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TECHNICAL LETTER NASA-79

RESOLUTION STUDY

By

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and
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U. S. Geological Survey, Topographic Division
Washington, D. C.

March, 1967

Prepared by the Geological Survey for the National Aeronautics and Space Administration (NASA) under NASA Contract No. R-09-020-024 (Geography and Cartography Program)

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UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
WASHINGTON, D.C. 20242

Technical Letter
NASA - 79
March 1967

RETURN TO:
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Dr. Peter C. Badgley
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Washington, D. C. 20546

Dear Peter:

Transmitted herewith is one copy of:

TECHNICAL LETTER NASA-79

RESOLUTION STUDY*

by

Robert H. Nugent**
Hugh B. Loving***

Sincerely yours,

William A. Fischer
Research Coordinator
Earth Orbiter Program

*Work performed under NASA Contract No. R-09-020-024 (Geography and Cartography Program)
**U.S. Geological Survey, Topographic Division, Washington, D.C.
***From report compiled by Hugh B. Loving, Topographic Division, U.S. Geological Survey

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

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RESOLUTION STUDY

1. INTRODUCTION

This is a study of the effect of resolution on the cartographic information that may be obtained using conventional stereoplotters with photographs taken at orbital heights.

Basic to the quality and extent of cartographic information that can be obtained from a sensor system is the ability of the system to record or define the smallest possible size details. For cartographic use, the most valuable sensor is the photographic system, and a key component of this system which largely determines its capability to record fine detail is the lens/film combination. The performance of this combination is expressed in terms of resolution. Resolution of the input imagery is an important factor in the analysis of a photogrammetric system, especially a system using space photography.

As the stereoplotting instrument is an integral part of the total photogrammetric system, its limitations must be considered when studying the capabilities of the total system. The performance of a stereoplotter can be expressed in terms of its height-measuring capabilities.

Therefore, in this study, the effectiveness of various photogrammetric systems was analyzed on the bases of static film resolution and height-measuring capability of stereoplotters. The results of this analysis are summarized in the enclosed chart (Appendix 1).

2. BACKGROUND

2.1 Definitions

The following terms used in this study are defined to assist the reader in understanding the procedure and to clarify the results listed in the accompanying chart. Many of the definitions are written in context with this particular study and should not be construed as classic definitions accepted by the photogrammetric community.

Resolution is the minimum center-to-center distance between two adjacent discernible features, or the minimum size of a feature on imagery produced by a sensing system. For photography, this distance is usually expressed in lines per millimeter recorded on a particular film under specific conditions.

Static film resolution of a system is a value representing the maximum number of lines per millimeter recorded on the film under laboratory conditions.

Theoretical ground resolution is the size of the smallest object that would be recorded by a sensing system of a given static film resolution if the imagery were not affected by factors introduced under operational conditions; that is, it is the distance on the ground represented by one line pair.

Theoretical contour interval is the minimum contour interval that can be practically measured based on the theoretical ground resolution only.

Theoretical C-factor is the ratio of the flight height to the theoretical contour interval.

Instrument contour interval is the value of the contour interval as represented at the instrument scale.

Base-height ratio is the ratio between the air base or distance between successive exposure stations and the flight height.

Instrument system C-factor is the ratio between the flight height and the minimum contour interval which can be drawn from that height with a particular instrument system. In operational mapping this is affected by the photographic conditions, personnel involved in the plotting, and condition of equipment.

Model scale is the scale at which the stereoscopic model is viewed in a double-projection instrument.

2.2 Approach

The known static film resolution produced by various photographic systems is used as a basis for comparisons in this study. In order that the performance of each system can be equally compared, two rationale are assumed: 1) all photographic systems have geometric fidelity equal to that of a metric camera; and 2) ground resolution deteriorates uniformally as the flight height increases. Utilization of these two rationale will support formulation of logical conclusions, even though the scope of this investigation is limited.

The measuring capability of a double-projection plotter with a 6-inch principal distance and a 760-mm projection distance is used as a basis for evaluating the performance of compilation instruments. Because of the known capabilities of this type of plotter, more valid extrapolations regarding the use of orbital-height photographs can be made.

Because 12- and 24-inch-principal-distance plotters are believed to be the most efficient instruments for compiling with 12- and 24-inch focal-length photographs, the capabilities of these plotters have also been considered in this study.

3. PROCEDURE

The average static film resolution in lines per millimeter are listed as known data for various state-of-the-art lens/film combinations. The theoretical ground resolution is computed by converting one line pair at negative scale to feet or meters on the ground. This value represents the size of the smallest object which can be accurately discerned. Five times the theoretical ground resolution is considered to be the minimum contour interval (theoretical contour interval) which could be accurately drawn. This is a reasonable assumption based on the absolute accuracy obtainable with photogrammetry assuming adequate height measuring capability. Yet it is conservative enough to allow for human factors which tend to reduce the precision of photogrammetric measurements. The theoretical C-factor is computed by dividing the flight height by the theoretical contour interval, and the instrument contour interval is the value of the theoretical contour interval at the model scale of the stereoplotter.

4. RESULTS

Appendix 1 shows the results of this study. A significant item is the small instrument contour interval which would result from the use of photographs taken at 200 km. with a 24-inch-focal-length camera giving 1.6-M ground resolution. The resulting 0.122-mm instrument contour interval is smaller than the practical minimum for present photogrammetric stereoplotters. A minimum instrument contour interval of approximately 0.45 mm is necessary for accurate plotting based on previous tests. Parallel situations develop for photographs taken at 200 km with a 24-inch camera giving 3.3-M ground resolution and for photographs taken at 80 km with a 12-inch camera giving 1.75-M and 3.5-M ground resolution. In each case an instrument contour interval is selected which would be feasible for compilation purposes.

5. DISCUSSION

5.1 Mathematical Approach

A mathematical approach which emphasizes the mean square error in measurements of parallax in the image plane and gives reasonable correlation with the theoretical-ground-resolution approach is as follows:

MATHEMATICAL DERIVATION OF EXPECTED ACCURACY (ROOT-MEAN-SQUARE ERROR) IN DERIVED ELEVATIONS USING PROPOSED SYSTEMS AND DESIGNATED VARIATIONS

$$u_H = \frac{2u_o Z^2}{Bf} (4.35 - 1.25N + 0.375N^2 - 0.0625N^3 + 0.015625N^4)1/2*$$

where u_H = Expected elevation accuracy (root-mean-square error)

u_o = The accuracy (mean-square error) of the measurement of parallax in the image plane. The value of u_o is in the order of 0.01 mm in modern photogrammetric systems of average precision (0.005 mm in highly precise systems). For this study a figure of 0.0075 mm will be used.

Z = H = Average flight height above ground.

B = Average length of aerial base.

N = Number of models

f = Principal distance of the camera

*(The formula for determining the expected accuracy in derived elevations of aerotriangulated points is from "Studies in Spatial Aerotriangulation" by Professor H. M. Karara, University of Illinois Bulletin, August 1963.)

National map accuracy standards specify that 90% of well defined points must be correct within one-half contour interval. Since 90% of the values in a normal error distribution lie within 1.65 standard deviations, the indicated allowable contour interval is equal to twice the product of 1.65 and the standard deviation. In this case the root-mean-square error is the standard deviation.

5.2 Evaluation of results

The contour intervals which would be feasible from a mathematical approach and the contour intervals developed from the theoretical-ground-resolution approach are compared in the table below to show the correlation between the two methods. A base-height ratio of 0.63 is used for the computations.

Flight Height	Expected Elevation Accuracy (RMSE)	CONTOUR INTERVALS	
		By Mathematical Approach	By Theoretical-Ground-Resolution Approach
24,000 ft.	8.0 ft.	26 ft.	20 ft.*
120,000 ft.	40.0 ft.	132 ft.	80 ft.*
80 km	13.1 M	44 M	36 M
200 km	16.4 M	55 M	66 M

Table 1. Contour intervals based on the mathematical approach and the theoretical-ground-resolution approach.

*This is in agreement with the empirical value.

The figures shown in this table, although theoretical in nature, are based on extrapolations from long-term production results with 6-inch plotters and can be used to evaluate space photography for cartographic applications.

In this theoretical context we can consider a direct-projection plotter which has a 24-inch principal distance and a 10-foot projection distance. According to the theoretical-resolution approach such a plotter would have an 8-meter contour-interval capability with 200 l/mm resolution and a flight height of 200 kilometers; by the mathematical approach this system would be capable of measuring within a standard deviation of 3.65 M and would be appropriate for drawing 12 meter contours.

5.3 Format

It is not the intent of this limited study to set up specifications for compilation plotters but the format requirements necessary for optimum results for 24- and 12-inch-principal-distance projectors under the conditions set forth in the chart should be of interest. The 24-inch principal distance plotter would need a 36-inch-long format and the 12-inch principal distance plotter would require an 18-inch format to maintain strong intersection of conjugate image rays (B/H = 0.63) in the stereomodel.

5.4 Planimetric Compilation

Another restricting factor that must be considered in medium-scale mapping is the so called P-factor. In the U.S. it is necessary with the 6-inch mapping cameras presently in general use to confine flight height to 15,000 feet or less in the eastern areas and to 18,700 feet or less in the western areas in order to be able to interpret planimetric detail for 1:24,000-scale mapping. If 6-inch photographs taken from a mean altitude of 16,500 feet is considered to be a requirement for planimetric compilation, a theoretical ground resolution of 2.75 feet is needed. The theoretical ground resolution of photographs taken from an orbital height of 200 km with a 24-inch focal length camera system capable of resolving 200 lines per millimeter is computed to be 5.25 feet. Therefore, such photographs would not be suitable for 1:24,000-scale compilation of planimetry.

6. CONCLUSIONS

It is obvious from this study that longer-principal-distance plotters offer advantages over the standard 6-inch-principal-distance plotters in producing larger model scales and smaller-contour-interval capabilities. With a 24-inch principal-distance plotter it is feasible to compile 30-meter contours from 200-km earth-orbital photographs taken with a 24-inch metric camera system delivering a resolution of 100 lines per millimeter or more. However, due to the small model scale and insufficient resolution, this system would not be conducive to accurate 1:24,000-scale mapping. But it should be adequate for compiling 1:250,000-scale and possibly 1:62,500-scale maps.

In the lunar case it is feasible to compile 25-meter contours from photographs taken with a 12-inch-focal-length metric camera provided that a minimum resolution of 75 lines per millimeter is obtained. Resolution greater than 75 lines per millimeter will not increase the minimum-contour-interval capability because of the small instrument scale.

7. RECOMMENDATIONS

In view of these conclusions it is recommended that further studies be made of compilation instrumentation with the goal of solving the scale problem presented by orbital photography so that maximum benefits may accrue from its utilization. It is further recommended that every effort be made to obtain 24-inch photographs from earth-orbital heights exposed under optimum conditions so that system-performance capabilities for cartographic applications may be determined from an analysis of the actual system product.

CONTOUR INTERVAL STUDY
Based on Static Film Resolution

	CAMERA/FILM DATA					STEREOPLOTTER PARAMETERS AND ASSOCIATED DATA						
	Flight Height[2]	Focal Length	Negative Scale	Static Film Res. (Neg.Scale)	Theo. Gr.Res.	Theo.C.I.=5X Theo.Gr.Res.	Theo. C-Factor	Instru. C.I.	Recom'd C.I.	Instru. C-Factor	Model[3] Scale	P.D. of Plotter
KNOWN PARA. Contour Info.	12,000'	6"	1:24,000	40	2'	10'	1,200	.63mm.	10'	1,200	1:4,800	6"
	24,000'	"	1:48,000	40	4'	20'	1,200	.63mm.	20'	1,200	1:9,600	"
	120,000'	"	1:240,000	50	16'	80'	1,500	.51mm.	80'	1,500	1:48,000	"
EARTH MODE Contour Info.	200 km.	24"(.61m.)	1:328,000	200	1.6m.	8m.	25,000	.122mm.[1]			1:65,500	24"
	"	" "	"	"	"	"	"	.457mm.	30m.	6,700	1:65,500	"
	"	" "	"	50	6.6m.	33m.	6,000	"	120m.	1,700	1:262,000	6"[4]
	"	" "	"	100	3.3m.	16m.	12,500	.244mm.[1]			1:65,500	24"
	"	" "	"	"	"	"	"	.457mm.	30m.	6.700	1:65,500	24"
	"	" "	"	25	13.2m.	66m.	3,000	.457mm.	120m.	1,700	1:262,000	6"[4]
MOON MODE Contour Info.	80 km.	12"(.305m.)	1:262,000	150	1.75m.	8.75m.	9,200	.167mm.[1]			1:52,500	12"
	"	" "	"	"	"	"	"	.476mm.	25m.	3,200	1:52,500	12"
	"	" "	"	75	3.50m.	17.5m.	4,600	"	50m.	1,600	1:105,000	6"[4]
	"	" "	"	"	"	"	"	.334mm.[1]			1:52,500	12"
	"	" "	"	"	"	"	"	.476mm	25m.	3,200	1:52,500	12"
	"	" "	"	37	7.1m.	35.5m.	2,250	"	50m.	1,600	1:105,000	6"[4]

1/Not considered an adequate instrument contour interval

2/All data relates to photography having a B/H = 0.63

3/Each instrument is considered to have capability for 5X magnification of negative scale

4/Original photographs reduced to a focal length equivalent to the principal distance of the plotting instrument