*Possibilities and Limitations for Elimination of Distortion in Aerial Photographs**

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EDITOR'S NOTE: Methods, consequences and obtainable results in the various plotting instruments are discussed in the paper published in *Photogrammetric Record*. The effect of not completely eliminated distortion or other radial displacement on mapping or aerial triangulation is demonstrated. The various lenses, aerial survey cameras and plotting instruments are considered. Effects on distortion, such as camera calibration, different wavelengths, temperature, flatness of negative plane, etc. are treated. Finally, consequences for elimination of the distortion are indicated for various procedures and cases by means of graphs, lists and tables.

SUMMARY OF A PAPER PUBLISHED IN PHOTOGRAMMETRIC RECORD
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A GREAT variety of items cause radial displacements in the sense of errors. The complex subject is generally headed under "distortion." The paper was an attempt to deal with all sources which are to be considered if one really wants to eliminate all "distortion." The following is little more than a list of the headings of the original paper, which contains 39 figures and 3 tables.

1. DISTORTION AS SUBJECT OF INTERIOR ORIENTATION

It should be borne in mind that distortion actually is an angular value. Four alternative equations defining distortion are given—two for distortion as a variation to the principal distance and two for distortion as radial displacement.

2. ORIGIN OF DISTORTION; FACTORS CONTRIBUTING TOWARDS ELIMINATION OF DISTORTION AND ACCURACY OBTAINABLE

2.1. *Distortion from camera calibration.*
Distortion should be determined while taking a photo, that is with the camera in action. The goniometer method is not so favorable.

2.2. *Limitations in the manufacturing process.*
Any lens, although its design may be identical with the design of others of the same type, has its unique characteristic distortion pattern. Lenses with asymmetric distortion should be rejected. An elimination of distortion should be based on the distortion pattern of a particular lens. Distortion patterns of particular categories or makes of lenses, such as The Metrogon or The Aviogon, may be of theoretical interest as representing the intentions of the lens designer or the mean results from a number of lenses, but have little practical value.

2.3. *Effect of different wavelengths.*
Distortion should be determined photographically and with the emulsion which is most likely to be used later in productive work.

2.4. *Effect of different diaphragms.*

* The complete paper was originally published in the *Photogrammetric Record*, and was later reprinted by John Wright & Sons Ltd., The Stonebridge Press, Bristol. It is suggested that anyone desiring a copy of the complete paper write to the author.

2.5. *Effect of temperature.*
Can possibly be considerable.

2.6. *Alteration of distortion due to wear.*
The distortion for any lens should be checked at regular intervals.

2.7. *Flatness and alteration of image plane.*
Datas are communicated. Effects are listed for 12 different cases of combinations for the unit instrument-film-diapositive glass plate. As an example, we read for the Kelsh Plotter: Effective are unflatness of negative plane and diapositive plate, irregular film shrinkage.

2.8. *Refraction and curvature of earth.*
Becomes effective for 6 inch photography at flying height 10,000 ft. Datas are communicated.

2.9. *Accuracy of plotting instrument.*
Accuracy for determination or elimination of distortion should be higher than the accuracy attainable in the restitution instrument.

2.10. *Effect of point of symmetry, fiducial marks and calibrated focal length.*

2.11. *Other determinations of distortion.*
The most advantageous method is to determine the "distortion" by taking a photo of a test field with a number of accurately coordinated points from that flying height which is used later when carrying out the flight mission. Any correction device for "distortion" should be based on a distortion curve obtained this way.

3. METHODS FOR ELIMINATION OF THE DISTORTION

Various methods are treated and attainable accuracy is discussed for the following categories.

3.1. *Porro-Koppe.*

3.2. *Correction Δf to plotting principal distance.*

3.2.1. Applied to image point.

3.2.2. Applied to projection center.
The unfavorable situation in the Kelsh Plotter is analyzed in some detail.

3.2.3. By means of an irregular surface.

3.3. *Compensation plates.*

3.4. *Use of diapositives which have been given a desired distortion.*
This is actually the most favorable treatment and can be recommended best.

3.4.1. Obtained by a projection printer.
An aspheric compensation plate can be used to vary the distortion. This system is applied by Wild, Zeiss and others in their respective instruments. The method is best suited for most efficient photogrammetry.

3.4.2. Pressure plate in the aerial survey camera used as compensation device.

3.4.3. Application of two Porro-Koppe cameras as projection printer unit.

4. MEANS APPLIED AND ACCURACY OBTAINABLE FOR ELIMINATION OF THE DISTORTION

This section deals with the actual treatment of the elimination of the distortion in almost all instruments. The pros and cons are considered. Many hints are given for achieving best results.

4.1. *Stéréotopographe BP Poivilliers, Thompson Plotter, Nistri Fotobeta.* The most precise system is applied at I.G.N. in Paris.

4.2. *Wild instruments.*

4.3. *Stereoplanigraph C8.*

4.4. *Kelsh Plotter.*
This is dealt with in much detail. There should be avoided, anyhow, the use of diapositives with emulsion up in the instrument. Best solution for this instrument

TABLE 1

Lens	*Maximum error*			
	Neat model		*Total model*	
	°/₀₀ *h*	*h* = *6,000 ft.*	°/₀₀ *h*	*h* = *6,000 ft.*
Metrogon	.80	5.3 ft.	1.60	10.7 ft.
Planigon	.30	2 ft.	.44	3 ft.
Aviogon	.20	1.3 ft.	.24	1.6 ft.
Pleogon	.05	.3 ft.	.10	.7 ft.

would be use of diapositives which had been given a desired distortion (see section 3.4.1.).

4.5. *Multiplex (Balplex).*

4.6. *Santoni instruments.*
The advantage is that a photogrammetrist can grind for himself the proper compensation cam.

4.7. *Stéréotopographe D.*

4.8. *Analytical photogrammetry.*

5. EFFECT OF INCOMPLETELY ELIMINATED DISTORTION OR OTHER RADIAL DISPLACEMENT ON MAPPING OR AERIAL TRIANGULATION

5.1. *Range of distortion.*
It is possible to distinguish between four different classes of lenses:
a) Topogon-type lenses (Metrogon, S.O.M. Aquilor, Williamson-Ross, Nistri-Riegel), distortion ranging between $\pm 100\ \mu$.
b) Planigon lens, distortion ranging between $\pm 20\ \mu$.
c) Wild lenses Aviogon and Aviotar, distortion ranging between $\pm 10\ \mu$.
d) Zeiss lenses Pleogon and Topar, distortion ranging between $\pm 5\ \mu$.
Figures 33–36 of the original paper contain contour line charts for each class from which the height error, of any point in the model, due to not eliminated distortion, can be derived. TABLE 1 provides some numerical values.

5.2. *Metrogon photography.*

5.3. *Planigon photography.*

5.4. *Aerial triangulation.*
It is suggested that an affinity in distortion has no effect on aerial triangulation.

6. CONCLUSIONS

6.1. *Factors to be considered when eliminating "distortion."*
TABLE 2 reviews the tolerances of the various items.

6.2. *Uncontrolled sources.*
Irregular film shrinkage; unflatness of diapositive glass plates; unflatness of negative or positive plates caused by developing; different temperatures.

6.3. *Sources to be avoided.*
Asymmetrical distortion; unflatness of suction plate; improper functioning of suction.

6.4. *Controllable sources.*
Camera calibration should be done photographically within a tolerance of $6\ \mu$; calibration should be checked at regular time intervals; distortion of the lens in question should be eliminated; earth curvature and refraction must be considered.

TABLE 2

Paragraph	*Subject*	*Radial displacement*		
		Standard deviation	*Maximum value*	*Maximum spread*
		μ		
2.1.	Calibration, with collimator	2	3	6
2.1.	Calibration, with goniometer	1	2–5	5
2.2.	Asymmetrical distortion	3– 5	10	20
2.2.	Various lenses of same type	5	10	20
2.2.	Various lenses of same type	7– 5	15	30
2.3.	Different wavelengths	4	—	15
2.4.	Different diaphragms	—	3	6
2.5.	Different temperature	—	5	10
2.7.	Unflatness of suction plate	4.5	—	12
2.7.	Unflatness of best glass plates	—	—	10
2.7.	Unflatness of glass plates, due to developing	—	—	25
2.7.	Unflatness of diapositive glass plates	—	—	25
2.8.	Earth curvature, $h=3,000$ ft.	—	—	7
2.8.	Earth curvature, $h=24,000$ ft.	—	—	58
2.9.	Accuracy of plotting instruments	5–10	20	40
4.	Compensation device in plotting instrument	2– 5	—	25

6.5. *Desirable treatment.*

"Distortion" should be determined under flight conditions (section 2.11.) and treated with a projection printer (section 3.4.1.). Proceeding that way, residual "distortion" can possibly be kept within the $\pm 5\ \mu$ belt.

*Raw Material Storage Volumes by Photogrammetry**

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(*Abstract is on following page*)

GROUND METHODS

THE most common bulk material of which the volume must be determined periodically is stock-piled coal used for power generation. However, other materials stored in bulk piles include fertilizer, iron ore, limestone, sawdust, sand, and pulpwood. These piles range in size from 30 feet to 80 feet in height and from 125 feet in width to 3,000 feet in length. Early methods of measuring

* This is a slight revision of the prize-winning papers submitted in competition for the Bausch & Lomb Photogrammetric Award in 1959.