*KC-2 Convergent Photography Aerial Triangulation Results**†

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ABSTRACT: *This paper describes an evaluation of KC-2 Convergent Photography by the Army Map Service as part of a comprehensive investigation of several types of convergent material. This camera was flown simultaneously with a vertically mounted KC-1 camera over Phoenix, Arizona at an altitude of 10,000 feet. Two adjacent flights of each material were aerial-triangulated three times each on the C-8 Stereoplanigraph and were adjusted by a combination of mathematical and graphical methods.*

Background material is presented concerning previous Army Map Service convergent aerial triangulation investigations, and some comparison is made between these and the present results. The results of the current test, simultaneous KC-2 convergent and KC-1 vertical, are presented and compared in detail.

PHOTOGRAMMETRISTS everywhere are constantly interested in the simultaneous attainment of two apparently conflicting goals. These are: 1) increased economy and 2) the same, or better, accuracy.

The most obvious method of increasing economy is to raise the ceiling of the photographic aircraft. Theoretically, one of the methods to do this and still maintain the accuracy of the Z-coordinate is to use convergent photography.

There are several types of convergent photography and many papers have been published concerning their theory and results (1, 2, 3). The theory, comparative geometry, (Figure 1) advantages and disadvantages have been discussed in great detail, by a wealth of literature, by many eminent, and at times, disagreeing authorities. Those aspects, therefore, will be treated only in a very general way. The primary purpose of this report is to give the background, conditions and results of an investigation which compared the aerial triangulation accuracies of the KC-2 convergent camera with those of a simultaneously flown, vertically mounted KC-1 camera.

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Since it was theoretically decided by Ohio State University,‡ that doubling the Base: Height ratio should result in a corresponding increase in the vertical accuracy of a stereo model, Army Map Service has conducted exhaustive tests, in coordination with GIMRADA, to determine whether or not this theory held in practice. (4). The resulting investigations used 20-degree Mark Hurd, vertical KC-1, 15-degree KC-1, 20-degree KC-1, and 13.5-degree RMK 21/18 photography, taken at altitudes of from 10,000 to 35,000 feet. The instruments used in the testing were the Multiplex, Kelsh and Balplex plotters for compilation, and the Stereoplanigraph C-8 for aerial triangulation.

In summary, the previous results indicate that:

1. In the compilation of single models,

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* The information contained herein does not necessarily represent the official views of the Corps of Engineers or the Department of the Army.

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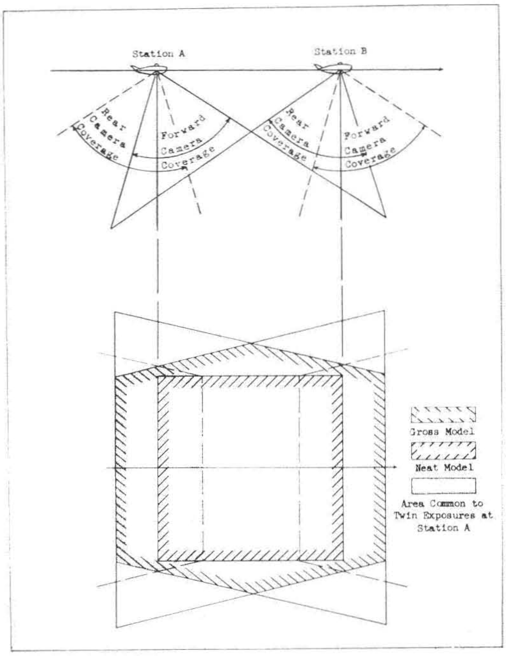

FIG. 1. Convergent photography.

20-degree convergent photography provides vertical accuracy superior to equal altitude vertical material by factors of from 1.3 to 1.5.

2. This superiority, however, does not carry over to the aerial triangulation process. Comparative Army Map Service aerial triangulation testing prior to the KC-2 provides the following results (5):

a. There is little difference in horizontal accuracy between vertical, 15-degree convergent and 20-degree convergent material.
b. The vertical accuracy of the photography, taken by the vertically mounted KC-1 camera, exceeded that of the corresponding 20-degree camera by a factor of 1.68.
c. The vertical accuracy of the 15-degree material exceeded that of the 20-degree by a factor of 1.45.

As a result of these previous investigations it was decided that, pending the findings of a test of the KC-2 camera, no type of convergent photography be considered for use in an assignment which would require aerial triangulation.

To conduct an evaluation of the KC-2 camera properly, the Army Map Service had requested three adjacent flights of simultaneous KC-2 and KC-1 photography at an altitude of 10,000 feet over the same area that was covered by previously tested material.

The Fairchild KC-2 camera, built for the U. S. Air Force, was specifically designed to take 20-degree (half-angle) convergent photography (6, 7, 8). It is believed to be the only wide-angle camera specifically built as a convergent camera and tested by a mapping agency. It offers the following advantages over the previously used, modified KC-1 convergent cameras:

1. Reduced size and weight.
2. Shutters remotely controlled by electronic means with synchronization to one millisecond.
3. Dual, interchangeable magazines.
4. Matched Planigon lenses mounted in convergent inner cones which are held in a precise relationship to each other by a reinforced single body structure.
5. Ability to operate at the faster speed of the latest aircraft as well as in a greater temperature range.

The test photography was flown in August 1959 at an altitude of 10,000 feet over the Phoenix, Arizona test area by the Aero Service Corporation. The Army Map Service received the material from GIMRADA, through official channels. This photography did not cover the area requested and only two, rather than three, adjacent strips were usable for aerial triangulation purposes. In addition, it was discovered that the KC-2 photography was stabilized while the KC-1 material was not.

An inspection of the camera calibration certificates showed that the distortion of each of the two cones of the KC-2 camera was less than 10 microns; that the distortion of the KC-1 camera, however, reached a maximum of 24 microns. Since 10 microns is considered distortion-free by Army Map Service, no further treatment was given the KC-2 photography. The KC-1 film, however, was processed in the Wild U-3 printer. This reduced the maximum distortion to a calculated 17 microns.

Preliminary model orientations were made to check the photography for residual *Y*-parallaxes. The KC-1 material oriented satisfactorily in this respect. On the other hand, approximately 20 per cent of the KC-2 photography models had residual *Y*-parallaxes of the order of a 0.10 mm.

At this point, considerable deliberation was given as to whether or not this material should be used for testing purposes. Finally, it was decided to use the material in spite of

TABLE I

HORIZONTAL AND VERTICAL RESULTS

Bands	Strip	Run	X-ft.	Y-ft.	Vert-ft.	Fl. Height/$RMSE_Z$
KC-1 Vertical						
8-9-10	1	A	±7.6	±7.3	±2.2	4,545
		B	±7.1	±7.6	±3.0	6,667
		C	±6.6	±4.7	±2.4	4,167
	Avg		±7.1	±6.5	±2.5	4,000
10-11-12	2	A	±5.4	±4.4	±2.8	3,571
		B	±4.8	±5.2	±2.3	4,348
		C	±7.1	±4.4	±2.7	3,704
	Avg		±5.8	±4.7	±2.6	3,846
KC-1 V	Avg		±6.4	±5.6	±2.6	3,846
KC-2 Convergent						
8-9-10	1	A	±7.7	±7.6	±1.2	8,333
		B	±9.7	±6.6	±1.1	9,091
		C	±8.9	±8.4	±1.3	7,693
	Avg		±8.8	±7.5	±1.2	8,333
10-11-12	2	A	±7.2	±7.1	±1.1	9,091
		B	±6.7	±6.4	±1.3	7,693
		C	±7.4	±6.4	±1.2	8,333
	Avg		±7.1	±6.6	±1.2	8,333
KC-2 C	Avg		±7.9	±7.1	±1.2	8,333

its deficiencies rather than to wait indefinitely in the hope for better photography. Some valuable indications, at least, would be given.

The two usable flights were 19 miles long (about 16 vertical models) and each contained 64 geodetic points. Nine of these points were used to control each strip—a band of three at each end and in the middle. The remaining points were withheld from the operator for later checking purposes.

The two adjacent strips of simultaneously flown KC-1 and KC-2 photography were oriented three times each on the Zeiss C-8 Stereoplanigraph by one operator. Each point was observed three successive times and the mean of these observations accepted as the instrument value. For purposes of later analysis, all instrument settings were recorded. Subsequent strip adjustment, horizontal and vertical, was performed by the UNIVAC.

The adjusted instrument coordinates were compared to the given values of the geodetic control and RMS errors computed from the differences (Table 1). The table shows the RMS errors in X, Y and Z of each of the three orientations of the two strips of the two types of photography. An inspection shows, for example, that the vertical material produced RMS errors in the Z-coordinate of from ±2.2 to ±3.0 feet for an average of ±2.6 feet; that correspondingly, the convergent material yielded ±1.1 to ±1.3 feet for an average of ± 1.2 feet.

A careful record was kept of time expenditure during this test. These records show that, in ground area covered, there were no appreciable time differences between the two types of photography in either the instrumentation or adjustment processes.

A summary of the results of this test, as compared with those of previous comparative testing, is given in Table 2.

The KC-2 photography has exceeded, in vertical accuracy, the results of all other aerial triangulation testing conducted to date at the Army Map Service. It is obvious that convergent photography did not get a fair evaluation until a wide-angle camera was specifically made for the purpose and the synchronization problem was solved.

The superiority in the Z-coordinate, of the 20-degree convergent material over the vertical, is about what the theorists had predicted. How much of this increase in vertical accu-

TABLE 2

ACCURACY SUMMARY

	X-ft.	Y-ft.	Z-ft.	$H/RMSE_Z$
Previous Comparative Test				
Vertical KC-1	±8.6	±7.2	±1.8	5,556
15° Convergent KC-1	±7.5	±10.6	±2.1	4,762
20° Convergent KC-1	±7.8	±7.8	±3.1	3,226
Current Comparative Test				
Vertical KC-1	±6.4	±5.6	±2.6	3,846
20° Convergent KC-2	±8.0	±7.1	±1.2	8,333

racy, however, can be attributed to the fact that the KC-2 was stabilized and the KC-1 was not? There undoubtedly was some bias here—exactly how much, cannot be fully determined.

Synchronization has been recognized as a critical factor in the accuracy of convergent photography aerial triangulation. In fact, it is believed that the primary cause for the accuracy breakdown in previous convergent aerial triangulation testing can be attributed to poor synchronization of the two convergent camera cones. For this reason, the KC-2 tolerance was 0.001 second rather than the 0.01 second as formerly used in KC-1 convergent cameras. That a considerable improvement in synchronization was achieved can be attested to by the base readings of the "zero-base" model. The average such base of the KC-2 camera was 0.38 mm. compared with 1.46 mm. for that of the previously used KC-1 convergent camera. It is realized, of course, that other sources of error, such as film change, are contributing factors here. It seems fairly certain, however, that the radical improvement in synchronization produced a corresponding increase in vertical accuracy.

As mentioned previously, the maximum radial distortion of the two KC-2 cones was under 10 microns while that of the KC-1 camera was 17, after compensation. Indications therefore are that the KC-2 camera was superior to the KC-1 in the distortion category. Since, however, the probable error in these distortion calibrations is given as ±10 microns, exactly how much better would be difficult to determine.

On the other hand, the KC-2 material was not flawless either, since traces of Y-parallaxes were noted on about 20 per cent of the stereo models.

Although the photography used was not ideal, the test provided some fairly reliable indications, that, with good synchronization, 20-degree convergent photography can produce an increase in Z-coordinate accuracy in aerial triangulation that is in keeping with that found in the single stereo model. Prior to any definite recommendations regarding the use of such material in a project requiring aerial trigangulation, however, further comparative testing with completely unbiased material should be performed. In addition, the results of current ultra-wide-angle investigations, will have a bearing on whether or not, and to what degree, the Army Map Service will use convergent photography.

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