ALTIMETERS AS USED BY THE 30TH ENGINEERS FOR MAPPING*

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ABSTRACT

The 30th Engineers successfully used altimeters transported by helicopter for vertical control of multiplex mapping. The two-base method proved best and bases were separated as much as 30 miles horizontally and 7,000 feet vertically. Altimeter runs included 69 points of known elevation which were checked within 8 feet. The new metal cased altimeter was more accurate than the wood cased model. The best results were obtained in flat or undulating areas when the wind speed was under 18 m.p.h. Nighttime is best for altimetry and overcast days are satisfactory. Lines were double run. Field calibration of altimeters at the start of the survey, as well as comparison readings at the bases for each run, improved results. Criteria for satisfactory altimetry conditions and for accepting altimetry elevations are given.

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IN EARLY 1950, the 30th Engineer Base Topographic Battalion, under operational control of the Army Map Service, was assigned the long range mission of mapping certain critical areas in Alaska. This project entails establishing the ground control required for the multiplex compilation of large scale maps.

A preliminary reconnaissance of the assigned areas disclosed that field operations would have to be conducted over some of the most isolated and rugged terrain on the North American Continent. It was evident that the survey could not be carried on in accordance with the practices commonly used in the comparatively developed and accessible areas of the United States. The establishment of vertical control particularly was problematical. Differential leveling was entirely impracticable and even trigonometric leveling was not readily adaptable to rapid, accurate progress in terrain which varied from great lake-studded tundra plains to precipitous ice-capped mountain ranges.

To meet the problem of establishing vertical control, consideration was given to the use of the altimeter. Available publications on this instrument were reviewed, but the results were not heartening. Apparently, very little had been done to exploit its use to the extent that would be required in Alaska. Concurrently, but practically independently, some experimentation had been undertaken by the Corps of Engineers, the U. S. Geological Survey, U. S. altimeter manufacturers and the survey agencies of the Canadian Government. The results obtained were quite varied, but in summary led to the conclusion that accuracies of somewhere between ±5 feet to 15 feet could be obtained during periods of stable weather if operations were confined to elevations under 2,000 feet. It appeared that the so-called "two base" method yielded the best results, but that the horizontal separation of the bases should not exceed 10 miles.

These apparent limitations were too restrictive to permit beneficial use of the altimeter in the Alaskan operation. The tests as conducted, however, did not appear conclusive. Accordingly, the Battalion developed and executed its own series of tests to more definitely determine the capability of the altimeter. These tests showed that under the adopted procedure, the altimeter would consistently give accuracies of ±8 feet up to elevations of at least 4,000 feet and over courses in which the horizontal separation of the two bases was as much as 20 miles. Even better results were subsequently obtained in actual operation as will be shown later in this discussion. The tests also emphasized a previously anticipated problem. To minimize the possibility of major atmospheric changes, a particular run over an altimeter

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course should be completed in a reasonable period of time, preferably not more than two to three hours. How to maintain this timing in an area where even foot travel is slow and laborious posed a considerable problem. Only one solution was apparent—the helicopter. Additional tests were run and it was enthusiastically concluded that by employing the team of altimeter, helicopter and dauntless men, barriers of time and terrain would become pregnable and many areas previously considered inaccessible could be quickly and accurately mapped.

On the bases of the Battalion helicopter-altimeter tests, Army Map Service revised the Alaskan project specifications to call for vertical picture point control accuracies of ± 4 feet below the 200-foot contour and ± 8 feet above the 200-foot contour. This is a relaxation from the normally required accuracies of 1/10 the contour interval which in this case would be 2.5 feet and 5.0 feet respectively, based on the 25-foot and 50-foot contour intervals to be used in compilation. With the anticipated achievable accuracies accepted by AMS, the Battalion was ready to put to test in the field the conclusions drawn and the procedures evolved from its experiments.

The considerable success of the first season's work demonstrated that accuracies obtained during experimentation could not only be equalled in an actual operation under field conditions, but could be bettered. Specified accuracies were obtained by altimeter on points up to 7,000 feet in elevation and in some cases over courses 30 miles long. Now, after additional tests and with two seasons field work completed, the Battalion has accumulated a considerable amount of valuable experience in altimetry. From this experience, an operating procedure has been established which, by checks in the field as well as by utilization of field work in actual compilation, has proven the great potential of the altimeter for the topographic mapping of large areas of difficult terrain. The remainder of this discussion is devoted to the use and peculiarities of the altimeter as experienced by the 30th Engineers.

The Battalion has found that, with certain incorporated refinements, the two-base method consistently produces the best results under the field conditions encountered. It is not intended to imply that the two-base method is unquestionably the best. Preliminary experiments have indicated that the "leap-frog" method has considerable potential and with refinements may equal the results obtained with the two-base method. The two-base method has a particular advantage in that temperature and humidity observations are not required. It has a disadvantage in that the elevation of the upper base must be known. In areas of sparse control such as Alaska, bench marks are generally rare and in the high mountainous areas are practically nonexistent. This necessitates the use of trigonometric methods to establish upper base elevations when required.

The two-base method is comparatively simple. In essence, it is a method to determine by altimeter (air pressure) the elevations of a series or line of points lying between two base points (an upper and a lower) whose elevations are known. This method assumes that atmospheric pressure has a definite relationship to altitude. This, of course, is true only under certain standard conditions. Thus, to reduce variations due to atmospheric instability to a minimum, as well as to offset friction and imperfections in the mechanism of the altimeter, a number of planning considerations, operational procedures and computation refinements have been incorporated into the two-base method. These can best be described by considering the planning, execution and computation of an altimeter run.

Altimeter runs are planned in the office and the points to be included are preselected from a study of aerial photographs. In planning a course or run, experience has shown that better results will be obtained if certain basic principles are followed. Acceptable results can be obtained over runs where the horizontal distance between bases is as much as 30 miles. However, better results (fewer points rejected) are obtained if the horizontal separation is limited to 15 to 20 miles. The vertical separation between bases apparently is not critical insofar as the altimeter is concerned. In operations, just as good results have been obtained with a 5,000 foot or 6,000 foot difference between base elevations as with a 1,000 foot difference. Normally the upper and lower bases should be higher and lower respectively than any of the vertical picture points in the course. If a particular situation requires it, elevations on points outside the vertical range of the bases can be obtained. In such cases, however, a low or high point should not be below or above a low base or high base respectively by more than 10% of the difference in elevation between the two bases. Similarly, an ideal course would have all the altimeter points lying in a straight line between the two bases. In practice, terrain features dictate a compromise with this ideal. Experience has indicated that better results will be obtained if the horizontal deviations from a straight line are limited to 1/10 the horizontal distance between the bases when in the immediate vicinity of a base and $\frac{1}{4}$ the horizontal distance between the bases when operating near the mid-point between bases.

Terrain is closely associated with instability of atmospheric conditions and should therefore be carefully considered in planning altimeter courses. In mountainous areas, temperature differences between high and low areas tend to generate winds and local disturbances. Similarly, the temperature differences between areas in sunlight and those in shadows have the same effect. It has been found that best results are obtained from the altimeter in flat or undulating areas. Next best are rolling hilly areas. Least best, but still acceptable, results are obtained in precipitous mountain terrain. When working in precipitous terrain, points should be located on peaks or tops of ridges. When necessary, side hill points can be used, but accuracies are decreased. Poorest results are obtained in deep valleys or canyons and over large glacial areas. Ice fields and glacial areas present a special problem. On many clear, sunny days when other areas are calm and ideal altimeter conditions prevail, erratic winds of 50 and 60 miles an hour have been encountered whipping across the surface of ice fields. During overcast days, the weather over such areas appears to conform more to the average prevailing conditions. It appears that on sunny days the generally warm air, upon coming in contact with the cold air of the glaciers, produces the chaotic wind conditions observed.

While the above planning considerations, if followed, contribute to the greater accuracy of an altimeter run, the major burden for success falls upon the chief of the altimeter party. In addition to assuring the proper handling and reading of instruments, he must be something of a climatologist since accuracies are directly related to atmospheric stability. As wind force is an excellent indicator of atmospheric conditions, altimeter parties should utilize it as a guide as to whether or not altimeter operations should be conducted on a particular day. An easy way of judging in the field is utilization of the Beaufort Scale as a guide to wind speed. Operations should not be conducted beyond Force 4 on this Scale, which is given as follows:

BEAUFORT SCALE

Force	Description	Specification of Beaufort Scale	M.P.H.
0	Calm	Smoke rises vertically	0–1
1	Light Air	Wind direction shown by smoke drift but not by wind vanes	1–3
2	Light Breeze	Wind felt on face, leaves rustle, wind vanes move	4–7
3	Gentle Breeze	Leaves and small twigs in constant motion, wind extends small flag	8–12
4	Moderate Breeze	Raises dust and loose paper, small branches sway	13–18
5	Fresh Breeze	Small trees in leaf begin to sway	19–24
6	Strong Breeze	Large branches in motion, whistling wires	25–31
7	Moderate Gale	Whole trees in motion	32–38
8	Fresh Gale	Break twigs off trees, progress impeded	39–46
9	Strong Gale	Slight structural damage occurs	47–54
10	Whole Gale	Trees uprooted, considerable structural damage	55–63
11	Storm	Rarely experienced, widespread damage	64–75
12	Hurricane		75

The altimeter itself is also a good guide to atmospheric conditions. A rising reading on a stationary altimeter indicates a falling barometer and thus an unstable atmosphere. If such a reading reaches a 300 to 400-foot variation from a normal reading, it is unwise to initiate altimeter operations for the day unless there are definite indications that a return to normalcy is in process. Party chiefs should make it a habit, while in camp, to frequently observe a stationary altimeter to better judge the advisability of undertaking operations.

Acceptable results can generally be obtained during any period of the day, but the degree of accuracy is related to time of day. During midday when the sun's rays are hottest, the air thins and pressure falls. The resulting fluctuation of the altimeter reduces accuracy. Nighttime is the most stable and thus suitable period for altimeter work, though it is not always feasible to conduct operations at this time. Next best in order of preference are late afternoon and twilight, early to midmorning, and midmorning to late afternoon. Overcast days are generally suitable throughout since the blanketing out of the sun's rays brings on conditions equivalent to twilight.

Once the atmospheric conditions are considered satisfactory, the next step preparatory to physically running the altimeter course can be taken. This step is in three parts and includes adjusting, calibrating and comparing altimeters. After arriving in the field, but prior to use, all altimeters in each group (a set of 6 altimeters) are adjusted to a reading on a mercury column. This can be done by setting an arbitrarily selected instrument at the nearest weather station and then using it as a master to set the other instruments. Such adjusting was, of course, done by the manufacturer of the instruments, but should be repeated in the field to assure that the original setting has not been disturbed.

It should be noted that a set or group consists of 6 altimeters. It has been found that by always using altimeters in pairs and taking the average of the two readings, accuracies are improved. Thus, during a run, 6 instruments are used. Two remain stationary at the lower base, two remain stationary at the upper base and two rove between the bases and are read at each point on which an elevation is to be determined.

After adjustment, the set of instruments are calibrated by taking simultaneous readings at each 100-foot change in elevation from or near sea level to the maximum elevation at which operations will be conducted. This is most easily accomplished by connecting the instruments to a pressure-vacuum pump and using one altimeter as a guide for reducing pressures in stages equivalent to a 100-foot rise in elevation. When the maximum simulated elevation is reached, the process is reversed by taking similar readings back down to sea level. This cycle is completed twice and the results recorded. Great care is exercised in taking the calibration readings. A magnifying glass should be used, and if the light is not good, a flashlight for each instrument reader is an asset. If a vacuum pump is not available or the type of altimeter being used cannot be made air tight, calibration can be effected by physically transporting the instruments up and down a mountain side throughout the elevation range in which they are to be used. If the range is extreme, increments of 200 feet or more can be used to simplify calibration. In either case, at each stop, a mean reading is determined by taking the sum of the readings of all instruments and dividing by the number of instruments. Each individual instrument reading is then compared with this mean reading. Any variation, either plus or minus, is the correction or "C" factor for that particular instrument. The average of the four "C" factors (two cycles of up and down the elevation range) for each instrument at each 100-foot change in elevation is more conveniently used if constructed in the form of a graph in which the ordinate is correction in feet and the abscissa is altimeter reading. Any subsequent reading on a particular instrument is adjusted (plus or minus as the case may be) by the amount indicated on its graph for the elevation at which the reading is taken. Recalibration is indicated if any of the following circumstances prevail: (1) if 30 days elapse since previous calibration; (2) if instruments are shipped over a long distance; (3) if an instrument is substituted in a group in which it has not been previously adjusted; (4) if any instrument in a group has been jarred.

An additional refinement which has been shown by Battalion tests to improve elevation accuracies by an average of 3.3′

per altimeter point is a system of "Comparison Readings." Prior to and upon completing an altimeter run, comparison readings between the instruments are made at the upper and lower bases. This is accomplished by transporting the six adjusted and calibrated instruments to the lower base where all are read simultaneously and the readings recorded. Two altimeters are left at the lower base where they are read every 5 minutes throughout the operation and the reading recorded. The remaining four altimeters are carried to the upper base where they are read simultaneously. Two instruments remain here and are read at 5 minute intervals while the other two become the roving altimeters and start down the course by helicopter, visiting each preselected picture point. All readings on the roving altimeters are made on even 5 minutes of time so as to conform to the base altimeter readings. Upon completion of the usual two runs over the course (preferably one down and one up), the roving altimeters are again compared with the upper base altimeters. These four altimeters are then transported to the lower base where all six are compared. All comparison readings are recorded together with the time they were taken. These data are used by computers to obtain a correction factor which is separate and distinct from the calibration or "*C*" factor. This factor, denoted as "*X*," is obtained by taking the mean of the readings of the six instruments at the first lower base comparison and again for the last lower base comparison. As in calibration, each individual instrument reading is compared with the mean of each comparison and the difference constitutes a correction factor for each instrument, based on time. From these data, graphs are prepared for each instrument in which the ordinate on the left represents correction in feet based on the first lower base comparison, while the ordinate on the right is the correction based on the last lower base comparison. The abscissa denotes time from left (first comparison) to right (last comparison). From this graph it is easy to determine the correction to be applied to an instrument reading taken at any time during the run. The same procedure is followed for the four instruments compared at the upper base.

Between calibration figures, comparison readings and readings obtained during the running of the altimeter course, the computer is faced with a comparatively simple, but somewhat lengthy process to arrive at elevation determinations of the selected altimeter points. The various field data are entered on specially devised forms by the computer. The computer also has a form on which his computations are entered. To obtain the elevation of an altimeter point, the two runs over a course are computed separately and a mean taken of the final results. The computer starts with two field readings since the instruments are always used in pairs. To each of these readings, the appropriate "*C*" factor correction, as obtained from the individual calibration graphs, is added (plus or minus as the case may be). The next step is to apply the comparison correction factor "*X*." This is done by reference to the comparison factor graphs to determine the amount of correction to be used for the time the reading was taken. Each altimeter has two graphs, one from the lower and one from the upper base comparison. To the reading of altimeter "*A*" (with the "*C*" factor already added) the lower base comparison graph factor is added. This is repeated using the upper base comparison graph to obtain the upper base factor. The whole process is repeated for altimeter "*B*." Thus there are four readings for the altimeter point. The mean of these is taken and the result becomes the "field reading" used in the final computation. Similarly, the appropriate factor "*X*" correction is applied to both the lower and upper base readings. Since each point in a run is computed separately, the "*X*" factor corrections, as applied to the base readings, are for the same time as the readings were taken on the point being computed.

The final computation utilizes five known or basic figures: the actual elevation of the lower base, the actual elevation of the upper base, the corrected lower base altimeter reading, the corrected upper base altimeter reading and the corrected roving altimeter reading on the point whose elevation is to be determined. The lower base reading is subtracted from the roving reading and the difference entered on the computation form as a plus value. The roving reading is subtracted from the upper base reading and the difference entered on the form as a minus value. Assuming, of course, that the altimeter point is higher than the lower base and lower than the upper base. Next, the lower base reading is subtracted from the upper base reading to obtain the altimeter indicated difference in elevation between the two bases. This figure is divided into the known elevation difference between the two bases to obtain a factor based on the ratio of the true elevation difference to the indicated elevation difference. This factor times the difference between the lower base reading and the roving altimeter reading (the + value referred to above) plus the known elevation of the lower base equals the computed elevation of the altimeter point. A similar computation, using the upper base, provides a check on the computations. This value averaged with a similarly computed value as a result of the second run over the course equals the final accepted elevation of the point.

When possible, it is most desirable to include one or more check points (points, other than the upper and lower base, whose elevations are known) in an altimeter run. Also, when lines are so located that it is feasible, a new run should include one or more points of a previously completed run. Such check points are not used to adjust an altimeter run, but they do provide an indication of the reliability of the work. No specific criterion has yet been established as to how far a check point must be missed before a run is discarded. If a check point appears "wild," the run will be under suspicion. If a second run confirms the first, then the check point will be suspect if it is a trigonometric or altimeter elevation. If it is a spirit level elevation, consideration is given to the possibility that it is poorly located in the run from either a terrain standpoint or with respect to the bases. If such is the case the run is temporarily accepted, but one or more of the altimeter points should be incorporated into the next run for confirmation.

Certain criteria have been established as to acceptance or rejection of an altimeter run. No single run over a course is acceptable. At least two runs from which a mean can be extracted are required. These runs should be in opposite directions. If the first run is down a particular course, then the second run should be up the course. The runs should agree within specified limits. If an accuracy of E feet is required, then the two elevations obtained from the two runs should agree within $1\frac{1}{2}E$. Where two successive elevations on a point vary by more than this amount, a third run should be made over the course and the allowable spread would be $3E$. If two of the three elevations disagree by more than $3E$, but the third elevation agrees with either of the other two within $1\frac{1}{2}E$, the mean of the two which so agree is accepted.

Altimeter results are improved by exercising care in handling and observing instruments. In reading, the observer should shift his head until he can see the pupil of his eye centered with the needle pointer in the annular mirror. The instrument should be level and firmly supported. Before reading, at least two minutes should elapse to permit the indicator to settle. A light tap on the glass panel with the finger will overcome any lag due to the possible presence of static electricity. The instrument should be protected from sun and strong winds both during observing and transporting. Watches of all observers should be thoroughly reliable and should be synchronized before each new run. One of the most important factors is tempera-

Analysis of Altimeter Checks on 69 Points of Known Elevations

(1)	Number of plus errors	29
(2)	Number of minus errors	37
(3)	Number of no errors	3
(4)	Average error on all points	8 ft.
(5)	Average error between sea level and 2,000 ft. elevation	9 ft.
(6)	Average error between 2,000 ft. and 4,000 ft. elevation	$9\frac{1}{2}$ ft.
(7)	Average error between 4,000 ft. and 5,000 ft. elevation	4 ft.
(8)	Average error on points 0 to 10 miles from nearest base	$8\frac{1}{2}$ ft.
(9)	Average error on points 10 to 15 miles from nearest base	10 ft.
(10)	Average error using old wood case type altimeters	9 ft.
(11)	Average error using new metal case type altimeters	5 ft.

ment of personnel utilized. Use of the altimeter is inclined to be routine and thus boring. However, to obtain results, personnel must be extremely reliable, conscientious, industrious and well grounded in altimetry.

During an actual field operation, 69 points of known elevations were incorporated in various altimeter runs under widely varying atmospheric and terrain conditions. An analysis of the results is an excellent indication of the potential of the altimeter when used in the manner outlined in this discussion. (See tabulation.)

The Battalion has converted to all metal case type altimeters, which is considerably improving results.

Personnel of the 30th Engineers recognize that comprehensive altimetry is still a comparatively new endeavor. While it has been successfully employed by the Battalion, it is apparent that much is yet to be learned. It is anticipated that presently planned experiments will result in further refinements. Particularly sought are influencing factors, corrections therefor and simplification of procedures and computations. In short, increased efficiency and accuracy.