IV. — " LEAPFROG " BAROMETRIC LEVELING

by H. R. CRAVAT,

Coast and Geodetic Survey

In the early 1940's the Coast and Geodetic Survey developed procedures for single-base altimetry, and used the method extensively in the initial phases of the airport survey program. Subsequently, experimental work was done on the two-base method. The latter method was used to a limited extent on mapping projects in Alaska.

In 1954 and 1955, the Coast and Geodetic Survey contracted with the Army Map Service for mapping extensive areas in California, Arizona, Nevada, Montana, and Idaho at 1/250 000 scale. The vertical tolerance for controlling the 200-foot contours was 20 feet. Hundreds of widely separated elevations were required in areas of extremely difficult access; many points could be reached only by pack or helicopter, with the nearest bench marks frequently 20 miles distant. Barometric leveling seemed to be made to order for the project.

The « leapfrog » method of barometric altimetry was developed subsequent to our initial interest in altimeters, but from evidence at hand it appeared to offer greater accuracy and more uniform results with fewer refinements required than for the single-base or double-base methods. Accordingly it was accepted as a suitable method for barometric leveling.

Field operations got off to a fine start in the summer of 1954. The parties were equipped with instructions and 7 000-ft range altimeters for the lower altitude work and 15 000-ft range altimeters for the higher altitude work. « Leapfrog » level loops were started and closed on geodetic bench marks; frequently check elevations were provided as precautionary measures near the mid-points of the longer loops.

Several months went by and the records coming in from the field appeared far better than anticipated. Closures prior to adjustment on 20 to 40 mile loops were generally 5 to 10 feet, and after adjustment none of the check elevations even closely approached the ± 20 feet allowable error. It was, therefore, most unexpected when the field party submitted puzzling information. One of their « leapfrog » level loops had a closure error of 35 feet ! Suspecting that the altimeters had probably been erroneously read at one or more points in the loop, the loop was completely releveled. A two-foot closure error was obtained on the releveling. But after both levelings were adjusted for the appropriate closure errors, comparison elevation points in the first and second running were in agreement within 2 feet.

Inquiries to other users of the « leapfrog » method failed to furnish conclusive information regarding the relation of closure errors to the reliability of the intermediate barometric elevations. Realizing that our application of the method was unusual because of the long leaps and the extreme distances between bench marks, it was decided that tests comparable to our specific application were required to determine the following :

1. Reasonable allowable closure error.

2. Allowable length of barometric level loop.

3. Over-all reliability of elevations.

A long series of tests were assigned to the field party in the fall of 1954 to be completed along with normal field operations. The tests were started by Mr. John C. Lajoye and were continued progressively by party chiefs, LCDR Lorin F. Woodccok and LCDR V. Ralph Sobieralski until completed early in the summer of 1956. The tests included nine « leapfrog » level loops totaling 414 miles in length, covering all types of terrain in southwestern United States. The test loops ranged in elevation from 600 ft to over 7 000 ft above MSL, with elevation changes of greater than 2 000 ft occurring in some loops. Each loop was started and closed on a geodetic bench mark, and comparison readings were observed at 113 intermediate geodetic bench marks. Tables 1 and 2 contain tabulated analysis and further statistics on the tests.

TABLE 1

STATISTICS ON « LEAPFROG » ALTIMETER TESTS

Tests made with W&T 7 and 15 thousand ft range altimeters

Scale readings estimated to nearest 1 ft

Test leaps :	1	2	2 rerun	3	4	5	6	7	8	9
Weather (W=windy) (C =calm)	C	C	C	W	C	W	W	C	C	?
Elapsed time (hours)	6	7	7	12	8	6	7	5	4	8
Length loop (miles)	40	42	42	64	52	42	59	26	24	24
Average Dist. between leaps	4	3.5	3.5	4	4	4	4	3	3	1
No. elevations tested	9	11	11	15	13	8	13	7	7	19
Closure error (feet)	3	8	2	15	16	9	19	40	11	19
Maximum Diff. from true	5	11	10	16	13	29	24	19	11	11
Average comparison error	4	6	5	7	6	10	9	8	5	5

DISCUSSION OF TESTS

Prior to the tests the reasonable closure error was unknown. The maximum closure error encountered during the tests was 40 feet. After adjustment this high closure error had no apparent effect on the over-all reliability of elevations.

The allowable length of a loop was not determined. A 64-mile loop, run on a moderately breezy day in a 12-hour period, produced accuracy results superior to a satisfactory 26-mile loop run on a calm day in a 5-hour period. It is difficult to explain why the results for the long loop were better than for the shorter loop, and it is easier to consider this typical of altimetry. It was determined, however, that there is a relationship between length of line and over-all accuracy. Several loops were recomputed as two independent loops, for example, a loop 24 miles in length that was recomputed as two 12-mile loops indicated an average increased accuracy from ± 5 to ± 3.5 feet.

TABLE 2

ANALYSIS OF TEST

Elevation Error (feet)	Number Points Tested	% Points Tested
0-5	58	51.2
6-10	40	35.4
11-15	10	09.0
16-20	3	02.6
21-25	1	0.9
26-30	1	0.9
31 and	0	0.0
Greater	—	—
Total	113	100.0

Ninety-eight per cent of the elevations determined during the test were well within the allowable tolerance. However, if a stricter accuracy tolerance were desired, such as ± 15 ft, modifications would be required. These modifications would be a shortening of both the leaps and total length of lines. Refer to Table 1, test line 9.

CONCLUSION

Altimetry involves three basic elements: the machine, the atmosphere, and the human element. The machine, or altimeter, is a scientific instrument manufactured to do a specific task under certain conditions. This element is predictable, but there are always factors of uncertainty in the other elements. In almost every barometric test loop the unpredictable factors are apparent by a few elevations that deviate considerably from the average. What makes these wide deviations? It could be an error or errors in scale readings, but this is unlikely because of the number of independent comparison readings that are made at each station. It is more apt to be the operator's inattention to changing atmospheric conditions, or his inability to cope with them, even if he recognizes them. That is, the two altimeters may be separated by a ridge, the altimeters may be separated too widely to accommodate changing atmospheric conditions, or atmospheric conditions are too unstable for altimetry on that day. These elements are always uncertain but can be minimized by special training and selection of personnel, but they cannot be disregarded.

The results of these tests are not startling, and some of our original questions remain unanswered. However, we have proven to our own satisfaction that the methods employed were sound and the desired accuracy was achieved. Also, as an important by-product, our knowledge has been broadened sufficiently to open new avenues for solving similar problems.