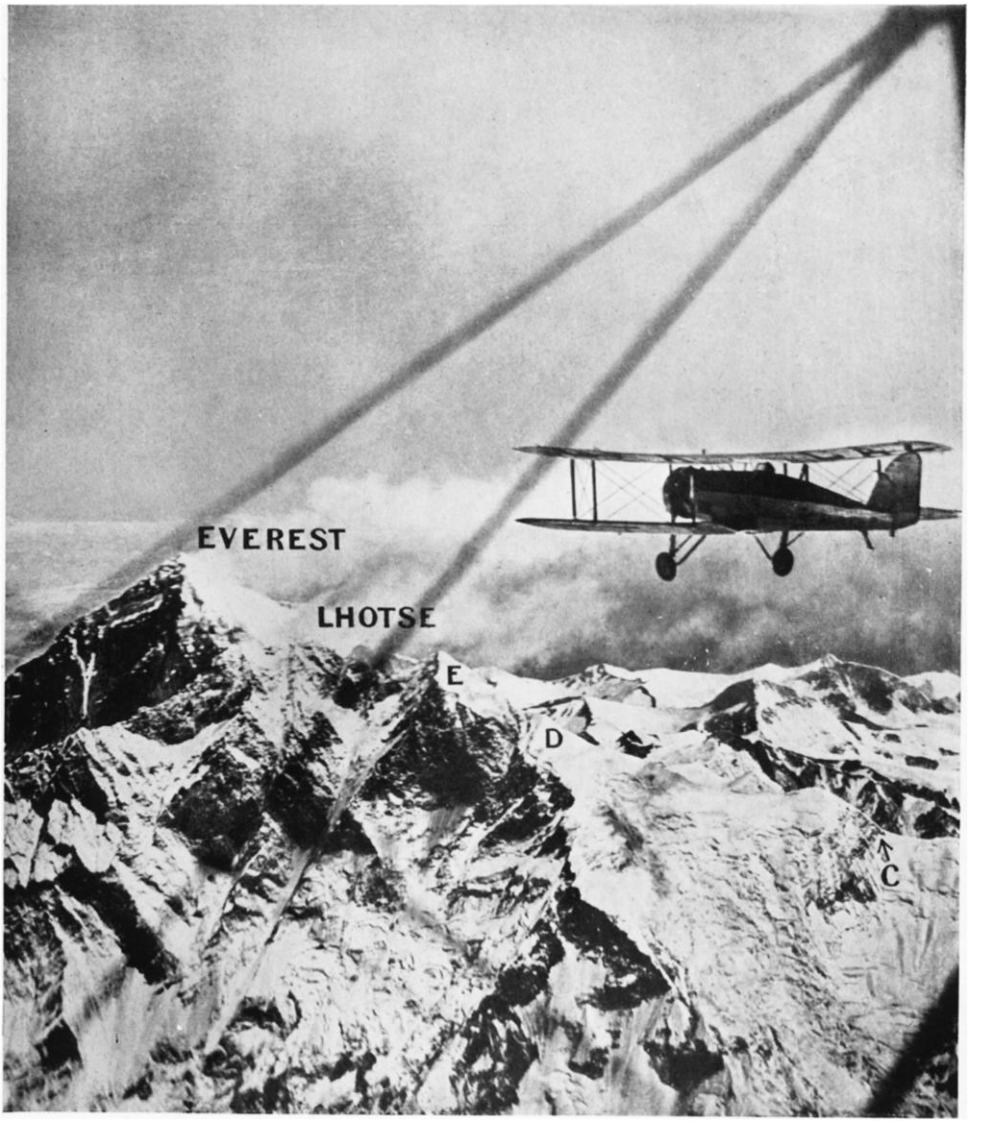


Plate 3. South-east slope of the Everest massif

the eyes converge on to the observed object and automatically focus themselves (accommodation) for its distance away. With a definite accommodation there is thus associated a definite convergence. But for viewing directly a pair of photographs stereoscopically, the eyes are focussed for their distance away but converged for a greater distance, since the two images of any one point are separated by at least the width of a single picture. If this width is greater than the inter-ocular distance (about 2^1_2 inches) the eyes would actually have to diverge. The art of negative squinting however cannot be indulged in without eye strain, and to bring accommodation and convergence into harmony a stereoscope is used. In this method a pair of fine grids superposed on the photographs may be adjusted to give the impression of a network floating in space. If the tilts are small, by varying the apparent height of this network it may be used as a horizontal reference plane, and, if a few spot-heights are known, contours may be drawn in by eye. These contours will all be at a different scale, but may be transferred to the map in the same way as detail.

Such, in brief, is the method it was proposed to adopt. In normal practice it involves a high class of flying with correspondingly small tilts, and is limited to a moderate variation in ground height. On the Mount Everest flight the conditions of flying would be so severe that far larger tilts were to be expected, and the variation in ground height would be more than 90 per cent. of the altitude of flight. Though these extreme conditions might be expected to invalidate the method, a few computations indicated that it was still the most propitious to adopt. In addition to being a practical solution it would also provide very valuable experimental data for further research on the method itself.

To collect the maximum amount of survey material a series of parallel strips would be the ideal. This objective however was soon realized to be too ambitious, and it was finally decided that all that would be possible would be a single strip to the peak and another on the return journey. These two strips would both contain an image of the summit, the position and height of which are known from trig. intersections, and since their other extremities would fall over the foothills, various points would no doubt be found, the positions of which are given on existing maps. In this way, scale and orientation of the plot could be guaranteed. The general line of such strips was planned to run up the Arun valley.

Before leaving England the pilots made certain experiments in which they attempted to imitate the actual conditions of the proposed flight. Apart from the general difficulties of high-altitude flying and the operation of a camera in extreme cold, the most important feature was the setting of the time interval between exposures to ensure the necessary percentage overlap. To cover the maximum amount of ground it is necessary to fly as high as possible. On an ordinary flight over undulating country the time interval can then be set (usually about 20 to 30 seconds) for the mean height above the ground and thereafter kept fixed. But in this case the ground would be steadily rising underneath the aircraft, and, were the time interval set for the lower ground maintained, the overlap would steadily diminish until there were gaps between the photographs, and therefore no means of connecting them at all.

On the other hand, if the time interval were set in advance as correct for the high ground, and the excessive overlap over the low ground regarded as merely a fault on the right side, the number of photographs required for the strip would be enormously increased, and there would be a danger of the film running out before reaching the objective. What was required was an organized way of steadily diminishing the time interval as Mount Everest was approached, and a rehearsal of this procedure was carried out at Farnborough.

The camera used was the Williamson Eagle Type III, fitted with a Ross Xpres (E.M.I.) F/4 lens, of 5-inch focal length. The size of the picture being 5 inches by 5 inches it follows that the side of the square patch of ground covered by a single photograph is equal to the height of the aircraft above the ground. This is the maximum field that can be covered by a single lens with adequate illumination and represents a high achievement of the lens-maker's art.

In addition to the vertical strips arrangements were made to take a series of obliques with a camera held in the hand. The actual survey value of such photographs is limited, but it was thought that a considerable amount of reconnaissance data might be extracted from them, and they might help in the identification of some of the peaks. The pictorial effect of these photographs would also be of general interest.

The story of the flight and of the many difficulties encountered has been told elsewhere. This account must continue at the point where the photographs arrived back in England.

There were two distinct flights to and from Mount Everest, and on each occasion an attempt was made to complete a vertical strip in each direction. On the first flight the obliques were very successful, but the negative rolls of the verticals revealed severe fogging, so that prints from them were of little value. On the second flight however fewer obliques were taken, but the negatives of the verticals showed excellent definition which enabled first-class prints to be produced. It was estimated by the expedition that the mountain was approached from the south-west. Lord Clydesdale and Flight-Lieut. McIntyre kept together at first, and then, while McIntyre flew directly towards Everest, Clydesdale turned off right-handed towards Makalu. During this latter stage the machines were not visible to each other, but it was certain that on the return journey McIntyre must have crossed Clydesdale's track somewhere to the west of Makalu. It was intended to start both cameras when the machines were over valleys in the lower ground recorded on the existing maps, and McIntyre on approaching Everest had banked in the "plume" so as to include the summit in the vertical strip, and then made direct for home. It seemed certain therefore that known points would be available at each end of this latter strip in order to determine its orientation and scale, and that the other strip could be tied in to it even if no further points were available in the direction of Makalu.

The first task was to plot a graphical triangulation for each strip. The material was as follows (see Fig. 1).

Clydesdale's Strip. No. 1

The camera was started when the machine was over a deep ravine well below the snow-line. Continuing in a north-north-east direction—as far as

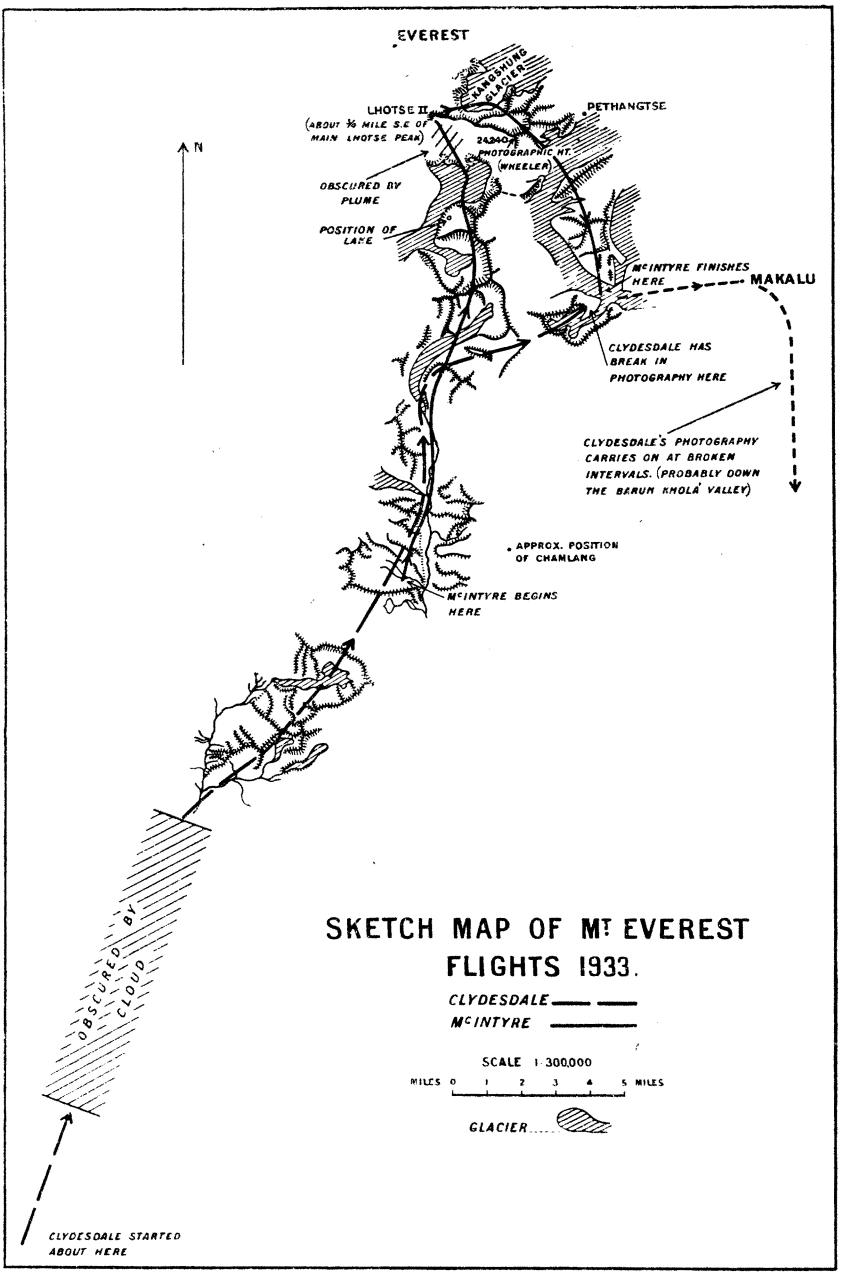

EVEREST
RAMSHUNG GLACIER
LHOTSE II
(ABOUT ½ MILE S.E. OF MAIN LHOTSE PEAK)
PETHANGTSE
24,240 ft PHOTOGRAPHIC HT. (WHEELER)
N
OBSCURED BY PLUME
POSITION OF LAKE
McINTYRE FINISHES HERE
MAKALU
CLYDESDALE HAS BREAK IN PHOTOGRAPHY HERE
CLYDESDALE'S PHOTOGRAPHY CARRIES ON AT BROKEN INTERVALS. (PROBABLY DOWN THE BARUN KHOLA VALLEY)
APPROX. POSITION OF CHAMLANG
McINTYRE BEGINS HERE
OBSCURED BY CLOUD
SKETCH MAP OF Mt EVEREST
FLIGHTS 1933.
CLYDESDALE
McINTYRE
SCALE 1:300,000
MILES 0 1 2 3 4 5 MILES
GLACIER
CLYDESDALE STARTED ABOUT HERE

Fig. 1

could be estimated from the shadows—for a few miles, it ran over a bank of clouds which almost completely obscured the ground for about 9 miles, after which it revealed a valley, clearly at a much greater elevation and with snow appearing in large masses. (N.B. The distances given here are those subsequently determined. At this stage of the proceedings the scale of the photographs was not known, and distances along the strip could only be measured in terms of the number of overlaps.) After a further 15 miles, during the latter half of which the two machines photographed very much the same line of country, the strip turns through nearly 60° to starboard, and, after crossing a vast snow plateau, reaches a very prominent glacier and then stops. The remaining photographs on the negative appear in short groups, as if the camera had functioned intermittently, and these therefore, unless independent ground control can be found, cannot be connected to the main body of the strip. The longitudinal overlap throughout is about 90 per cent.

McIntyre's Strip. No. 2

The camera was started on the same line of flight as the other strip but about 22 miles farther on, so that the first 7 miles of McIntyre's strip cover the same ground as Clydesdale's before the latter turned to starboard. This strip continues in the same direction over a magnificent mountain mass, in which lie the heads of several glaciers, and then runs into the plume of Mount Everest which obscures all but fragments of the detail. (The overlap in this section was about 95 per cent.) Here the machine banked heavily (as can be observed by the lateral tilt) and McIntyre believed that in so doing he had been able to secure a picture of the summit taken by the vertically mounted camera. Turning on a fairly small radius through nearly 180° the strip makes its way down a broad glacier and finally stops, by the hand of Providence, with a photograph covering almost exactly the same area as that in the last picture of the main series of Clydesdale's strip. The overlap in this latter section was 75 per cent. to 80 per cent. The two tracks here cross at right angles. The reason for stoppage was that owing to the large initial overlap the film magazine had been prematurely exhausted.

The work of constructing the graphical triangulation, or "minor control plot," as it is called, was not entirely straightforward. On Strip No. 1 the principal difficulty was the section obscured by cloud. Where no ground is seen it is hardly possible to plot anything, but an attempt was made to bridge the gap in this way: On those photographs on which the cloud bank first appears, by graphical construction some estimate can be made of the speed and direction of the movement of the clouds relative to the ground. Thereafter definite cloud features can be regarded as moving trig. beacons and a method can accordingly be devised for eliminating the disturbing effect of their movement. In this case however, though the clouds appeared to move in an orderly manner, they defeated the surveyor by changing their shape, and succeeded in causing a gap in the strip. The rest of the strip, with the exception of the above-mentioned separated sections, proved to be fairly plain sailing. By this method of plotting an estimate can be made of the order of tilt encountered, and this was not infrequently large.

On Strip No. 2 a start was made by tying it into the same scale along the

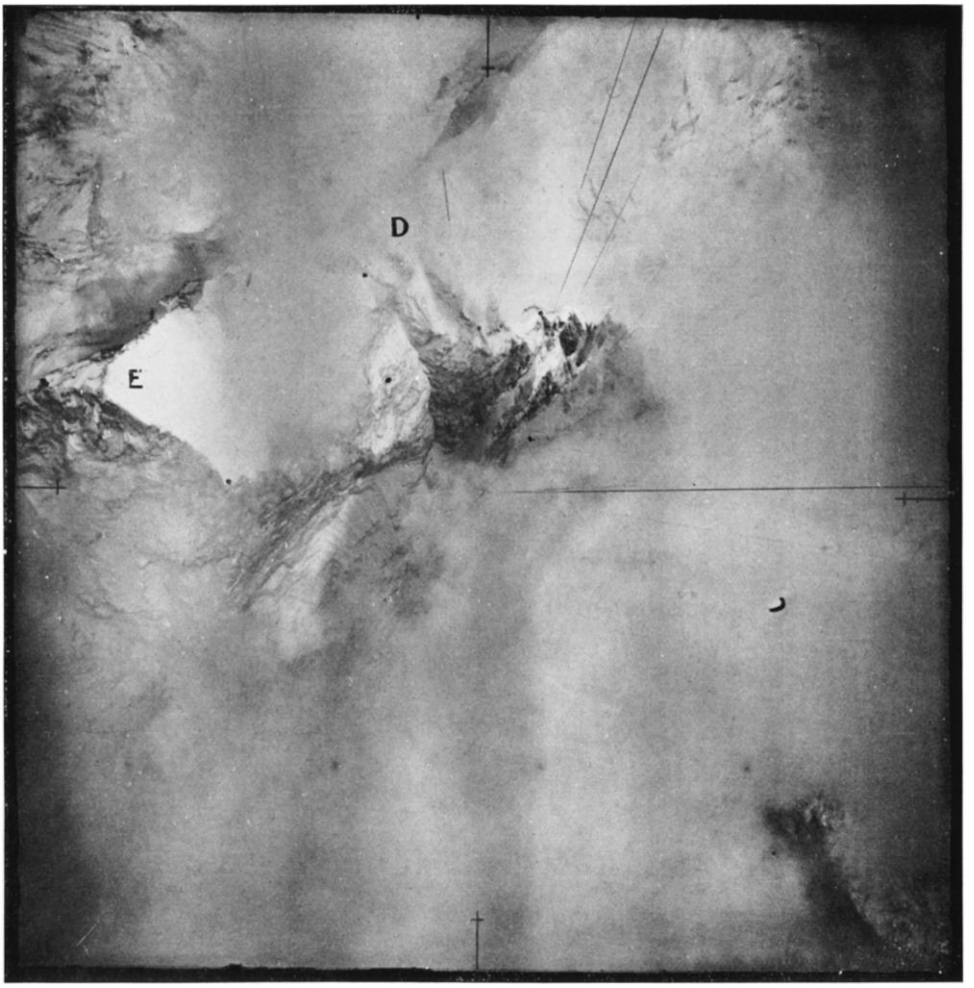


Plate 4. Vertical photograph showing ridge culminating in Lhotse II: the highest point appearing on the vertical strips

Plate 5. Vertical photograph showing western slope of Chamlang

stretch common to Strip 1, but difficulties were met with on approaching the plume of Mount Everest, where the banking of the machine had caused very large lateral tilts. The plotting here appeared so unreliable that it was extremely doubtful if the scale and orientation of the second part of the strip would be properly related to the first. Resource was therefore had to the providential right-angle join between Strips 1 and 2.

By resecting the last photograph of Strip 2 on to the last overlap of Strip 1, the second part of Strip 2 was plotted backwards. Its scale should therefore be the same as that of Strip 1, to which the first part had already been made equal, and the relative orientation should likewise be correct. On the backwards plot difficulties started as before with the large tilts caused by banking in the plume, but the gap to be bridged was then small and had firm abutments on either side. Errors could therefore be smoothed out.

At this stage the principal parts of both strips had thus been plotted in skeleton form and were joined together to form a whole. The next problem was to find within this plot points whose positions were known. The first question to decide was whether the summit of Mount Everest actually appeared on the photographs. Projecting out of the hazy masses partially obscured by the plume was a definite peak of roughly the same type of formation as Mount Everest but with the orientation of its faces rather different. It was thought however that the orientation of the plot itself might have been estimated wrongly, and this peak was therefore accepted provisionally. At the southern end there was a striking resemblance between the forked ravine and the valley junction shown a few miles north-east of Namche Bazar on the map. Assuming these two points, therefore, the plot was provisionally scaled and oriented, and the detail, roughly intersected on the plot, was compared all over with that shown on the map. The results were not too promising.

At this stage the evidence of the oblique photographs was introduced. Most of these had been taken on the first flight and therefore did not necessarily correspond to the course covered by the verticals, but starting with the most general views taken some distance away, the many features shown were gradually analysed and various points of detail occurring on the verticals were identified. Only the more striking results of the examination can be dealt with here.

Reference to Plate 1 will show very clearly the general lie of the most interesting sections of both strips, the right-angled junction appearing at A. Here the first great doubt as to the correctness of the provisional scaling and orientation arose, for by comparing the detail beyond A with the same features on Plate 2, it seemed clear that the glacier must run south-east past Makalu, which would then be very nearly abeam from A. But, according to the plot, A should fall far nearer to Everest and more to the south-west of the line joining Everest and Makalu. This indicated that the scale might be too small and the orientation too easterly. An attempt was made therefore to trace out point by point on the obliques the detail shown on the verticals of the south-east slope of the Everest massif.

At the start this presents no difficulties; the feature at B, for instance, appears in the middle of the vertical strip. Comparison of detail may then be

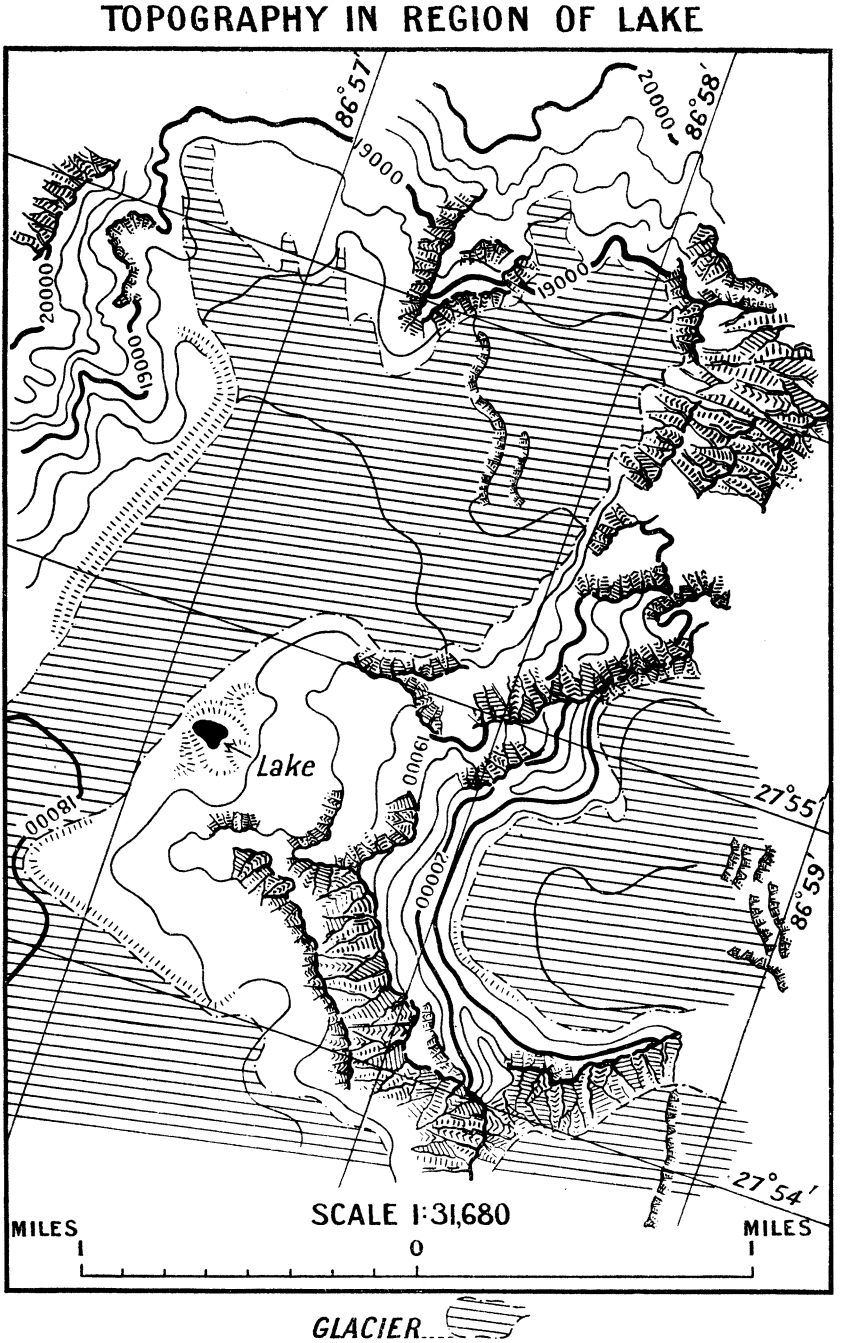

TOPOGRAPHY IN REGION OF LAKE
86°57'
86°58'
20000
19000
18000
Lake
27°55'
86°59'
27°54'
SCALE 1:31,680
MILES
1
0
1
MILES
GLACIER

Fig. 2

Plate 6. Vertical of the area surrounding the lake

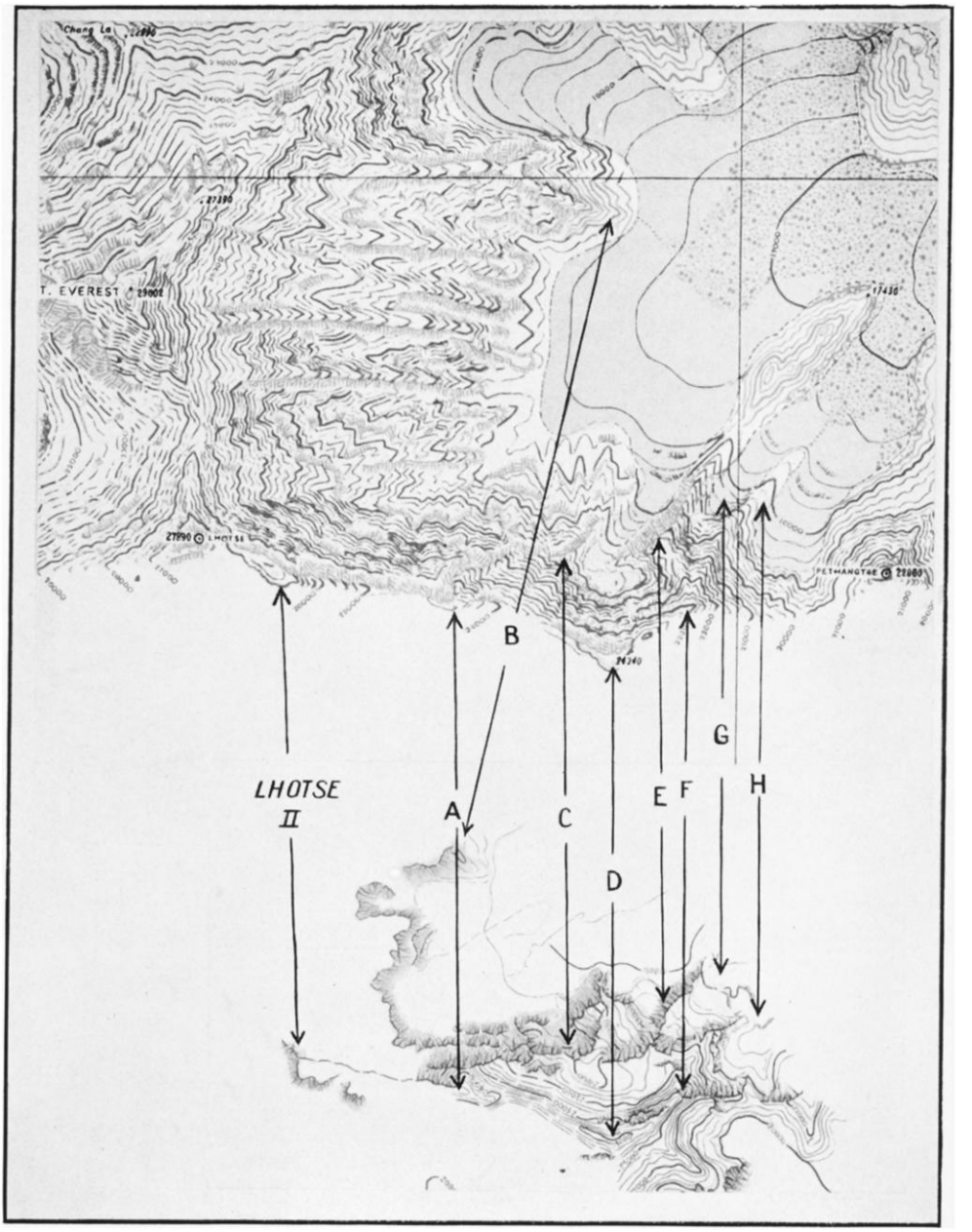


Fig. 3. Comparison between common ground covered by Major Wheeler's ground photographic survey of 1921 and the plot from the Everest flight

made along the ridge, where the point C appears clearly on the verticals and on Plate 3. Continuing along the ridge we can identify the feature at D with that shown on Plate 4. Finally the peak E on Plate 3 is seen to be the same as E on Plate 4. This is the second and smaller of the two peaks of Lhotse, the first of which is shown as an intersected point on the map and is named Lhotse on Plate 3. It has therefore been called Lhotse II, and is indicated by a small ringed contour on Major Wheeler's map. But this was the point previously thought to be the summit of Everest. Though the disillusionment was damping, the verifying of a first definite point was gratifying.

The next stage was to find some other definite point, and this was rendered more difficult by having made a false identification of the starting-point. Ultimately the situation was saved by the two photographs published opposite p. 59 of the *Journal*, July 1933. The arguments for identifying the peak as Chamlang—an intersected point—will not be repeated here, but having done so, although these obliques were taken on the first flight and the verticals on the second, it seemed probable that the course followed on the two occasions would be roughly the same, and therefore some of the detail appearing in the oblique might also appear on one of the verticals. This proved to be the case, and it will be seen that the ground in the top left-hand corner of the vertical shown in Plate 5 is the same as that shown halfway up the right-hand side of Plate 9 in the July paper. The same feature can be seen in Plate 10. By means of certain graphical constructions on the obliques, the approximate position of a point in this feature was obtained relative to the summit of Chamlang, and thus a second and reasonably definite point was obtained.

Though two points are sufficient to determine scale and orientation, a third point supplies the answer to the surveyor's prayer—a check. Further inspection revealed the identity of one of the peaks in the north-east corner of the plot as that shown on Major Wheeler's map as a "Photograph Intersected Point," and heighted 24,240 feet (shown on Plate 1).

The whole plot was therefore rescaled and reoriented on these three points as control, and the agreement between them was most satisfactory. It showed that the true course on the approach to Everest was a little east of north and not north-east, as previously supposed, and that the preliminary scale adjustment had given a scale very much too small. This agreed with and corrected the original discrepancy observed. Subsequent examination of all other areas has revealed general agreement, with some striking examples in the small area north-west of Pethangtse common to the air survey and to Major Wheeler's work. In the area immediately south of Everest there is very little resemblance between the plot and the existing map, but this was to be expected, since in that region the map shows clear signs of artistic imagination rather than sober survey. The scale of the plot thus adjusted is 1/23,190, and on this the physical features have been plotted with very fair accuracy by means of intersection and interpolation.

Under normal circumstances the contours would be plotted on the photographs by measurement and observation in a stereoscope, using as control a fairly close network of spot-heights. In this case the only heights which could be assumed were those three points used as control, and the height of one

of them, near to Chamlang, could only be estimated by somewhat uncertain methods of graphical construction on the obliques. The tilts, moreover, were in many cases severe and made any stereoscopic measurements, even had there been an adequate number of spot-heights, somewhat fortuitous. It was therefore necessary to evolve a more suitable method. Now, the plot as constructed is at a definite scale, whereas ground at different heights photographs at different scales. There will therefore be a discrepancy between the plotted position of any point and the uncorrected position obtained by a direct tracing from the photograph, and this discrepancy will depend on the depth of the point below the aircraft and the tilt of the photograph. In this type of country the former effect is very much larger than the latter, and, since the position of each point is the result of intersections from three photographs, by measuring all these discrepancies and taking the mean, the tilt effect tends to be eliminated. The results can then be turned into differences of height by applying simple formulae. By this means a number of spot-heights can be deduced, and using these as control the contours can be drawn in by observing the physical features in a stereoscope in the ordinary way. An example of the result of this method is shown in Fig. 2.

Though this account must confine itself to the actual survey work and cannot undertake to analyse the physical forms depicted, attention must be drawn to one remarkable feature shown in Fig. 2 and on the corresponding photograph in Plate 6—a small lake. The shape is roughly triangular with maximum length and breadth of 560 feet and 440 feet respectively. That it is a lake may be deduced from the following evidence: the surface can be clearly seen as flat in a stereoscope; the surface is very dark in colour; if a solid surface, snow would collect and make the colour lighter. The water must therefore be in a liquid state and presumably is in connection with some source of heat below. Its altitude is 18,090 feet. In the stereoscope one can see clearly that the lake lies in a small crater, which rests in the side of the main mountain slope just above its junction with the glacier below. The ridge line of the crater is about 70 feet above the level of the lake. On the glacier side of the crater there is a V-shaped notch, and level with the bottom of this and along the inside of the crater runs what is apparently an old shoreline from the time when the lake at a higher level drained through the notch into the valley. The difference between the two levels is about 25 feet. The mountain side cuts the glacier about 30 feet below the level of the lake.

The final result of the plot from the vertical photographs is shown in the folding map. The original scale is 1 inch to the mile (here unavoidably reduced to half inch to the mile) and the contour interval 250 feet, so that the work may be readily compared with Major Wheeler's map where common ground is covered. It is possible that more detail may be extracted from the obliques and added to this plot, but any such work will be of a much lower order of accuracy, and what is shown here may be regarded as the main substance of the survey results. The principal problem throughout has been the question of ground control and the identification of points, and in view of these difficulties the method chosen was undoubtedly correct. It is possible that more accurate detail could be extracted in any given area by using the photographs in an automatic plotting machine, but bearing in mind the

approximate nature of the control available it is doubtful if this would do more than adorn with ornament a not entirely stable structure. From the survey point of view it is certain that such a procedure would be thoroughly unpractical. This is not to say that from the point of view of a survey problem the method would be without scientific interest, nor does it infer that extra local detail might not be of value for certain purposes, *e.g.* glaciology.

DISCUSSION

Before the paper the PRESIDENT (Major-General Sir PERCY COX) said: Most of those present are probably aware that the idea of flying over Mount Everest was not altogether new in 1932, when the plan ultimately carried into effect took shape; but when the idea of flying over the mountain first occupied the minds of airmen, it was not a practical proposition because there was then no engine in the market which was competent to carry to a height of about 33,000 feet the load that would be necessitated by a party sufficiently well equipped for really scientific work. In 1932 Colonel Blacker was inspired by the belief that the new Pegasus engine made by the Bristol Aeroplane Company, a British engine of course, could accomplish the task, and thanks to his perspicuity and initiative at that time the Mount Everest flight took shape.

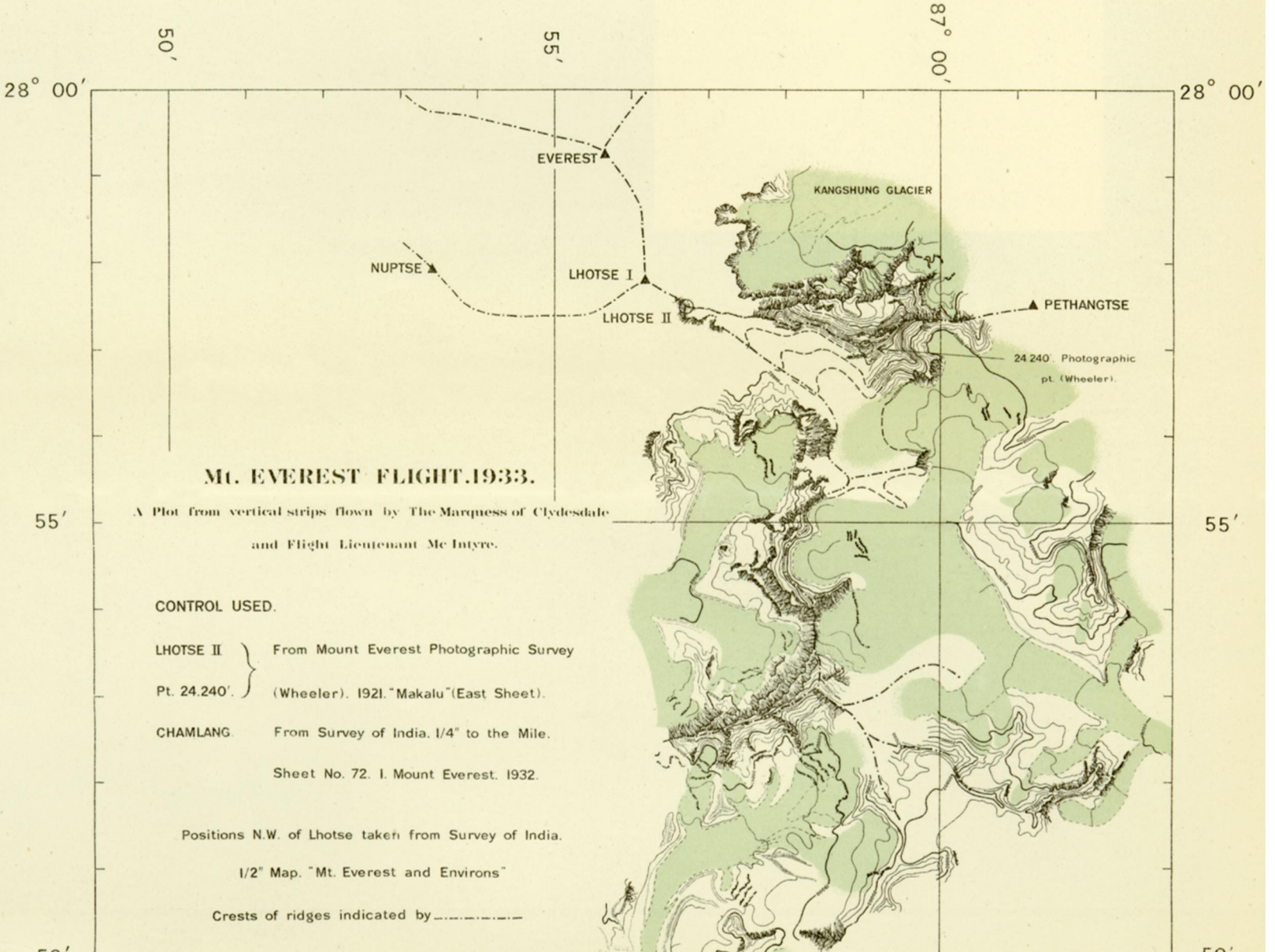
Colonel John Buchan, in a foreword he has written to the book, 'First Over Everest,' which has just been published, is at pains to impress upon the reader that the purpose of the flight "was not to perform a feat of daring and endurance, to break a record, to do something for the first time. . . . The true purpose was austerely scientific." It was on that account that the enterprise received the support and co-operation of the Council of this Society. We were of opinion that the results to be expected from the flight over Mount Everest would be of undoubted scientific importance and interest, and it is of some of those aspects of the flight that we are going to hear to-night.

The reader of the paper is Lieutenant Salt, R.E., who is a member of Colonel MacLeod's staff in the Geographical Section of the General Staff at the War Office. Lieutenant Salt is especially employed on research into methods of mapping from air photographs, and he has made a close study of the Everest flight from that point of view. I may mention that the plotting of the vertical photographs taken by the Mount Everest Flight was undertaken by Colonel MacLeod as providing an exacting test of the Arundel Method developed by the Geographical Section of the General Staff for mapping from air photographs. I now call upon Lieutenant Salt.

Lieutenant Salt then read the paper printed above, and a discussion followed.

The PRESIDENT: I call first upon Colonel MacLeod, Chief of the Geographical Section of the General Staff at the War Office.

Colonel MACLEOD: There are some who might say that a comparatively small strip of mapping, such as Lieutenant Salt has described, is rather a small result from what, after all, was a pretty big expedition. That, of course, depends on what the expedition set out to achieve. Admittedly, south of Mount Everest there is a blank on the map, and any blank on the map is an incentive to somebody to go and fill it in; it is a gap in our knowledge which is worth filling in for its own sake. But it must be admitted that there is not much prospect of anybody going to that part of the world for the moment, so, looked at from that point of view, the filling in of this particular gap is rather an academic matter. But when Air-Commodore Fellowes and Colonel Blacker consulted me as to what they ought to try to do on the flight, they made it quite clear that their object was not


50′
55′
87° 00′
28° 00′
28° 00′
EVEREST
KANGSHUNG GLACIER
NUPTSE
LHOTSE I
LHOTSE II
PETHANGTSE
24.240′. Photographic pt. (Wheeler).
55′
55′
Mt. EVEREST FLIGHT.1933.
A Plot from vertical strips flown by The Marquess of Clydesdale and Flight Lieutenant Mc Intyre.
CONTROL USED.
LHOTSE II
Pt. 24.240′.
From Mount Everest Photographic Survey (Wheeler). 1921. "Makalu" (East Sheet).
CHAMLANG
From Survey of India. 1/4" to the Mile. Sheet No. 72. I. Mount Everest. 1932.
Positions N.W. of Lhotse taken from Survey of India. 1/2" Map. "Mt. Everest and Environs"
Crests of ridges indicated by

A Plot from vertical strips flown by The Marquess of Clydesdale and Flight Lieutenant Mc Intyre.

CONTROL USED.

LHOTSE II, Pt. 24.240'. } From Mount Everest Photographic Survey (Wheeler). 1921. "Makalu" (East Sheet).

CHAMLANG. From Survey of India. 1/4" to the Mile. Sheet No. 72. I. Mount Everest. 1932.

Positions N.W. of Lhotse taken from Survey of India. 1/2" Map. "Mt. Everest and Environs"

Crests of ridges indicated by _._._._

Glaciers shown blue

N.

⊙ CHAMLANG

Position deduced approximately from oblique photographs.

55′

50′

45′

Geographical Section, War Office, 1933.

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approximate nature of the control available it is doubtful if this would do more than adorn with ornament a not entirely stable structure. From the survey point of view it is certain that such a procedure would be thoroughly unpractical. This is not to say that from the point of view of a survey problem the method would be without scientific interest, nor does it infer that extra local detail might not be of value for certain purposes, *e.g.* glaciology.

DISCUSSION

Before the paper the PRESIDENT (Major-General Sir PERCY COX) said: Most of those present are probably aware that the idea of flying over Mount Everest was not altogether new in 1932, when the plan ultimately carried into effect took shape; but when the idea of flying over the mountain first occupied the minds of airmen, it was not a practical proposition because there was then no engine in the market which was competent to carry to a height of about 33,000 feet the load that would be necessitated by a party sufficiently well equipped for really scientific work. In 1932 Colonel Blacker was inspired by the belief that the new Pegasus engine made by the Bristol Aeroplane Company, a British engine of course, could accomplish the task, and thanks to his perspicuity and initiative at that time the Mount Everest flight took shape.

Colonel John Buchan, in a foreword he has written to the book, 'First Over Everest,' which has just been published, is at pains to impress upon the reader that the purpose of the flight "was not to perform a feat of daring and endurance, to break a record, to do something for the first time. . . . The true purpose was austerely scientific." It was on that account that the enterprise received the support and co-operation of the Council of this Society. We were of opinion that the results to be expected from the flight over Mount Everest would be of undoubted scientific importance and interest, and it is of some of those aspects of the flight that we are going to hear to-night.

The reader of the paper is Lieutenant Salt, R.E., who is a member of Colonel MacLeod's staff in the Geographical Section of the General Staff at the War Office. Lieutenant Salt is especially employed on research into methods of mapping from air photographs, and he has made a close study of the Everest flight from that point of view. I may mention that the plotting of the vertical photographs taken by the Mount Everest Flight was undertaken by Colonel MacLeod as providing an exacting test of the Arundel Method developed by the Geographical Section of the General Staff for mapping from air photographs. I now call upon Lieutenant Salt.

Lieutenant Salt then read the paper printed above, and a discussion followed.

The PRESIDENT: I call first upon Colonel MacLeod, Chief of the Geographical Section of the General Staff at the War Office.

Colonel MACLEOD: There are some who might say that a comparatively small strip of mapping, such as Lieutenant Salt has described, is rather a small result from what, after all, was a pretty big expedition. That, of course, depends on what the expedition set out to achieve. Admittedly, south of Mount Everest there is a blank on the map, and any blank on the map is an incentive to somebody to go and fill it in; it is a gap in our knowledge which is worth filling in for its own sake. But it must be admitted that there is not much prospect of anybody going to that part of the world for the moment, so, looked at from that point of view, the filling in of this particular gap is rather an academic matter. But when Air-Commodore Fellowes and Colonel Blacker consulted me as to what they ought to try to do on the flight, they made it quite clear that their object was not

primarily to fill up gaps on the map. They wanted, first, to show what could be done by British pilots and British aircraft in a difficult flight, and they wanted to demonstrate the value of some particular kind of air survey technique for filling in gaps in the map, not only round Mount Everest, but at any place. They selected the Mount Everest area as representing the most difficult proposition in both respects that anybody was ever likely to be up against.

It was in the light of these objectives that I advised them as to what they ought to attempt. I recommended that they should attempt an out-and-back "strip" only. Originally they had a rather more ambitious programme in mind. They wanted to cover a large area, but it seemed to me that was not essential. I felt it was more important that they should try out the technique which the Air Survey Committee has been working on for a long time past, and which the Committee have tested under less exacting conditions. That technique, as Lieutenant Salt has explained, depends on certain approximations (for example one assumes the photographs are vertical), and if its approximations are not justified the technique will break down. We have tested the technique on ground where the heights to be plotted are of the order of 10 to 15 per cent. of the flying height of the aeroplane, and found it works very well. But when it was a matter of dealing with heights which are 90 per cent. the flying height, it was doubtful whether the approximations would be permissible. Indeed, it was by no means certain that with that immense relief one would be able to get a measurable stereoscopic impression at all.

To cut a long story short, I advised that it would be best to concentrate on getting one good out-and-back strip, and I emphasized the importance of starting and finishing over points which could be identified with absolute certainty. That was what Colonel Blacker set out to try to do in the first flight, but unfortunately something went wrong with the camera; the film was either over-exposed or got fogged, and that particular strip was of no use. Lord Clydesdale and Flight-Lieutenant McIntyre made another attack on the mountain and succeeded in getting a good strip, but unfortunately owing to the strength of the wind at great heights they could not approach the mountain up the Arun valley, as I had recommended; they had to approach from the west, and were not able to do the out-and-back flight. The result was they could not say categorically where they had started. They told us where they thought they had started, and they were not absolutely certain where they had finished. Thus instead of a certain point to begin at and to close on, we had no points at all. Lieutenant Salt has explained how we set about the problem. What he did not say was actually where they did go. They told us they thought they had gone up one valley, and we worked on that supposition for a time but produced an answer which was obviously wrong. Ultimately we found they had gone up an adjoining valley, and we were able to identify that.

The net result is, I think, of great interest. Although the technique has been tested on the flight under most unfavourable conditions, as you saw, the little check that we have been able to give it, that is to say comparison with Wheeler's map, shows exceedingly good accordance. Starting with only theoretical arguments from the sort of basis on which the plotting has been carried out, one would say that such a good agreement was coincidence. Possibly it is; but the fact remains, as Lieutenant Salt has said, that this air survey technique each time it has been tried has given better results than theory would lead one to expect. I think therefore the results of the Mount Everest Flight have been most encouraging. They have, in fact, established what Air-Commodore Fellowes and Colonel Blacker set out to establish. They have tested this technique under the most unfavourable possible conditions and shown that

it can be worked; that it will give an answer. They have shown that it could be used, if necessary, to map the rest of the Himalaya. Moreover the experience of the flight has revealed a number of the difficulties. Undoubtedly, if it is ever desirable to repeat this sort of mapping, we shall be in a very much better position to advise how it should be handled.

Lieut.-Col. STEWART BLACKER: I feel I must say that whatever contribution our expedition has been able to make to the advancement and interests of science has been above all due to the kind, cordial, and spontaneous co-operation of those from whom we solicited help. First of all there came the Council and Secretary of the Royal Geographical Society, but not the least important part of the help so generously accorded us came from Colonel MacLeod and from Mr. Salt in the War Office. We cannot be too grateful for the valuable and (I use the word advisedly) inspired work which Mr. Salt has put in on behalf of the scientific results of our expedition. He has expounded the nature of the work and its tribulations in that lucid and masterly manner to which we are accustomed from him.

In this work of plotting he was confronted by abnormal and harassing difficulties, and I feel that I owe it to him to convey the apologies of the expedition for having handed him these problems for solution. However, the difficulties were not all of our own making. The especially difficult problems of plotting, apart from the unavoidable ones due in this case to the remarkable differences in height shown on one portion of each picture and another, were due firstly to the fact that we were forced to make the flight at a disadvantageous time of the year. We were compelled to do this for economic reasons which I need not enlarge upon now; but it would obviously have been preferable to have undertaken the flights in the months of October or November, when we might reasonably have expected not to have been troubled either by masses of clouds filling the valleys for days on end nor with winds of high velocity which made devastating demands upon our fuel supply. In any case we are convinced that in October and November we should have had a much wider choice of suitable days for the flights and therefore have been relieved of great anxiety on this score.

The anxiety was the greater because it must be remembered that we had sanction from the Government of Nepal only to carry out a single flight, and that once we had crossed the frontier we were morally committed and had to see the thing through, even if conditions were not really suitable. This brings me to the matter of the diplomatic sanctions. Generous as these were they still prescribed that we should fly to the mountain from British territory and back again by the most direct route. This, as it turned out, limited our action and gave rise to difficulties which we were in turn compelled most unwillingly to transmit to Mr. Salt. Had it not been for the wording of this sanction, and had we known as much then as we know now about the great winds from the west at 25,000 and 30,000 feet, we should have been well advised to have started for the flight from somewhere 100 miles farther west than we did either from Darbangha or from Raxaul, or even, given permission, from Khatmandu, and to have landed considerably farther east, *e.g.* at Siliguri or Jaipalguri, well downwind of the mountain. By using tactics, or rather strategy, of this sort we should have secured for ourselves a bigger margin of fuel and have been able to expose twice as much survey film, insomuch that it would have been possible for the pilot to have circled about above the mountain whilst the observer replaced the used film magazine by a fresh one without hazarding the vital continuity of the strip. Anxiety on the score of fuel supply was always present in our minds. We wanted not only to fly to the mountain, but to fly back. Then again, we had difficulties imposed on us because we were not allowed into Tibetan territory. Had it not

been for all these alien considerations the survey work of the flight would have been very much simpler and would not have been beset with the difficulties which have caused Mr. Salt such hard work to circumvent. We are all convinced now that the task of carrying out as much more air survey as would be necessary to map the remainder of the unmapped portions south of the Everest massif would be a straightforward problem which one would be very happy to undertake, given freedom from the restrictions to which I have referred.

The mapping is however not a matter of vertical photography exclusively. Both the "still" cameras and the ciné cameras were expected to contribute their quota. I think Colonel MacLeod and Mr. Hinks will support me when I say that from the early conferences onward we intended to rely more on the oblique photographs, or at least to rely to a considerable degree on the results of the oblique photographs as regards the steep ground between 29,141 feet and the South Peak, because vertical photographs probably would not have overlapped. The wind on the occasion of the second flight was, we estimated, 110 m.p.h., so that if we had gone straight over the summit, as we did in the first flight, our ground-speed downwind would have been something like 235 m.p.h. As the camera took between five and six seconds to re-wind itself, it would have been practically impossible to get overlapped vertical photographs unless we had been 3000 feet up over the summit. Therefore we relied on oblique photographs, and we were very fortunate, as the slides showed, in that we were able to get two oblique photographs pointing steeply down at short range on to the actual summit. We hope, as Mr. Salt has suggested, that a certain amount more of the configuration of the ground, sketched in with the form-lines, will be obtainable from a more detailed study of the obliques not only from the still cameras, but from the cinematograph film which affords a certain number of "stereoscopic pairs." These remain to be disclosed to the public.

The results of the expedition, apart from the point of view of mapping, have been sufficient to make us feel that we have learned a great deal, and I think I am speaking on behalf of the rest of the expedition when I say that if we were invited to tackle the complete map of the bald patch from the air we should be happy to do so.

It is very appropriate that the Arundel method should have been used so near the Arun valley, and especially gratifying to me because I live in the other Arun valley myself. It is also gratifying that it should have been a British method that has produced this plot of country which is certainly not easy. I think Lady Houston, to whose generosity the whole expedition is due, would have been pleased to know it was a British method of plotting, as well as a British engine and aeroplane, used in the flights.

Finally, I have to explain that the whole of the expedition consisted of amateurs, except our very expert cinematographer, Mr. Bonnet, and that these were our first flights over a mountain 29,000 feet high.

The PRESIDENT: We had hoped that one of the pilots would have been present. Unfortunately Lord Clydesdale is in Switzerland and Lieutenant McIntyre was doubtful whether he could get here. Evidently he has not been able to come. Perhaps Mr. Colin Williamson, the designer and maker of the vertical cameras, would like to add a word or two.

Mr. COLIN WILLIAMSON: I would like to take this opportunity of congratulating Mr. Salt not only on his very interesting paper but also on his patience and the impartial way in which he has collected and co-ordinated the information from the photographs taken during the flight.

I do not pretend to be an expert on survey matters, but I have been very closely connected with the photographic equipment from its commencement,

and I should like to make one or two comments on the references made to the cameras. It was very disappointing to hear that the film of the first flight had been fogged, and I should be interested to know whether the heating of the magazines had anything to do with the fogging; whether we over-estimated the heat that was required to maintain the film at the correct temperature? Secondly, I understand that the overlap was very much greater than was intended. That was probably due to the fact that the flight did not actually take place at the same height above the ground as was originally intended and for which the interval between exposures was calculated. Thirdly, there is the question of the tilt of the photographs. Lieutenant Salt stated that the angle of tilt of the photographs was not available. I wonder whether, if the cameras had been made so that the horizon, either actual or imaginary, had been actually photographed at the same time, that would have assisted Lieutenant Salt in getting a more correct survey.

It will, I feel, be admitted that the excellence of the photography not only does justice to the equipment but also reflects the very greatest credit on the none too highly experienced operators. Mr. Salt has succeeded in extracting much more information from the photographic results than one would have thought possible, and the important part he has played in the survey cannot be too highly stressed.

Lieut.-Col. STEWART BLACKER: During the first flight there was a phenomenal dust haze, and we did not get clear of that until we had climbed to 19,000 feet. This had the effect of rendering the details of the ground, and our southern "ground controls," quite obscure.

On the first flight however we were able to fly on a dead straight course, precisely to the summit of the mountain. It may be of interest to describe our special procedure of navigation which made this accuracy possible.

The observer had a Hughes Drift Sight in the floor of his cockpit. He set this roughly from the wind speed forecast for him by the meteorological Upper Air Sounding Station, by means of their sounding balloons. Then, in flight, his task was to check the angle of drift by observing the passage of visible points on the ground, rotating the sight until they moved apparently parallel to the cross wires. He then read off the corrected angle and telephoned it to the pilot, who then had to place a point on the under surface of the leading edge of his upper plane, corresponding to the angle of drift, over the summit of the mountain. By this plan, which worked perfectly, the machine flew in a practically straight path, on a bearing of 342°, to the summit. But for this procedure, the track over the ground would have been curved, which was not what was required for air survey, and would have hampered the subsequent plotting.

On the second flight unfortunately there was a thick blanket of cloud of which the top surface was about 18,000 feet. This blanket of cloud covered the whole of the central portion of the country of Nepal and prevented the observers from picking up any objects on the ground by which to measure the drift. That, in combination with the very powerful wind from the west, which I estimated at 110 m.p.h., brought the course of both machines rather farther to the east than was originally intended. If we had been able to use the Hughes Drift Sight on the second flight our course would have been considerably more accurate, in fact as accurate as it was in the first flight.

Professor KENNETH MASON: As certain bald patches on the Survey of India map have been mentioned, perhaps I may make a few remarks on the existing $\frac{1}{4}$-inch map of Nepal. Up to about 1924 our map of Nepal was simply derived from the route surveys of Indian explorers, such as Hari Ram, and native reports. In that year the Surveyor-General obtained permission to send into the country a few surveyors trained by British officers, but British officers were

not allowed to go in themselves. Sir Edward Tandy begged to be allowed to send in cameras with which the Indians could take photographs, but he was not allowed to do so. Between November 1924 and March 1927 some eighteen Indian surveyors surveyed 55,000 square miles on the $\frac{1}{4}$-inch scale, contoured at 500 feet. They were not trained mountaineers and they could not, of course, visit the whole country; the heads of the glacier valleys must therefore be considered as "bald patches." It is expeditions such as that of the flight over Everest and others equipped with stereophotographic apparatus that can help us to fill in these blanks.

I should like to ask Mr. Salt whether, in his opinion, if earlier Mount Everest expeditions had taken stereophotographic pairs of photographs from the ground and plotted them in a machine, there would not have been a better control for plotting the mountains that were photographed during the flight. It seems to me that ground stereophotogrammetry and air survey could be linked up very much more than is done at present. Very little interest in ground stereophotogrammetry is taken in this country, whereas some nine or ten European countries are working at the method now. Could Mr. Salt tell me whether ground stereophotogrammetry with accurately plotted contours would have given a better control than an occasional odd point picked out from Major Wheeler's map?

The PRESIDENT: Our Secretary has taken the strongest and most expert interest in the flight and survey. I ask him to make some observations.

Mr. HINKS: I should like to say a word on behalf of the despised obliques. Mr. Salt referred kindly to certain detective work which we assumed in the obliques rather early in the summer, of which the first fruits were published in the July *Journal*. But that detective work is not finished, and we have been devoting ourselves to ascertaining how many of the points on the Survey of India triangulation diagrams, which appear as numbered points upon the diagrams, can be identified in the oblique photographs. Although they no doubt appear also upon the Nepal map they cannot be properly represented in the detail because, as Professor Mason has said, the detail at the heads of the valleys and glaciers is scanty. It seems to me that when we bring together material picked up partly from the Survey of India diagrams, partly from ground photographs, such as those taken by the late Dr. Kellas from the Kang La, we shall be able to make a sketch-map somewhat better in detail than the $\frac{1}{4}$-inch map of Nepal, and vastly more extensive than the strip so beautifully plotted at the War Office; a sort of sketch-map which will not be a mere reconnaissance sketch but will contain quite a lot of geographical material derived from the despised obliques that could not be derived from the verticals because they did not cover the ground.

I make this plea for the obliques largely in order to emphasize the point that they are of more value than has sometimes been assumed, and probably they will become of increasing value. I am rather anxious for the safety of the original negatives, and hope whoever controls them will realize that they are not things that have lost their value when they have provided very interesting and magnificent illustrations for journals and books, or even provided the first illustrations which we had in our *Journal* in July. It seems to me that the value of the negatives will increase year by year. Gradually we shall know more about the surrounding country; gradually we shall get more ground control, and it is by no means impossible that ten or twenty years hence we may put all those negatives into a plotting machine and do some reasonably accurate contouring with them. That will be precipitated if, as Professor Mason asked, some ground stereophotogrammetry could be practised.

It has been long a favourite dream of mine that some one would borrow the phototheodolite belonging to the Society and make a series of photographic stations along the Singalila ridge. From there one would be able to plot not the whole ground but many of the crests that we see in the oblique views of Mount Everest. A process such as that would provide the greatest amount of ground control and make possible the fuller utilization of the obliques. Whether that is possible or not, I hope all means will be taken to preserve undamaged and for use one hundred years hence these exceedingly valuable negatives produced as a result of the Mount Everest Flight.

The PRESIDENT: I will ask the lecturer to reply to one or two of the points raised during the discussion.

Lieutenant SALT: With regard to Mr. Williamson's suggestion that by photographing the horizon the tilt can be obtained, this method can be used, and is, in fact, used in Finland at the present time with a camera built specially for the purpose. But in the region of Mount Everest the horizon has a habit of not coinciding with sea-level and also of being somewhat jagged. I do not think that such a method would have been of much value on the occasion of the flight, but I think that had a bubble-level been recorded, we might have been able to make use of the deduced tilts. They are not true tilts because an aircraft cannot distinguish between acceleration and gravity, but they would certainly be better than nothing.

As to the possibility of using ground photogrammetry in conjunction with this kind of work, it is difficult to make any definite statement without seeing the country, but provided that suitable points of vantage are available, that is to say high up and subtending a reasonable base, it would probably be extremely useful. I imagine most of the really prominent peaks which can be viewed from the existing trig. stations have actually been intersected, but I do not know. In any case, by means of photogrammetry a great many more subsidiary peaks, which it would be difficult to identify other than by the stereoscopic method, could be fixed sufficiently well to serve as ground control for the purpose of reconnaissance air survey.

One word about the "despised obliques." When difficulties arise in reconnaissance surveys, one often hears the remark "Why not sketch it in from the obliques?" But the problem in practice is not quite so easy. You cannot simply put the oblique up on an easel and sketch in by hand. All that an oblique gives is a round of angles taken in space from an unknown point. If you consider what is necessary in order to make use of that information—the number of known points for purposes of resection in space, and the fixing of further points by intersection—you will realize that the process may be complicated. Therefore if I am guilty of despising the obliques, it has been mainly because of the fear of having more work to do!

Colonel Blacker mentioned the fogging of the photographs. All I can say about these photographs is that they give the *appearance* of having been fogged. That might be due to light coming from a variety of sources into the camera, reflected possibly in some obscure way, or it might, as Colonel Blacker suggested, be due to a duststorm which would have the effect of adding diffused light over the whole photograph. One cannot decide that point upon the evidence of the photographs alone. Therefore one cannot make any statement more precise than that the photographs appear to have been badly fogged.

In response to Colonel Blacker's kind remarks about me, I may say that the only inspiration required for this kind of work is the twin daughter of necessity, and, in any case, the work gave a great amount of pleasure.

The PRESIDENT: I am sure you all realize what an extraordinarily difficult and

intricate task it was that Lieutenant Salt undertook when he was put on to collate the photographs and to get them on to the map. He has clearly mastered very thoroughly the subject he was dealing with, and has given us a most lucid description, as far as lucidity is possible, of the process which he went through to obtain the results at which he arrived in that sketch which he put before us. It is impossible for me—I am not an expert in the subject under discussion—to enter into details of the scientific aspects of the expedition. I only ask you to join with me in thanking Lieutenant Salt very much indeed for his most efficient and interesting paper.