*A Key Link in the Photogrammetric Chain— The Human Being**†

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ABSTRACT: *Limited to the vertical coordinates of the single, stereoscopic terrain model, this paper presents results from four test projects involving 10 different instrument operators and at least 15,000 independent observations. These results indicate that there is as much difference in accuracy potential among individual operators, as there is among instruments and methods of accepted varying orders of accuracy.*

INTRODUCTION

IN THE relatively brief interval since World War II, unbelievable advances have been made in methods, equipment and materials in the field of photogrammetry. The terrain image passes through a distortion-free, high-resolution lens and is frozen on an extremely stable film. At the instant of the shutter click, electronic data are recorded that will enable the fairly accurate positioning of the camera at its exposure station. The photography is processed with automatic exposure and dodging control. The results are handed to an operator of an instrument capable of being read to a few microns. Electronic computers can process the aerial triangulation operator's automatically recorded readings in almost the blink of an eye.

These strides in methods, equipment and materials are wonderful, but there is a fourth vital link in this chain, the instrument operator himself. What has been done in the same period of time to determine, analyze and remedy his inherent weaknesses?

This paper will: 1) review some basic characteristics of people, 2) summarize the published work on the subject of the stereoplotter operator, and 3) present, and analyze, technical data which will show the variations in results obtained by different operators under otherwise identical circumstances.

Let no one fall victim to the erroneous impression that such a spread in instrument operator results is merely an operational phenomenon of the Army Map Service. In this post WW-II period, hundreds of operators have been graduated to other government and commercial mapping concerns. We are proud to say that this great mass of AMS Alumni now forms the backbone of many a mapping agency.

Although the test data to be used in this paper have been given out previously in Army Map Service Technical Development Reports, they were presented and analyzed only in terms of the vertical accuracy of various stereoplotters in the single-model phase of photogrammetric compilation. Nevertheless, the information was there, as a by-product, to allow a good determination of the spread that can exist among average and above average operators.

Anyone mulling over this mountain of accumulated test data could not help but ask himself the question, "Are we possibly so engrossed in keeping up with and improving technology, that we are overlooking one of the key links in the cartographic chain—people?" Let us briefly refresh ourselves on some general characteristics of people.

PEOPLE IN GENERAL

People. They are here. Within human recollection, they have always been here. They will be here for a long time to come. They have a useable working life of about 50 years. They are made on the open market; they do not have to be amortized—at least by the

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employer, and—they meet all civilian and most military requirements.

They can operate in extremes of heat, cold and humidity that cause equipment to malfunction or break down. They can work in any location:—five miles under water or 200 miles above ground. Indeed, people have compact propulsion, guidance and decision-making systems that are the envy of those who attempt to simulate human functions. And—maintaining their own power supply, they don't have to be plugged in anywhere.

They carry on their own preventive maintenance programs. Moreover, when they do need maintenance (unusual, in the first 20 years of a working life) they take care of it themselves—on their own time. A battery of experts need not stand by to maintain them—and, there normally is no spare parts problem.

There have been rumors that certain supervisors, especially when in the midst of a knotty personnel problem, dream of the ultimate system. In this other world, the supervisor reclines in upholstered luxury, merely pushing the appropriate buttons—which have no feelings, cannot think and therefore do not argue with him. As a result of this button-pushing, conveyor belts carry diapositives in, completed manuscripts out; other gadgetry automatically performs the minor details in-between. This optimum in push-button photogrammetry, unfortunately, is not in the foreseeable future. All planned automated systems will need human operator attention. The difference will be that the human operator will not be as busy as he now is, or should be. Consequently, he will have more time to think up more advanced ways to outwit his supervisor.

On the other hand, there has been considerable progress in the field of automated decision-making. So—perhaps it won't be too long before a machine will review a proposed action, compare it with stored information regarding policy, precedent and regulation and stamp out a decision. If this should come to pass, then perhaps most of us "human" chiefs will be replaced by infallible pieces of hardware, which will theoretically supervise groups of super-operators.

Previous Investigation

Just what have we done to study and improve the human instrument operator? Much has been written concerning the theoretical aspects of stereo acuity. Some of the most extensive writings on the subject, however, seem to have been written, with each oblivious to the existence of the other writings. Moreover, very little published data exist on tests that measure stereoscopic acuity under controlled conditions. I will summarize my background findings.

In 1950, the Research Committee of the American Society of Photogrammetry had a Sub-Committee—on Vision. The report of this Committee, published in the April 1951 issue of PHOTOGRAMMETRIC ENGINEERING,* was as follows, "The Vision Sub-Committee is currently working on the development of a work-sample test which can be administered in a short period of time, and which will permit an objective rating of a multiplex operator's ability. . . . Owing to the time required to coordinate and conduct a test of this nature, it is recommended that the Vision Sub-Committee be retained during the coming year for the pursuance of its objective."

In vain did I search the Research Committee's report, in the following year, for any mention of the continuation of the work of the Sub-Committee on Vision. In fact, it was never mentioned again in an annual report of the ASP Research Committee. These reports, however, were loaded with news of developments concerning more straight-forward and cooperative photogrammetric components: methods, equipment and materials. The study of humans, by humans, and for humans was, perhaps, too discouraging.

Of course, all along, fine papers, primarily on the theoretical aspects of stereoscopic vision, were being printed, e.g., by C. Von Frijtag Drabbe[1] of Holland and W. Wright[2] of the United Kingdom.

The search of the background of this subject turned up several surprises. Perhaps the biggest came while reading the report of W. Radlinski in the June 1957 issue of PHOTOGRAMMETRIC ENGINEERING.‡ The report was entitled, "A Reappraisal of Photogrammetric Research." One part concerned the presentation of a list of research items that the mapping industry felt required the greatest attention. Government and commerical mapping organizations and educational institutions were queried. One government-suggested item concerned, "Hiring and keeping competent personnel." One commercial pro-

* Vol. XVII, No. 2.

[1] Von Frijtag Drabbe, C. A. J., "Some New Aspects in Stereoscopic Vision," *Photogrammetria*, Vol. VIII, No. 4 (1951–52).

[2] Wright, Professor W., "Stereoscopic Vision Applied to Photogrammetry," *The Photogrammetric Record*, Vol. I, No. 3 (April 1954).

‡ Vol. XXIII, No. 4, p. 607.

posal mentioned, "Equipment to do work of remembering and automatically performing duties in order to reduce losses encountered by operator fatigue or normal human shortcomings." That was the extent of the mention of the human being—one of the key links in the mapping chain. Most surprising of all, the educational institutions, whose primary purpose is to improve people, made no mention of the human element whatsoever. Apparently we were going to accept the human being as an inalterable product that must be tolerated for a while yet.

The Army Corps of Engineers took this bull by the horns in April 1956 through the award of a contract to the University of Rochester Institute of Optics. The project was entitled, "Study of Visual Stereoscopic Acuity," and was completed in July 1958. As reported by A. Anson,[3] "The comparison of operator stereoscopic acuity was made under a variety of viewing conditions, chosen as representative of those found in present-day photogrammetric stereoplotting instruments. Thirty observers performed 47,000 stereoscopic elevation readings from which comparisons were obtained." The study involved a consideration of such things as: Comparison of near and far vision, correlation of interpupillary distance to stereo acuity, comparison of illumination intensity, comparison of unbalanced illumination, comparison of the use of transparencies with opaque prints, comparison of color separation to white light, effect of the reversal of color filters, comparison of the color of illumination and relation of resolving power to stereo acuity.

Perhaps the most significant work performed in the area to date is that reported by R. Dwyer, Jr. in an excellent paper published in the September 1960 issue of PHOTOGRAMMETRIC ENGINEERING, under the title of, "Visual Factors in Stereoscopic Plotting." In his abstract, the author stated that, "The human visual system, with all its variables, is an important factor in photogrammetric mapping. This paper discusses the methods and results of a recent research project on this subject, conducted by the United States Geological Survey, Topographic Division, in cooperation with Dr. Wendell E. Bryan, O. D." Mr. Dwyer discussed the following: visual problems of stereocompilers, prescription filters, elimination of constant Y-parallax separation, fixed filter orientation preferences, use of optical loupes, and illumination of stereoplotting rooms.

A survey of the activities of the International Society of Photogrammetry, on matters concerning the human element, was quite disappointing. Only one faint ray pierces the void. Professor B. Hallert, in an article describing, "The Working Group on Fundamental Problems," in Vol. XVII, No. 1 (1961–62) of *Photogrammetria*, made an encouraging statement. In the section on, "The Absolute Orientation and Coordinate Determination," he wrote that there will be tests of operators. Professor Hallert, incidentally, recently worked on a temporary assignment to the Geodetic Intelligence and Mapping Research and Development Agency (GIMRADA), Fort Belvoir, Virginia. Mr. Bodnar, GIMRADA, has informed me that Professor Hallert performed some experiments[4] to determine systematic changes in stereoscopic elevation settings.

In the same issue of *Photogrammetria*, Å. Jonsson outlined, "The Tasks of Photogrammetric Ophthalmology." He divided the subject into three general areas: hygienic questions, interpretation questions and metric questions. He stated his purpose as, "a small attempt to show the multitude of problems and possibilities in the actual field, the following concentrated view is intended to serve as an aid for differentiation at technical discussions, research, and education."

And—bringing our survey up to date, the ASP Research Committee Report of 1961, published in the May 1962 issue of PHOTOGRAMMETRIC ENGINEERING,‡ under "Physiological Investigations" stated:

"a. 'Swedish Royal Institute of Technology—Tests of stereoscopic vision to find possible systematic variations.'

b. 'U. S. Geological Survey, Topographic Division—Investigation of visual fatigue in photogrammetry. Sixty stereo-compilers will be given periodic optometric examinations and will be supplied with special prescription glasses, anaglyphic glasses and optical loupes, as necessary. Other studies will include the effect of scribing on visual fatigue and the effect of lateral and vertical heterophorias on stereo operations. A stereoplotting area will be designed to house 20 to 25 plotting bars operated under optimum ambient illumination levels.'"

As can be seen, the Geological Survey's work is continuing, but an organization of even the size and stature of USGS can hope only to scratch the surface in any reasonable

[3] Anson, A., "Significant Findings of a Stereoscopic Acuity Study," PHOTOGRAMMETRIC ENGINEERING, Vol. XXV, No. 4, p. 557 (September 1959).

[4] Results yet to be published.

‡ Vol. XXVIII, No. 2, p. 316.

period of time. There is plenty of room for others.

THE ARMY MAP SERVICE DATA

The AMS test results, to be presented and analyzed in this paper, are limited to the vertical coordinates of the single, stereoscopic, terrain model. This information was sifted from the results of four projects involving a total of 10 different operators of average, or above average, abilities. A brief résumé of the pertinent data of these four projects follows.

"*Service Test of Stereoplotter, Topographic, Projection Type (Kelsh),*" and "*Evaluation of Balplex Equipment,*" Project Engineer in both cases, D. Coulthart; 6-inch focal-length, Metrogon photography flown at 34,000 feet for the vertical material, 30,000 feet for the 20° convergent material; 55 control points for the vertical double model, 49 for the convergent model; the same four operators for each individual project; one forced substitution in operators between the first and second project. The Balplex Plotter tested had an optimum projection distance of 525 mm.

"*Comparative Evaluation of Stereoplotting Equipment,*" Project Engineer, C. Lawrence; 4-inch focal-length, Aviogon, glass-plate photography flown at 20,000 feet; 49 control points; three different operators.

"*Test and Evaluation of the AMS M-2 High Precision Stereoplotter,*" Project Engineer, D. Coulthart, same photography and control points as for the Comparative Evaluation Project; three different operators.

In all terrain model flatness cases, three independent orientations were made by each operator of each stereo model, and 3 to 4 independent observations were made at each control point. In the model contouring phase, one compilation was made of each model by each operator. The resulting contours were checked by profile lines referred to existing, larger scale maps.

To give you an idea of the magnitude of the work being discussed, the terrain model flatness phase alone involved at least 15,000 independent vertical observations. It would seem that this effort should have provided enough information to arrive at some indication of the variation between operators, since for a given test all other factors were the same.

In TABLE I are listed the projects, by official title, instruments tested, the average results of each operator, the average of all operators for each instrument, and the spread factor, or ratio of the poorest to the best result, for each instrument. I.e., the best Kelsh operator (#3) produced work 1.36× more accurate than the poorest Kelsh operator (#1).

In Table II are shown the results of the contouring phase of the same projects, instruments and operators, this being presented in the same manner as in Table 1. It will be noted that the average of the spread factors is 1.41, as compared with 1.47 obtained in the terrain model flatness phase.

A PRELIMINARY ANALYSIS OF THE DATA

Before attempting an analysis of these data, let us refresh our memories on several important points. In the first place, all operators were certified by their supervisors as being in the average, or better than average, category. Moreover, in the model flatness phase, each operator set up each model three

TABLE I

VERTICAL RESULTS—INDIVIDUAL POINTS*

Project	*Instrument*	*Operator*				*Average*	*Spread Factor*†
		No. 1	*No. 2*	*No. 3*	*No. 4*		
Service Test of Stereoplotter, Topographic, Projection-Type (Kelsh). *Published Dec 55*	Kelsh Multiplex	1/4,750 3,150	1/5,450 3,500	1/6,450 3,600	1/5,900 3,250	1/5,550 3,350	1.36 1.14
Evaluation of Balplex Equipment. *Published May 59*	$Balplex_{vert.}$ $Balplex_{20° conv.}$	3,950 4,900	3,700 3,800	4,600 6,000	4,450 4,850	4,100 4,850	1.24 1.58
Test and Evaluation of the AMS M-2 high Precision Stereoplotter. *Published Jan 60*	M-2	9,100	5,200	12,100	—	7,800	2.33
Comparative Evaluation of Stereoplotting Equipment. *Published Jan 61*	C-8 A-8	6,650 7,700	6,650 6,650	4,650 6,250	— —	5,750 6,900	1.42 1.23
							1.47 Average

* In terms of flight altitude.

† Spread factor = Poorest result / Best result.

TABLE II

CONTOUR RESULTS*

Project	*Instrument*	*Operator*				*Average*	*Spread Factor*†
		No. 1	*No. 2*	*No. 3*	*No. 4*		
Service Test of Stereoplotter, Topographic, Projection-Type (Kelsh). *Published Dec 55*	Kelsh Multiplex	1/4,500 2,750	1/3,750 2,800	1/4,400 2,500	1/3,600 1,950	1/4,000 2,450	1.25 1.44
Evaluation of Balplex Equipment. *Published May 59*	$Balplex_{vert.}$ $Balplex_{20° conv.}$	2,900 4,300	3,750 3,850	4,500 3,950	4,000 7,000	3,700 4,500	1.55 1.82
Test and Evaluation of the AMS M-2 high Precision Stereoplotter. *Published Jan 60*	M-2	4,100	4,050	4,850	—	4,300	1.20
Comparative Evaluation of Stereoplotting Equipment. *Published Jan 61*	C-8 A-8	6,100 3,900	4,350 4,650	5,550 4,650	— —	5,250 4,350	1.40 1.19
							1.41 *Average*

* In terms of flight altitude.

† Spread factor = $\frac{\text{Poorest result}}{\text{Best result}}$.

independent times and repeated his readings on each point 3 to 4 times. An average of his point readings determined his individual point values per setup, and an average of the three setups gave his official values for the model. To a large extent, therefore, random bad readings and an occasional bad setup should have been absorbed.

Although not designed for this purpose, these tests were, nevertheless, ideally suited for a determination of operator variation, since all non-human factors in each test were identical for each operator.

These test results permit making a tentative, 3-way comparison of accuracy: 1) operator spread, to accuracy difference due to method, 2) operator spread, to accuracy difference due to order of instrument, and 3) individual operator results in point reading, to individual operator results in contouring.

A comparison of this operator variation with the spread in accuracy between methods, yields some startling information. E.g., a convergent Balplex model, in the vertical accuracy of individual points, is 1.18× superior to the Balplex vertical model. It will be noted, however, that the operator spread factor (see TABLE I) in the Balplex convergent test is 1.58, while that in the Balplex vertical test is 1.24. Therefore, there seems to be more variation between operators, in this instance, than there is a difference in accuracy obtained from vertical, as compared with convergent photography. It seems that an improvement in operator quality would do more good than this particular significant improvement in stereo model geometry.

A comparison of operator variation, with the spread in accuracy indicated between instruments, yields some equally noteworthy information. E.g., the average Balplex vertical[5] results are 1.22× better than the average Multiplex results. Note, however, that the average of the Multiplex and Balplex (vertical) operator variations and the difference between Balplex and Multiplex accuracy is the same order of magnitude (1.19 as compared with 1.22, respectively).

A comparison, by operator, of the terrain model flatness results with the corresponding contour results, is also very interesting. In the flatness category, the same person is best in the Kelsh and Multiplex phases. Also, the same operator is best in both types of Balplex models. Again, in a third operator group, the same person is best in both the C-8 and A-8 models. In the contouring category, however, there is no such distinct operator supremacy. The honors are distributed over-all. In fact, the relatively poorest Kelsh operator (#1), in the flatness phase, is the best in the contouring phase.

CONCLUSION

A number of conclusions are indicated from the preliminary analysis of this voluminous, yet truly limited, test data:

a. Certain persons have the necessary acuity to consistently read points more accurately than others.
b. Just because a person can read a fixed point very well, does not necessarily mean that he can keep a moving floating mark on the ground equally well. Likewise, the opposite is true, since a poor fixed point reader may be a good "contourer."

[5] Using nominally vertical photographs.

c. There is as much difference in accuracy potential, among individual operators, as there is among instruments and methods of accepted varying orders of accuracy.

Equating these data in terms of an actual job, photography could be flown almost 50 per cent higher for the best, relative to the poorest, operators. This would result in a coverage of about 2.25× more terrain-per-model and result in a corresponding saving in ground-control, photographic processing, aerial triangulation effort and compilation model orientation time.

We have spent millions of dollars to develop new equipment and methods which will permit the photographic aircraft to go up about the order of 50 per cent higher and still retain the same map accuracy. We have done this because anything that will permit such an increase in photographic ceiling would certainly be a breakthrough. *On the other hand, what have we done to raise the technical level of our people?* Have we made an effort somewhat comparable to that which we have made on our hardware and methods?

The answer, of course, is that *we have sadly neglected the human field.* What we have done is pitiful by comparison with our expenditure on the inanimate components. I believe that, in order to stimulate work in this area, and to make any appreciable headway in the foreseeable future, a comprehensive program should be set up involving a group of mapping agencies, preferably on an International scale. I suggest that the International Society of Photogrammetry set up a group to conduct an International program in this field of "Photogrammetric Ophthalmology."

I hope that my presentation of these test data has helped to emphasize the magnitude of the human problem; also that, in so doing, this paper will not only encourage the dedicated few to continue their efforts, but also induce others to enter this vital, yet wide-open, field. It is a wilderness of undeveloped potential. It is photogrammetry's "depressed area."

Half-Base Convergent Photography

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TO PROPERLY introduce the technique of half-base convergent photography and its attendant parameters it is appropriate to clarify the meaning of the term by describing the basic photogrammetric instrumentation and geometry. The half-base system is a modification of the "standard" convergent system presently used by the U. S. Geological Survey, uncomplicated in execution, yet showing favorable promise toward enlarging the scope of application of the convergent system in mapping operations.

The successful development of the ER-55 projector (recognized by some of you as the Balplex) with its built-in capability for the Scheimpflug accommodation gave impetus to the use of convergent photography within the Geological Survey. The "standard" convergent system, as adopted by the Survey, utilizes a twin-camera couple arranged so that each camera axis is in the plane of the flight line and is inclined 20 degrees with respect to the vertical. Two simultaneous photographic exposures at each camera station, one pointing forward, and the other to the rear, provide this system with a tremendous advantage over vertical photography in terms of total angular coverage and resultant area coverage. Each stereomodel is composed of the forward-looking exposure from one station paired with the backward-looking exposure of the succeeding station. By virtue of the larger base-height ratio inherent in this system the accuracies of vertical readings are improved relative to those derived from conventional vertical models of comparable flight-height photographs. The base-height ratio adopted for the "standard" convergent system used by the Topographic Division of the U. S. Geological Survey is 1.23.

The standard convergent system just described has proved to be efficient, economical, and practical, yet circumstances arise that force project planners to avoid its use. Areas of extreme topographic relief and/or heavy timber cover have been the most common deterrents to the universal application of the standard convergent system. In circumstances where severe relief is prevalent, the extremes of perspective viewing in stereo-