Experiences with Convergent Photography[*]

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THE study and application of twin camera convergent aerial photography for mapping purposes is not new. It has been used by several European countries and would have realized a much more universal application except for the introduction of the wide-angle mapping camera lens. Most photogrammetrists, who would otherwise have resorted to convergent techniques, were attracted by the advantages of the wide-angle lens for a solution to their problems and, except for a very few, interest in convergent photography was lost.

In the U. S. where a great part of the country is yet to be mapped satisfactorily at scales of 1:25,000, or even smaller, an ever present pressure exists to find methods of producing topographic maps with the highest possible accuracy, but with maximum speed and economy.

Recently, the question occurred to photogrammetrists in the U. S. that if convergent normal-angle photography improved performance and economy of normal-angle techniques, why shouldn't convergent wide-angle photography improve the performance and economy of wide-angle techniques? Superficial inspection of usage of convergent wide-angle photography was very interesting and promising. The greater base height ratio promised higher vertical accuracies; the coverage of twin convergent camera installation indicated economy of photography, stereomodels, and ground control. There were difficulties anticipated too. Convergent photography in terrain of considerable relief could cause holidays; two cameras are required which of course means more opportunity for failure; contact prints are not usable for mosaic work or control identification—questions arose as to what equipment could be utilized, how could aerial triangulation be effectively accomplished. However, the advantages appeared to outweigh the disadvantages and studies were initiated by the U. S. Geological Survey and the U. S. Army Corps of Engineers to evaluate the full potential of convergent wide-angle mapping photography. It was agreed by both organizations very early in their investigations that a convergence angle of 40 degrees (each camera 20 degrees from the vertical) appeared to be the optimum arrangment for wide-angle lenses. It was also determined that the stereoplotting equipment most commonly used in the U. S., the direct projection, dichromatic anaglyphic instruments, namely the Multiplex, the Kelsh Plotters, and the ER-55 or Balplex plotter were exceptionally well adapted to convergent photography with a minimum of modification. This fact no doubt played an important part in the acceptance in the U. S. of the idea of convergent photography.

The first investigations of the application of 20-degree convergent wide-angle photography made at the Engineer Research and Development Labora-

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tories were with the Multiplex equipment. Simple mechanical adapters were designed to permit tipping of the projectors the required angle; no other modification of the equipment was required. It was necessary to modify the relative orientation procedure somewhat, but this caused no confusion to the operators. One phase of the investigation was a comparative stereoplotting test where the same area was photographed with conventional wide-angle vertical techniques and simultaneously with convergent methods. This test revealed that with the convergent photography, the contouring accuracy of the Multiplex equipment was increased from 1.5 to 2 times that of vertical photography. No increase in the planimetric accuracy was observed. The remarkable increase in performance of the Multiplex brought the next question to our consideration. How much could the stereoplotting potential of the Kelsh Plotter be improved if it were adapted to convergent photography? Here again it was fortunate that the Kelsh Plotter required very little modification to make it suitable for use with 20-degree convergent photography. As in the Multiplex test, there was prepared two maps of the same area with simultaneously taken photography, using the same type cameras, except of course one coverage was vertical and the other convergent. Again discovered was a remarkable increase in contouring and heightening accuracy, 1.5 to 2 times that with vertical stereo models, and no change in planimetric accuracy.

It was observed in the stereomodels formed with convergent photography that a considerable fall-off in resolution existed. This condition was more noticeable in the Kelsh Plotter than the Multiplex. This is understandable because of the greater magnification in the Kelsh Plotter system and also the depth of focus of the Multiplex projector lens is extremely great. This fall-off in resolution is caused by tipping the plane of best focus of the projector twenty degrees to the datum. Special wedge shaped plate holders were designed to improve the resolution by satisfying the Scheimpflug condition. This was done by tilting the plane of the diapositive to intersect with the common intersection of the datum plane and the lens plane. Care was taken to see that the principal point of the diapositive coincided with the foot of the perpendicular from the projection lens. Use of these special plate holders increased the resolution of the projected image considerably. However, and surprisingly, the contouring and heightening accuracy of these more highly resolved stereomodels did not differ significantly. Here was encountered a problem which has been met before by many photogrammetrists but to our knowledge has not been answered in a definitive quantitative manner, to wit; what is the correlation between resolution and stereo-acuity? This problem is being investigated at the Laboratories at present.

It was recognized early in the investigation that for convergent photography to be of real practical use in solving the peculiar mapping problems, that is, covering great areas with maximum accuracy and minimum time and expense, it would be almost mandatory that such photography lend itself to accurate aero-triangulation. Accordingly another phase of the investigation concentrated upon methods and instrumentation required to successfully bridge control, both vertical and horizontal, with accuracies commensurate with the stereoplotting capabilities. This was not so simple an investigation as stereoplotting, but then any form of aero-triangulation is hardly as simple a task as the plotting of an individual stereomodel. The initial studies of possible methods of aerotriangulation concerned principally establishment of vertical control. It was here that most difficulty was anticipated. Conventional methods for bridging horizontal control could always be resorted to if necessary. Slotted templet and radial line techniques are readily adaptable to convergent photography, however, conventional stereo-aero-triangulation techniques could not be used. Convergent photography, as we apply it, requires a two-camera exposure at each station—one camera shooting fore, the other aft. The problem, very simply stated, in convergent aero-triangulation, is given the spatial attitude of one of these two cameras, how can the spatial attitude of the complementary camera be recaptured? Because of the physical proximity of the two cameras and instantaneous exposure, the three base components can be considered as zero. If the mount is carefully calibrated, differential phi, omega and kappa are known and the problem can be solved mechanically by projector rotation. This is a solution which is being developed at the U. S. Geological Survey by Mr. R. K. Bean and is referred to as the Twinplex. For military mapping, it is not always certain that camera mounts will be carefully calibrated. At Fort Belvoir there is a greater inclination to seek a solution which would permit a greater freedom or latitude in mounting the cameras. The development of the Stereopontometer by Mr. J. T. Pennington (described in detail in March 1954 issue of PHOTOGRAMMETRIC ENGINEERING) was an answer to this requirement. To accomplish its function the stereopontometer does not require prior information as to the differential angular attitudes of the complementary convergent cameras. The instrument makes use of the non-stereoscopic congruent images from each projector, of the terrain area common to both cameras when exposure was made. If the spatial position of one camera is known, the other is obtained by a relative orientation process, matching congruent images in a flat plane. The first Stereopontometer was built to be used with Multiplex equipment. When it was determined that the instrument functioned satisfactorily, a larger one was designed and built for the Kelsh Plotter. It was also determined that the Stereopontometer bridging technique could be applied to the Zeiss Stereoplanigraph C-8 and the Wild Autograph A-7 with no auxiliary devices required.

It was decided that in order to calibrate the instruments to be used in the triangulation trials it would be extremely desirable to have precise 20-degree convergent grids. In this way errors inherent in the aerial photography would be eliminated. Accordingly there was constructed an extremely accurate reseau designed to project a precise square grid when truly positioned with phi equal to 20 degrees and omega equal to zero. The etched lines of the reseau were properly tapered to project lines of equal and uniform thickness. It was a difficult task to make such a reseau but it has proven invaluable in our investigations—not only for aero-triangulation, but also for studies of interior and relative orientations in various stereoplotting instruments.

Aero-triangulation attempts with the convergent grids, using the Stereopontometer technique resulted in extremely promising data. These tests were followed up with aero-triangulation attempts with 20-degree convergent photography taken over well controlled areas at very high altitudes.

With photography at 40 thousand feet altitude, a series of four triangulation attempts were made between two bands of control forty miles apart, using a Kelsh Plotter and the Stereopontometer. It must be recalled that the Kelsh Plotter was never considered an aero-triangulation type instrument but rather, as its name implies, just a stereoplotter. Inspection of 47 vertical check points revealed an average root mean square vertical error of 22 feet for the four attempts. It is felt that to bridge forty miles with a Stereoplotter and obtain errors of this order of magnitude is very promising, for this was a single strip, with no block adjustment or refined techniques of error adjustment. However, we are not satisfied, for simulated aero-triangulation attempts with our convergent grids indicate possibilites of accuracies at least two to three times as great as those obtained in our tests with aerial photography. Therefore, at present the studies are being concentrated upon possible sources of error in convergent photography and upon means for eliminating or nullifying such errors. In connection with these studies we have been most fortunate to have had the aid of such eminent and internationally known photogrammetrists as Professor Hallert, Professor Roelofs and Dr. Brandenberger. Through the contracts with The Ohio State University Mapping and Charting Research Laboratory the assistance of these talented scientists has been made available to Fort Belvoir and has been of great value.

Much work remains to be done on the development and evaluation of wide-angle convergent photography. In addition to the work with Kelsh Plotters and Multiplex, we are investigating the use of C-8 and the A-7 for aero-triangulation; the results are quite promising. Work remains to be accomplished on simplification of procedures and techniques of triangulation. The methods used at present admittedly require a high degree of skill. Investigations are now being made of the advantages to be gained from block adjustment of the convergent triangulation strips and optimum ground control distribution patterns. A very interesting test along these lines is planned. In the Southwestern part of the United States there is a test area consisting of a square—thirty miles long and thirty miles wide. At approximately every mile, in the manner of a reseau, there is a well defined control point the coordinates of which are known. This area is being photographed simultaneously with a vertical and convergent installation; it is hoped with this photography to complete a thorough and impartial investigation of the differences to be expected with vertical and convergent compilation and aero-triangulation.

Before bringing this paper to a close, perhaps it would be appropriate to make a few observations on the general subject of the use of convergent photography in mapping. Some thoughtful criticisms of this method of aerial photography have been made. It has been pointed out that low altitude photography, particularly for cadastral work, over urban areas, would produce blind spots, areas of no stereo-coverage, if taken with wide-angle convergent photographs with a base to height ratio of approximately 1.2. In the Corps of Engineers, U. S. Army, there is no argument with this point. Using convergent photography for low altitude mapping, cadastral or otherwise, is not planned. Convergent photography is being studied at Fort Belvoir as a high altitude mapping procedure. It is believed that no one system of mapping can answer universal requirements. One might almost try to design a single method of transportation that would meet all requirements. The photogrammetrist or photogrammetric engineer earns his professional status by virtue of his ability to determine the best method, when presented with given conditions. A common criticism of convergent photography is the inconvenience of using contact photographs prepared from the aerial negatives. This could be a serious inconvenience; however, it is relatively simple matter to design a transforming printer which will produce nominally rectified prints almost as quickly, if not just as quickly, as contact prints. A more interesting and recent comment is that the introduction of a super wide-angle lens will make wide-angle convergent photography relatively obsolete—just as the wide-angle lens terminated interest in the convergent-narrow-angle photography. The idea of an acceptable super wide-angle mapping lens is very interesting. Our position on this question may almost be considered an enviable one. We represent no commercial organization, nor do we profit in any manner if one system should prove to be better than another, except that we will always tend to accept what we consider the superior solution for our purposes. Should a super wide-angle lens be produced which in our opinion performs satisfactorily as a lens, we will no doubt investigate its potential as a component of a mapping system and made an impartial comparison with other existing systems to determine whether it fills a Corps of Engineers need. There are too many questions to be answered on the use of a super wide-angle lens to permit one to arbitrarily state that such lens will make convergent photography obsolete.

To summarize, we are faced with a problem not common perhaps in Europe but common enough throughout the rest of the world, the problem being to map large areas previously unmapped or mapped poorly, at medium scales with a high degree of accuracy and with a minimum amount of time and expense. To solve such a problem we are investigating the combination of high altitude flying and convergent wide-angle photography. Our laboratory studies clearly indicate that contouring accuracy can be improved by as much as 100 per cent if convergent photography with a base to height ratio of 1.2 is used in place of the conventional vertical photography with a base to height ratio of 0.6. Our aero-triangulation tests have not been conclusive as yet; however we feel we can say that aero-triangulation can be accomplished with convergent photography with no less accuracy than vertical photography, and possibly greater accuracy. We are at present continuing our investigations and hope to make our findings available to the photogrammetric world through papers prepared by our scientists and engineers, to the extent possible in keeping with our policy of not making direct comparisons of competitive commercial equipment.

*Instrumentation for the Integrated Photogrammetric System of the U. S. Geological Survey**†

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IMMEDIATELY after World War II a staff photogrammetry section was set up in the Topographic Division of the U. S. Geological Survey, with the prime objective of exploiting photogrammetry to its fullest through the medium of research. The attack on the problem was made simultaneously on three major fronts—aerial photography, photogrammetric instruments, and techniques and standards. Thus the concept of a "system" was evolved whereby all of the elements required to accomplish the goal of photogrammetrically compiling topographic maps more efficiently were considered as a unit, and the development work on any one element did not proceed until its effect on the system as a whole was determined.

A prime consideration was the basic geometry of aerial photography. For a

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