UNITED STATES AND INTERNATIONAL METHODS OF COMPARING ACCURACY OF PHOTOGRAMMETRIC INSTRUMENTS

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As WE are a technical group discussing accuracy of photogrammetric systems, I believe it appropriate to draw renewed attention to the fundamental way the accuracy of a map is specified. Map users are primarily interested in the accuracy of the final map produced to a desired specification; but they are not necessarily interested in the instruments or organization which produced the map. The vertical and horizontal positions for all ground points can be checked in a random manner in the field, to any degree decided upon. The number of points checked is limited only by the cost of an independent field check. Each of the points checked against its true position is in error from its horizontal or vertical position by an amount known as its error or deviation. A curve can be drawn by plotting the number of measured ground points, randomly selected, having the same error, against the amount of this error; this is the usual error function curve with which most surveyors are familiar. Two such curves, one for vertical and one for horizontal positions of these points, are the most exact and only complete way to state the accuracy of a completed map applicable to all points. Methods of obtaining an error distribution curve with a minimum number of field check points is a separate subject of recognized economic importance, but beyond the scope of this paper. It involves, among other factors, the method of least squares.

Consequently, each error distribution curve is a true statement of the accuracy of a map; one for the vertical points, another for the horizontal points. For simplicity of discussion, my remarks will be confined to vertical accuracy, which is usually less than horizontal accuracy in photogrammetric systems using wide-angle (90°) vertical photography, but the remaining remarks parallel those applicable to horizontal accuracy.

As an error distribution curve cannot be described in a word or two, it is common practice among engineers and mathematicians to recognize the fact that this error distribution curve has a characteristic shape that is fixed. By stating the properties and value of one point on this curve, and by giving it a technical name, the entire curve is usually defined in engineering practice by a number and a name. Different points on this curve have been given different names; but for each named point the value of the error is defined, and the percentage of measured points having errors greater or less than this point, is known. In the tabulation, we have listed the common names given these points by mathematicians, engineers, or photogrammetrists. Also listed is the magnitude of the error or deviation related to this name. The value of the error has been listed in two ways: in terms of standard error familiar to mathematicians and engineers, and in terms of height-accuracy factor. For this table the particular factor of $\pm H/3{,}000$ was selected as an example, to be equal to the unit standard deviation for comparison proposed. The height-accuracy factor is a term familiar to photogrammetrists. In the table, percentages are stated to three significant figures.

A good reference among many available for the mathematical values of this table is *Advanced Mathematics for Engineers* by Reddick & Miller.[1]

Having set up this tabulation, let us look at the conclusions that can be

[1] Reddick & Miller. *Advanced Mathematics for Engineers*, John Wiley & Son, 1938, Sec. 88–90.

made. In International photogrammetric writings, most authors when discussing accuracy, have apparently used the standard error or deviation in specifying the accuracy of their maps, which means, as we see from the table, that only 68% of the points are less than this error, and 99.7 of the points are just within 3× this value. This is also common practice among ground surveyors in this country. In the U.S. and Canada, photogrammetric references to accuracy in photogrammetric literature have been usually to that factor which shows 90% of the points to lie within plus or minus one-half the counter interval, listed in the table as one-half the U.S. Photogrammetric Error; and 100%[2] of the points within plus or minus one contour interval, an error equal to the U.S. Photogrammetric error.

In International writing, for example, one would say of the accuracy from this tabulated example of an error curve for a particular map, "You see all of

Name of Error or Deviation	*% of Points Below Error*	*Error in Terms of Standard Deviation*	*Height Ratio Factor*
Probable Error	50.00	±0.66	±H/4,500
Mean Square Error / Std. Deviation ($n \gg 1$) / International Map Error	68.3	±1.00	±H/3,000
Mean Error	78.9	±1.33	±H/2,250
½ U.S. Photogrammetric Map Error	90.0	±1.66	±H/1,800*
2×Std. Error	95.1	±2.00	±H/1,500
3×Std. Deviation	99.7	±3.00	±H/1,000
2×U.S. Map Error / C-Factor	99.9	±3.33	±H/900

* Note—The total error *spread* is commonly known as the C-factor or H/900.

the vertical points measured, have a standard deviation of H/3,000, where H is the flying height." In reporting the same accuracy in an American publication, one would say "90% of the points lie within an error ±H/1,800 and 100%[2] lie within a total error of ±H/900, which error we call the C-factor." This latter statement gives a more exact picture to the engineer with limited training, but leaves an impression of lesser accuracy.

The one recent exception to this rule in the PHOTOGRAMMETRIC ENGINEERING journal is a paper by Mr. Cottrell on the Stereoplanigraph in which paper, it is believed, he uses twice the U.S. standard photogrammetric error. So when he refers to ±H/2,500 for the Stereoplanigraph, he is speaking of H/1,250 in terms of the U.S. standard error or C-factor.

I should like to take this opportunity to apologize to our good friend Mr. Saralegui from the Argentine, for not making clear to him during his recent visit to the United States, this difference in methods of stating map error. In his letter read to us last year,[3] he apparently used a method of stating error in

[2] This figure to be technically correct should be 99.9%.

[3] PHOTOGRAMMETRIC ENGINEERING, March 1950, Vol. XVI, No. 1, p. 128.

the usual International manner of plus or minus the standard deviation. He was apparently confused by the fact that in the United States we use C-factor, which is about three times the standard deviation, and was the figure he used as his basis of comparison when using War Department Manual TM 5-244 as a reference. Thus we see that *an accuracy "C-factor" of H/900 in this country's photogrammetric terminology is equivalent to an accuracy factor of H/3,000 as used in the International photogrammetric terminology.* This difference should help to clarify some of the misunderstanding among those readers who are confused by such claims as the Stereoplanigraph or Poivilliers or Wild A-5 being three times as accurate in vertical mapping as Bausch & Lomb Multiplex system of mapping. Comments from Dr. Hugo Kasper, who has written privately on this subject, as well as from Mr. Saralegui would be most welcome regarding the difference between the "plus or minus" standard error or deviation as used in Europe, and standard mapping error as used in the U.S. It is apparently a coincidence that both men use as a basis for comparison a factor of 3 times, which is approximately the difference between the two ways of stating map accuracy. I hope that all photogrammetrists will take time to understand these differences, since such action should aid in clarifying past and future technical publications on this subject.

With this error curve generally understood, and used as the engineering basis for true measurement, there are other clear quantitative answers which are needed for each system of mapping; for example, how much improvement in a particular map accuracy curves can be expected, if all other factors are held constant in a particular system,

a) If the average value of distortions in a system is reduced to one half the present values?
b) If the final compilation scale of a system of the mapping is doubled?
c) If the resolution in the final projected images of a system is doubled?
d) If the contrast (or illumination) in the final projected image is doubled?
e) If convergent photography is used and the base-height ratio is doubled?

Controlled experiments, to answer questions of these types under map production conditions, are now needed to establish their effect quantitatively. (Graduate students please take note.) Qualitatively we all know that improving distortion, resolution, contrast, and scale in some cases improves accuracy—but how much and how little? Once these questions are answered quantitatively, then the economic effect can be evaluated.

As manufacturers of photogrammetric equipments, we at Bausch and Lomb must depend on statements of accuracy of equipment based not on one experiment, or by one organization, but on the statistical average of results of all systems stated to us, privately, and in trusted confidence, by national as well as international photogrammetrists, and on observations by us in visits to various mapping organizations here and abroad.

It is well to note the particularly important observation that all systems tend to perform better over well developed areas. Since most areas in Europe are intensively developed, we would expect reports of higher accuracy from there using any particular system. Also in the United States considerable 2, 5, and 10 foot contour map work is on developed areas, and consequently well delineated terrain. So a higher accuracy would be expected than the 20, 50, and 100 foot work over undeveloped terrain. Also most 2, 5, and 10 foot work is being accomplished by small, closely organized groups, whereas 20, 50, and 100 foot work is carried on by larger organizations. This latter situation apparently makes a difference in results, due to control of all factors in their statistical effect.

These comments are primarily made to encourage quantitative discussions where possible, instead of the usual qualitative discussions of the past. I trust that frankness in this matter offends no one, as many of our friends, both here and abroad, agree that this situation needed clarification.

Moderator Sharp: Our next speaker is Mr. Leon T. Eliel.

Mr. Eliel is well known to practically all of us. I personally have had many contacts with him and have received a great part of my photogrammetric education from and through him.

The title of Mr. Eliel's talk today is "How to Build a Dam." I didn't know that photogrammetrists were going into the building of dams, but Mr. Eliel has ventured to investigate that subject and will present it today. I am interested, as I know you are, to learn how he built a dam.

HOW TO BUILD A DAM

Leon T. Eliel, Fairchild Aerial Surveys, Inc.

IN BUILDING a dam one is faced with a choice of equipment. It is not unlike the choice of equipment confronting the photogrammetrist who wants to build a map. Because you are all familiar with photogrammetry, I will discuss the choice of equipment for building a dam in terms of corresponding photogrammetric problems.

If you build only a very small dam and infrequently, you would be wise to minimize your capital investment through using a wheelbarrow to haul in your cement, sand and stone. Then you could mix these in a board box with a hoe, and carry the water in a bucket. It would take a long time to do the job even though it is a small one, but it would be cheaper than buying a lot of mechanized equipment and hiring experts to run it. And when you get through you will have just as good a dam as it is possible to build.

This approach is like building a map with a Stereocomparagraph or a Contour Finder. It may be smart for an occasional small job. You can put in lots of ground control—perhaps ten or twenty points per model. Anybody who can run a wheelbarrow ought to be able to run a Stereocomparagraph, and the final product can be all right. And you have practically no money tied up in equipment.

If you build a larger dam, and think you might use the equipment you are going to buy every now and then on other projects, you would be wise to buy a small truck, perhaps a half-ton pickup. Also a small concrete mixer. Of course you will make an awful lot of trips in that little truck, and the concrete mixer will have to work hours and hours. If you want to build the dam in a hurry you will have to get dozens of these little half-ton trucks and mixers. But each unit is pretty cheap, and when you finish you will have as pretty a dam as anyone would ever want.

The preceding is something like using KEK or Wernstedt-Mahan plotters. Their cost is comparable to that of the pickup truck. While the capacity per machine is pretty small, you do get the map made. The low C factor, like the carrying capacity of the pickup, requires a lot of loads or models per map. The total labor is much greater although the investment in equipment is nominal.

If you have to build a pretty big dam, you might go in for two-ton trucks and fair-sized concrete mixers. You might even get a truck and a string of