PHOTOGRAMMETRY APPLIED TO AEROLOGY

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PHOTOGRAMMETRY has been chiefly concerned with mapping operations, and in this field the major emphasis has been placed on high precision. Other applications of this science, in which high precision is neither feasible nor important may be useful. Examples are found in a variety of uses of aerial photographs in the measurement of natural phenomena, such as cloud formations over the ocean or the distribution of floating material on the surface—things of interest to aerologists and oceanographers. The purpose of the present communication is to describe two such applications.

WIND BANDS ON THE SEA

On several days in January and February, 1945, the surface of the Gulf of Panama, as seen from the air, presented a peculiar banded appearance, presumably indicative of alterations between rough and smooth water. They suggest a regular eddy pattern in the air. Straight lines along which the surface of the sea was more ruffled than elsewhere, were seen to be nearly parallel to each other and at nearly equal intervals (Fig. 1). They could not be mistaken for the crests of long ocean rollers, for they remained apparently relatively stationary. They were only clearly seen on days when the wind was light and the sea fairly smooth. Several times they were observed to end abruptly at a terminal band beyond which none were visible. Fig. 2 shows an example of this condition. On one occasion two distinct patterns were seen, the bands intersecting at an angle

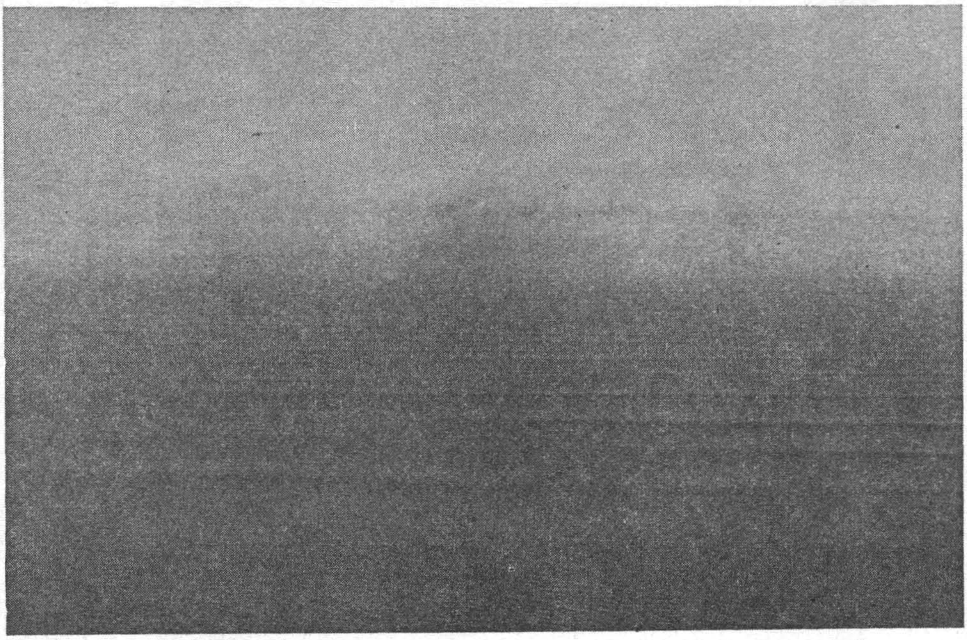

FIG. 1. Wind bands on ocean surface from approximately 700 feet altitude, Jan. 24, 1945.

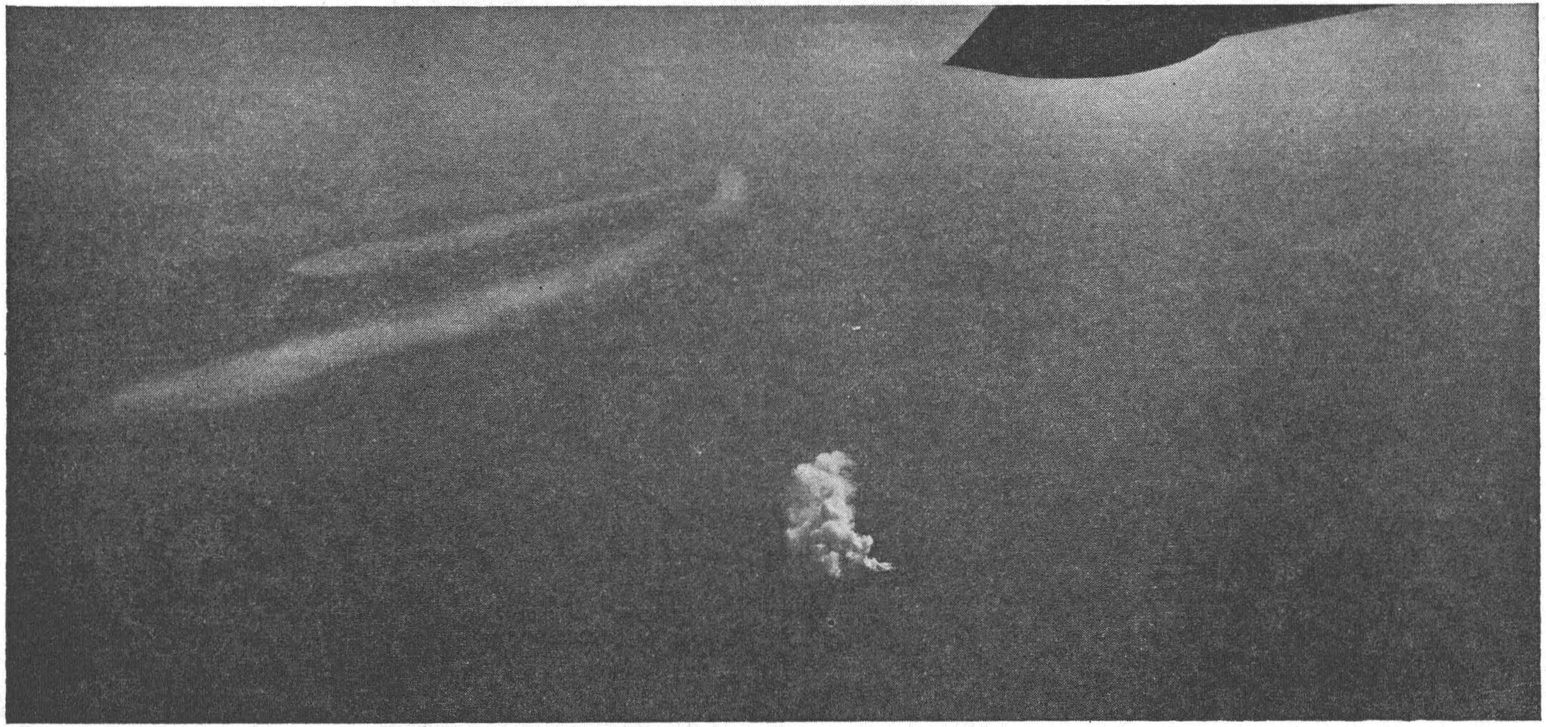

FIG. 2. Bands related to wind direction, Feb. 5, 3:28 P.M. from 4500 ft. altitude. Smoke from floating pots in foreground shows surface wind direction clearly, and approximate direction of upper wind, estimated from this photograph at 104° to right of surface wind; angle measured from vertical photograph 4 minutes later, 110°.

(Fig. 3). In this picture it may be seen that one set of bands, more widely spaced than the other, terminates as described above, being absent in the foreground.

It was of interest to a group of oceanographers who observed this phenomenon to know the approximate distance between adjacent bands and their orientation in relation to the wind; therefore aerial photographs, taken on seven days when the effect was clearly visible, were subjected to photogrammetric analysis.

In the case of photographs in which the bands were nearly parallel to the horizon, a simple graphic method was used to measure the distance between them. On tracing paper laid over the negative the principal line was traced and its intersections with the bands and with the horizon trace were marked. A line perpendicular to this line, equal to the focal length, was erected at the principal point, thus making an elevation or profile view of the principal plane (Fig. 4). The distance of the true horizon above the horizon trace on the photograph was found by the standard method (expedited by use of a precomputed table) and its place on the principal line was marked. Straight lines were ruled from the perspective center through the band intersections and one through the mark of the true horizon.

FIG. 3. Two intersecting patterns of bands, Feb. 6, 3:00 P.M., from 3900 feet altitude. Smoke laid by ship steaming on slightly curved course nearly into surface wind. Undulating tail of smoke train shows direction of upper wind and alternate zones of stable air and rising air.

The construction thus drawn was then superposed on cross-section paper with the horizontal line (perspective center to true horizon) parallel to the axis of abscissae. At a distance below this, representing altitude of the air station on a convenient scale (2 inches = 1000 ft.), a line was drawn parallel to the horizontal. The intersections of this line with the rays passing through the photographic images of the bands simply marked the positions of the bands on the sea, drawn to scale. The principle is illustrated diagrammatically in Fig. 4A; the construction for one of the photographs is shown in Fig. 4B.

When the bands as imaged in the picture were so oblique to the horizon as

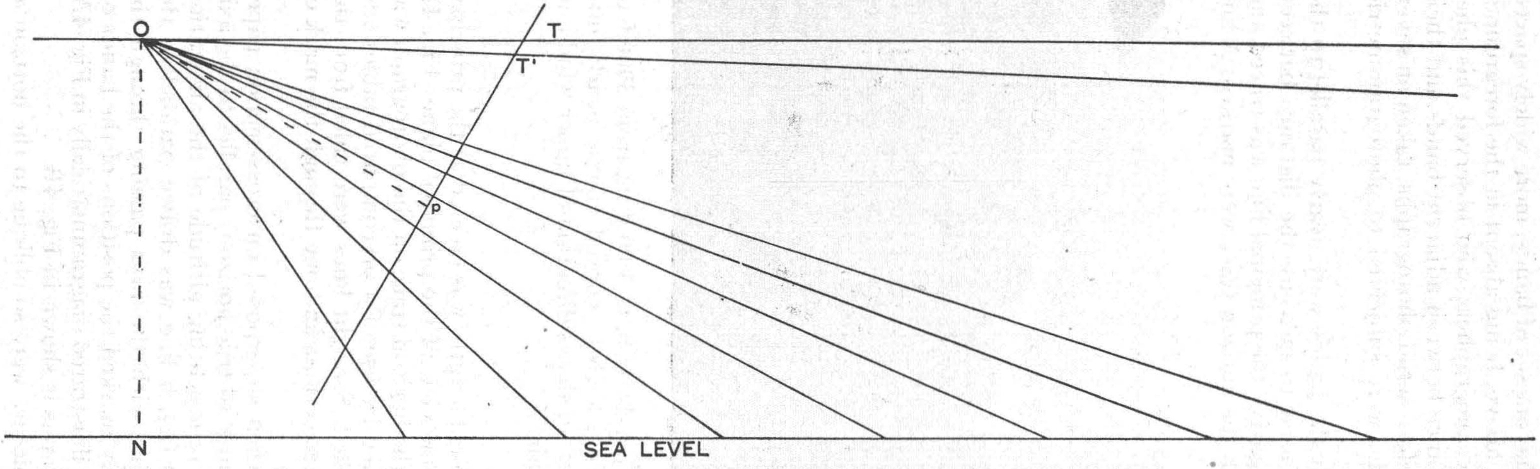

FIG. 4A. Diagram to show method of measuring distance between bands on surface. Section in principal plane of oblique photograph. *O*, perspective center; *p*, principal point on picture plane; *T*, true horizon; *T'*, horizon trace; *N*, nadir; *ON*, altitude of air station to scale of plot. Rays are projected through images on picture plane to points representing actual positions of bands on sea.

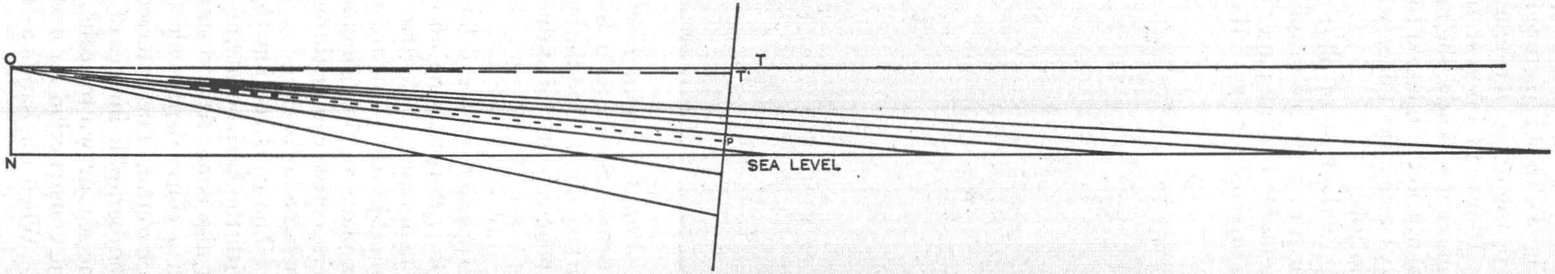

FIG. 4B. Actual plot of band positions from photograph of Jan. 30, altitude 700 feet.

to introduce an appreciable error in using the intersections with the principal line, as a basis of measurement, a Canadian perspective grid was superposed on the photograph in order to determine the angle between the bands and a projection of the principal line on the sea surface. Having thus placed one or two of the nearer bands on the rectangular grid, it was a simple matter to place the more distant bands, using their intersection with the principal line, and drawing them parallel to the nearer bands already placed on the grid.

When the sea horizon was so indistinct that its position was in doubt and the tilt of the photograph was therefore uncertain, it was assumed the mean interval between all but the terminal bands was fairly constant, an assumption justified by the measurements on all photographs with clear horizons. The profile construction (Fig. 4) was then rotated around the perspective center until the tilt was found at which the base-line, representing sea level, intersected the rays drawn through the band images at most nearly equal intervals. This was taken as the most probable value of tilt and the successive intervals were measured as before.

TABLE I

Date	Jan. 24	Jan. 28	Jan. 29	Jan. 30	Jan. 31	Feb. 5	Feb. 6
Altitude	700 ft. (assumed)	540	700	700	700	4500	3900
Distance between bands in feet; foreground bands listed first	1000	800	1000	1350	1050	2900	1400
	900	750	900	1350	1200	1600	900
	900	650	800	1550	1200	1700	1250
	1150	700	900	1400	1300	1250	1200
	750	600	1200	1550	1000	1250	1100
	1500*	700		1550	700	1350	1200
	900	900		1450	1400	1450	1400
	650	1200*				1450	1100
	1000	650				1200	1000
		650					1050
							950
							850
							1100

* Double Interval.

Altitudes measured by altimeter except on Jan. 24 when it was assumed to be at the standard cruising altitude of the operation.

Sixteen photographs were used in this way to measure the distance between bands. Table I shows a set of measurements from one photograph on each of the seven days. From this it will be seen how nearly uniform the measurements were on any single picture. In each case the measurements are listed in order of distance from the camera, the nearest band being first in each column, and at the bottom the most distant one measured. It should be emphasized that in the case of the more distant bands a very small error in draftsmanship will necessarily cause a relatively large error in the measured interval between bands; consequently the average value of three or more successive intervals is more significant than the individual measurement in this distant range.

It is also noteworthy that on February 5 the interval between the two nearest bands was much greater than the more distant intervals, a fact corroborated by independent measurements from two other photographs taken in rapid succession from nearly the same position as the photograph used in the table. The nearest band in all three pictures was the limiting band and in the foreground of each of these pictures no bands were present. Thus is established the fact that in this condition the bands become more widely spaced as the region where they are absent is approached.

To show the degree of uniformity in successive pictures on the same day and under closely similar conditions, the stabilized averages are given for all sixteen photographs (Table II). By "stabilized average" is meant the mean interval, excluding those marginal ones that are clearly greater than the intervals well within the banded zone. In the course of an hour, or even much less, a considerable change could occur in the atmospheric conditions that cause the bands.

TABLE II

Date	Time	Altitude	Stabilized Average
Jan. 24	not recorded	700 (assumed)	875
Jah. 28	11:48 A.M.	540	690
Jan. 29	1:00 P.M.	700	976
Jan. 29	1:48 P.M.	635	1075
Jan. 29	1:57 P.M.	630	920
Jan. 29	3:18 P.M.	700 (assumed)	767
Jan. 30	12:24 P.M.	700	1500
Jan. 30	12:40 P.M.	700 (assumed)	1210
Jan. 31	1:49 P.M.	700	1120
Feb. 5	3:14 P.M.	4500	1325
Feb. 5	3:44 P.M.	4430	1240
Feb. 5	3:45 P.M.	4430	1150
Feb. 6	3:02 P.M.	3900	1125
Feb. 6	3:03 P.M.	3900	1192
Feb. 6	3:04 P.M.	3900	1114
Feb. 6	3:19 P.M.	4150	1185

Note: When the time interval was less than one hour and the altitude was known by measurement, the greatest divergence was 17%.

In general it may be said that since the bands are not sharply defined, and since they are measured mostly by angles too weak to serve for precision even in the case of well-defined objects the uniformity is as satisfactory as can be expected; at least it is adequate to establish the order of magnitude of the dimensions measured.

ORIENTATION

It is of interest to aerologists to know the orientation of the bands with reference to the wind, as well as the distance between them. This presented a more complex problem than the measurement of distances, for in most, if not all cases there was a great difference in direction between the winds on the surface and at altitudes of two or three hundred feet, and these directions had to be judged by the way in which smoke was blown at different levels. Also the obliquity of the photographs was such that a small error in plotting the bands would introduce a large error in the resulting orientation. Only by using the average of several photographs taken from different directions in rapid succession, as the plane circled the field of view, could the errors be minimized to a satisfactory degree. The most difficult direction to determine was that of the wind, especially that aloft. Smoke pots dropped on the water showed the surface wind clearly, and its direction could be quite accurately measured in pictures

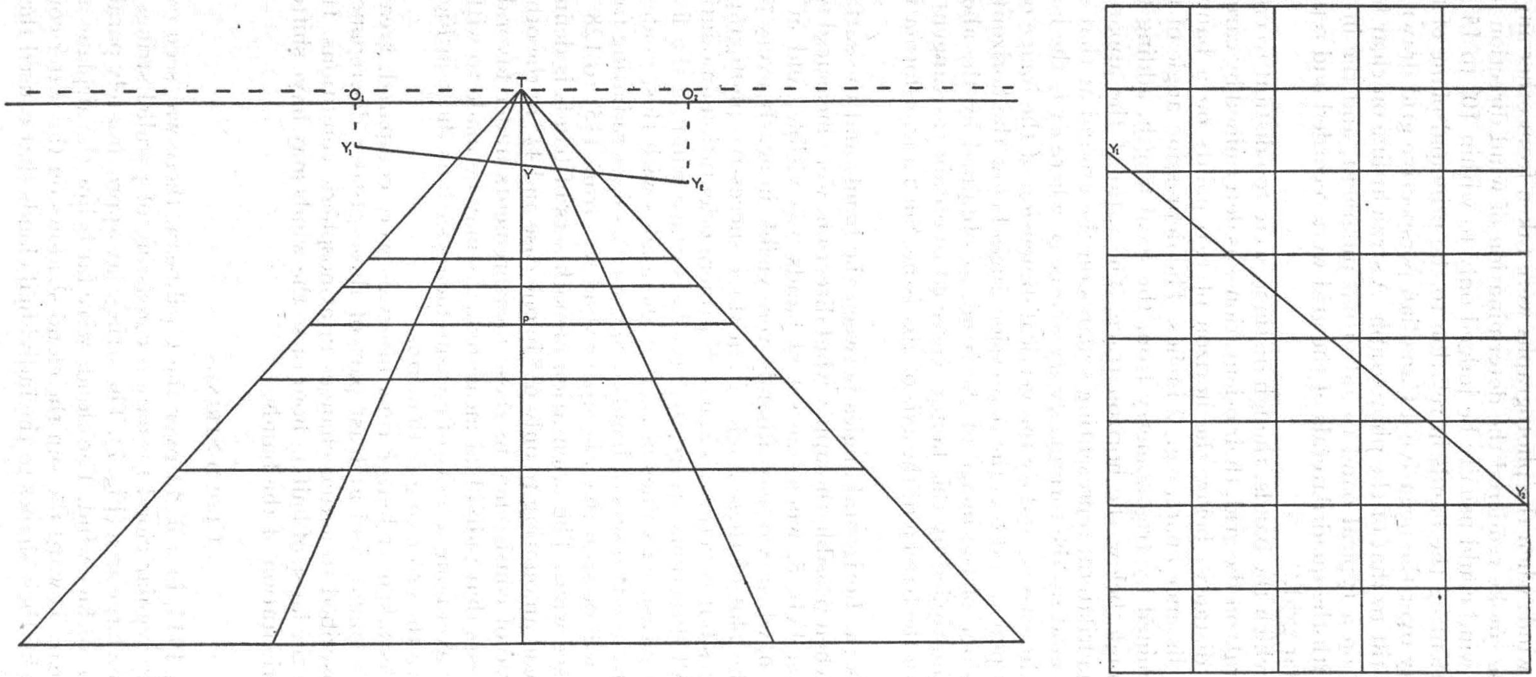

FIG. 5. Transformation of slope from oblique photograph. Left: perspective grid with sloping line, Y_1Y_2, beyond the range of grid quadrilaterals. Vertical distances O_1Y_1 and O_2Y_2 measured from horizon trace. $(O_2Y_2-O_1Y_1)/Y_1Y_2$ gives the tangent of the image slope. From distance TY is found the vertical angle ϕ and from this the ratio of transverse to vertical dimensions of the image of a square on the ground seen at that angle from the horizontal. This ratio multiplied by the image tangent gives the tangent of the angle between the surface band and the axis of abscissae normal to the projection of the principal plane on the surface, shown on the rectangular grid at the right.

taken straight down wind; when the photographs were taken from other angles the oblique rise of the smoke rendered the determination of wind direction less accurate. The upper wind could usually be judged only to within 10° to 15°.

The method of orienting the bands in relation to the principal plane of the photograph was to lay over the negative a Canadian perspective grid drawn to the nearest degree of tilt to that of the photograph. A straight line on clear film was then superposed on a typical band to aid visual judgment, and the intersections of the line with the quadrilaterals of the grid were recorded and reproduced on a rectangular grid.

In a few cases in which the bands, though distinct, were too distant to cross any of the quadrilaterals on the grid, their orientation was determined by careful measurement of the distances below the horizon of two points on a band a measured horizontal distance apart, e.g., 2 inches. The depression angle of the mid-point was determined by trigonometry from the focal length, adding the horizon dip to the angle below the horizon trace. The ratio of the apparent dimensions of the quadrilateral representing squares on the ground at that depression angle, was found by the formula $dx/dy = \operatorname{cosec} \phi$, where dx is the horizontal or transverse dimension, and dy the vertical dimension of the image of a square on the datum plane, and ϕ is the depression angle below the horizontal. The tangent of the slope of the image of the band, as obtained by the above measurements, was multiplied by this factor ($\operatorname{cosec} \phi$) to obtain the tangent of the true angle between the band and the axis of abscissae. Such a transformation is shown in Fig. 5.

By these methods the horizontal angles between the bands and the surface wind direction, and when possible the upper wind direction, were measured in 7 photographs taken on Feb. 5, when one set of bands was visible, and in 19 photographs on Feb. 6, when two sets of bands were visible in nearly every picture. Fig. 6 shows the plot of these angles from three successive photographs taken within 2 minutes but covering a change of camera orientation amounting to more than 60°. All directions are related to the surface wind as the fixed datum and the three measured values of each of the angles with this, made by the upper wind and by the two sets of bands, are drawn as lines radiating from a common center. It will be seen that the upper wind was from 115° to 128° to the right of the surface wind. The orientation of both sets of bands is defined more closely, the spread amounting to only $6\frac{1}{2}°$ in one case and $4\frac{1}{2}°$ in the other. This shows the degree of consistency in these measurements under favorable conditions, and suggests that individual measurements may be made to within about 5° and that by averaging a series of measurements such as those in Fig. 6 it is possible to reduce the error to less than this.

When photographs taken at longer time intervals were compared, greater differences were often found, and at least part of these greater discrepancies may reasonably be ascribed to actual changes in atmospheric conditions. It is quite possible that in the lapse of half an hour or so the winds may have shifted, and with them the orientation of the bands.

CLOUD STRINGS

On December 30, 1944, in a flight over the Caribbean, there was seen over the water a strikingly regular cloud formation consisting of parallel strings of clouds extending over a large area (Fig. 7). The strings lay approximately parallel to the direction of the surface wind. The clouds were far below the airplane and the sky above was clear. Toward the sun the cloud shadows on the water could frequently be related by their shapes to the individual clouds that caused them.

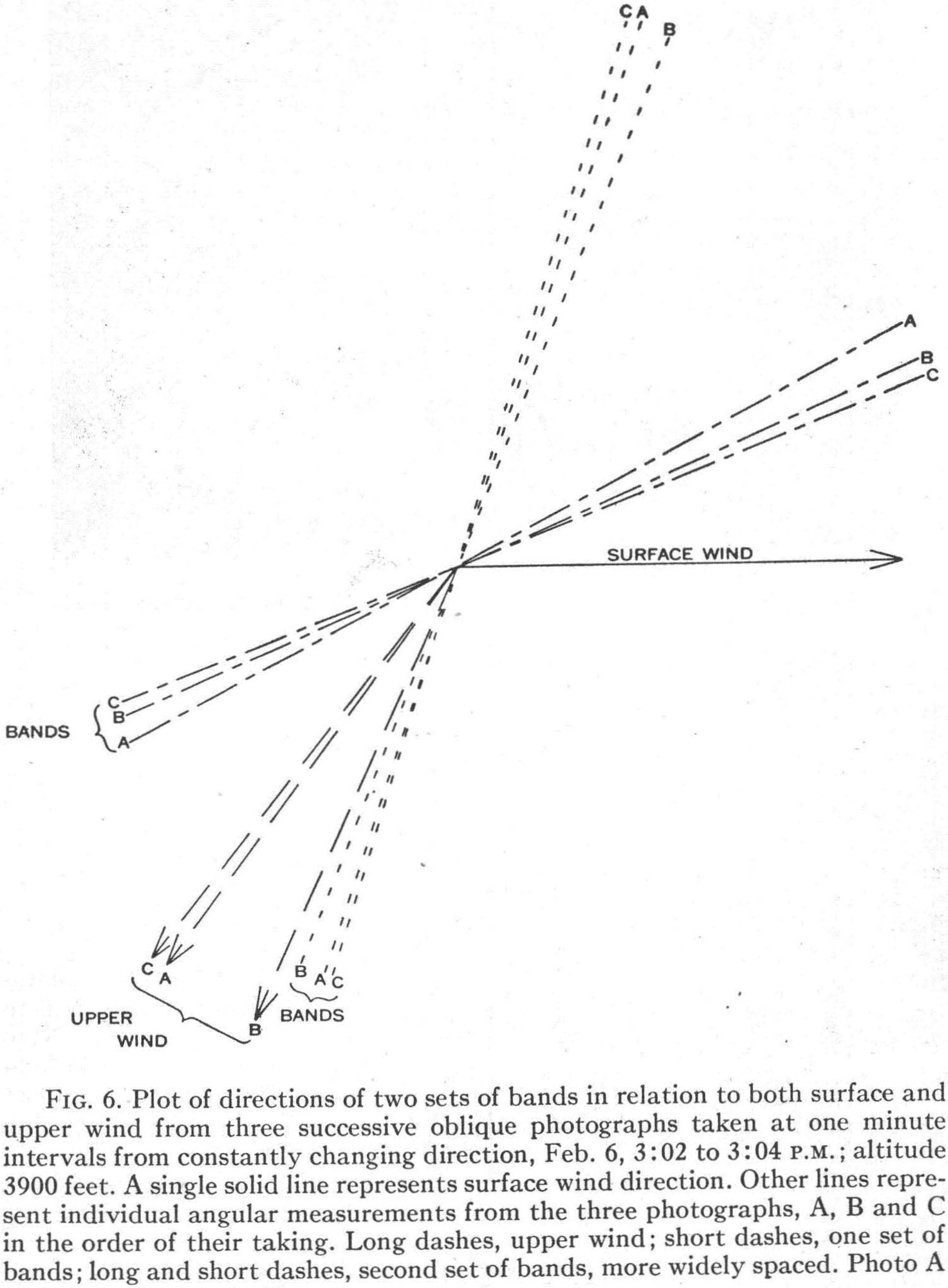

FIG. 6. Plot of directions of two sets of bands in relation to both surface and upper wind from three successive oblique photographs taken at one minute intervals from constantly changing direction, Feb. 6, 3:02 to 3:04 P.M.; altitude 3900 feet. A single solid line represents surface wind direction. Other lines represent individual angular measurements from the three photographs, A, B and C in the order of their taking. Long dashes, upper wind; short dashes, one set of bands; long and short dashes, second set of bands, more widely spaced. Photo A is that reproduced in Fig. 3.

Thus all the data needed for photogrammetric measurement of the altitude and spacing of the cloud strings were available, the altitude of the plane, 8,000 feet, being known. Six photographs were taken from the window of the plane, three of them so oriented toward the sun as to show recognizable shadows and the clouds that cast them, as well as the cloud-layer horizon (Fig. 8).

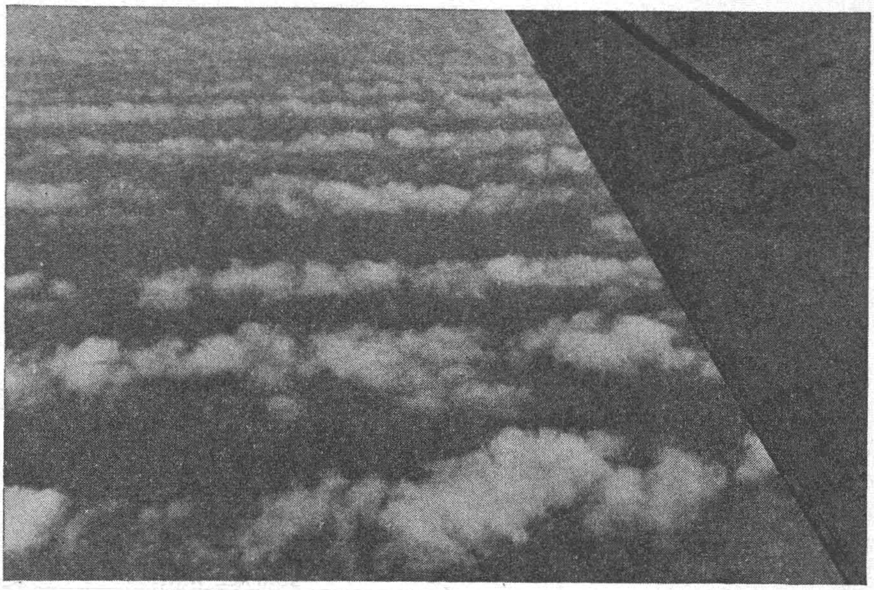

FIG. 7. Cloud strings over Caribbean, Dec. 30, 1944, from 8000 feet.

FIG. 8. One of three photographs of cloud strings used to measure their altitude. Note cloud shadows on water in foreground. Horizon trace of upper surface of cloud layer serves to establish approximate tilt.

It remained to find the sun's altitude at the time the pictures were taken. The approximate position was 10° North, 77° West; the time, between 17:40 and 17:50 G. C. T., and the sun's declination was 23° 10′. From this the sun's altitude was found to be approximately 55° 50′.

The pictures used to measure the height of the cloud layer were taken so nearly toward the sun that the distances of the cloud and its shadow below the horizon, as measured on the photograph, could be used to find vertical angles without serious error due to obliquity of the sun's rays to the principal plane of the photograph. With each picture a section in the principal plane was drawn from these measurements, using the focal length, 6.0 inches, to establish the angles (Fig. 9). This section was then adjusted to the horizontal with due allowance for dip, and the altitude of the airplane laid off on a convenient scale (1 inch = 2,000 ft.). The path of the sun's ray interrupted by the cloud was related to the horizontal with a protractor and drawn to intersect sea level at the shadow, *S* (Fig. 9). The image of the cloud (*c*) in the photograph establishes the path of the ray, *OC* from the cloud to the camera; where this intersects the sun's ray interrupted by the cloud, is the position of the cloud, *C*, and its height above the sea can be directly measured in this construction.

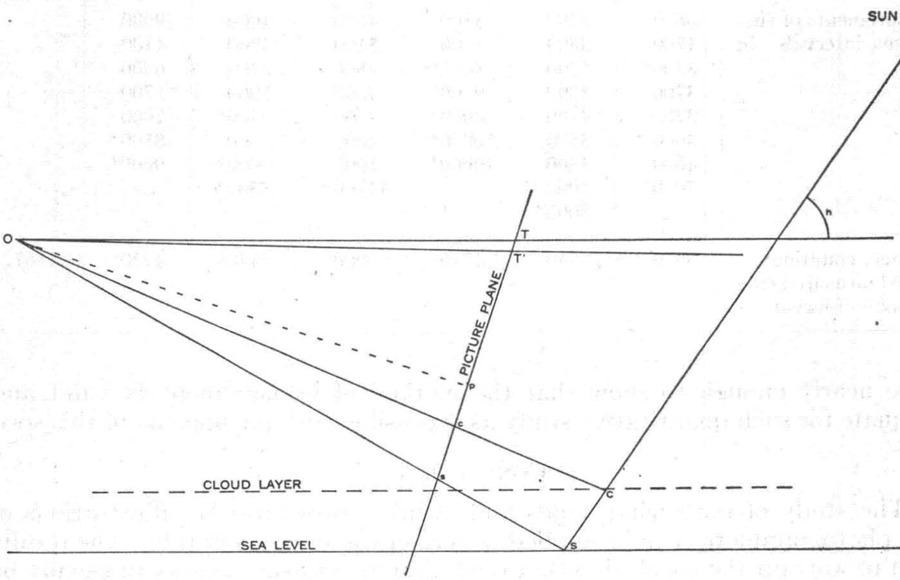

FIG. 9. Diagram showing measurement of height of cloud layer above sea. *O*, perspective center; *p*, principal point. *C*, cloud; *S*, shadow of cloud; *c* and *s*, photographic images of cloud and shadow; *h*, angular altitude of sun.

Measurements thus made from three photographs established the height of the clouds at about 1,600 feet above the sea, or 6,400 feet below the airplane. Having thus established the vertical distance between the airplane and the cloud layer, the intervals between adjacent strings of clouds could be measured by exactly the same procedure that was used for wind bands on the surface of the sea, described above. Measured intervals from the six photographs are tabulated in Table III. A distinct tendency to alternation between large and small cloud strings was noticeable in some parts of the area under observation, and in the more distant regions only the large strings could be discerned in the photographs. When the measured interval was nearly double the mean value for the nearer strings it was interpreted as a double interval and so designated by an asterisk in the table. The average value for each photograph was calculated with due allowance for these double values. These averages and the general average are given in the table. It is obvious from the photographs that there are irregularities of form in the cloud strips and that the intervals between them are not all equal, but the measurements from the different photographs agree nearly enough to show that the method of measurement is valid and adequate for such quantitative study as is possible with phenomena of this sort.

TABLE III

Photograph number	1	2	3	4	5	6	General Average
Measurements of successive intervals in feet.	6800*	3200	5300	4600	4000	9000	
	4700	3800	5500	5100	4800	4100	
	8300*	4700	8000*	4800	3700	6000	
	3700	4000	9700*	4300	5000	5700	
	3200	4100	8000*	4700	7300*	7000	
	4000	3800	10000*	4800	6500	8500*	
	4500	4800	10000*	5000	9000*	9000*	
	7000*	4000		11700*	8500*		
		8000*					
Average, counting starred measurements as double intervals	3840	4040	4710	5000	4440	4930	4567

CONCLUSION

The study of both wind bands and cloud strings furnishes illustrations of how photogrammetry can be applied to aerology and oceanography. The results seem to warrant the conclusion that photographic measurements can usually be made with as high precision as the observed phenomena demand, and that the errors in photogrammetry are generally small compared to the actual variations of the dimensions measured.

RESOLVING POWER

Many readers of PHOTOGRAMMETRIC ENGINEERING have requested publication of news notes regarding the movements and activities of members of the Society. There is a precedent for a section containing information of this type. Early copies of *News Notes* contained many such references. With the return of members from military service, and the probable initiation of projects necessary to our peacetime economy, many members will be changing jobs.

It is the intention of the Publication Committee to carry, under the above heading news notes of and for the members. Such information can come only from the membership of the Society. If you wish to keep track of what is going on, help by sending in items of interest to the Editor.