Introduction

The Manual of Photogrammetry defines photogrammetry as, “the art, science, and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring, and interpreting photographic images and patterns of electromagnetic radiant energy and other phenomena.”

Land surveyors are primarily concerned with the photogrammetric applications involving aerial photography used for topographic mapping, including the ground location of physical objects, lines and points, and the determination of earthwork quantities.

The Land Surveyors Act includes within the definition of surveying practice the determination of the “configuration or contour of the earth’s surface or the position of fixed objects thereon” by photogrammetric methods. Land surveyors must be able to use the basic principles of photogrammetry necessary for flight and ground control planning to ensure that photogrammetric projects will meet National Map Accuracy Standards or other project-specific standards.
Performance Expected on the Exams

Change scales given as a ratio to scales given in ft per in. Explain the difference between large- and small-scale mapping.

Calculate the flying height necessary for a given photo scale.

Explain the concept of C-factor.

State National Map Accuracy Standards.

Given required mapping scale, contour interval, and project limits, determine the most efficient flight plan and ground control net for a photogrammetric project.

Key Terms

Focal length Neat model
Fiducial marks Overlap
Negative format Sidelap
Photo scale Ground control
Map scale Premark
Contour interval Flight line
Large scale Crab
Small scale Stereovision
Ratio scale Block
Flight height Halation
C-factor Spot elevations
Terrain height Plannimetrics
Datum height Areotriangulation
Base sheets Photo identification

National Map Accuracy Standards
**Video Presentation Outline**

**Photography**

- Cameras
- Focal length

![Diagram showing the relation of focal length to area coverage.](image)

*Figure 9-1. Relation of focal length to area coverage.*

- Aerial photographs
**Scale**

- Expression of scale
  
  1 in = 250 ft or 1:3000

- Large scale/small scale

![Figure 9-2. Large scale/small scale.](image)

- Terrain
  
  Datum

![Figure 9-3. Determining photo scale.](image)
• Basic formulas

\[ S = \frac{f}{H-h} \]

Where:
- \( S \) = scale given as in/ft or as a ratio
- \( f \) = focal length of camera as in or as ft if scale is given as ratio
- \( H \) = flying height above datum as ft
- \( h \) = average terrain elevation as ft

\[ S = \frac{d}{D} \]

Where:
- \( S \) = scale given as in/ft
- \( d \) = distance on photograph as in
- \( D \) = corresponding distance on ground as ft

For ft per in

\[ S = \frac{f}{H-h} = \frac{d}{D} = \frac{1}{x} \]

Where:
- \( x \) = ft/in on photograph

• C-factor

\[ \text{C-factor} = \frac{H-h}{\text{C.I.}} \]

Where:
- \( H \) = flying height above datum
- \( h \) = average terrain elevation
- \( \text{C.I.} \) = contour interval

• Flying tolerances
Models

• Overlap

![Diagram of Overlap]

*Figure 9-4. Overlap of two successive photos.*

• Sidelap

![Diagram of Sidelap]

*Figure 9-5. Sidelap of two flight lines.*
• Neat model

![Diagram of neat model and successive photos]

*Figure 9-6. Relationship of neat model to successive photos.*

• Flight line and models

![Diagram of flight line and models]

*Figure 9-7. Flight line and neat models.*

• Blocks
Photo Control

- Neat model (fully controlled)

Figure 9-8. Control for neat model.
• Aerotriangulation

\[ \text{Premark with Horizontal and Vertical Control} \]

\[ \text{Premark with Vertical Control} \]

\[ \text{Pug with Horizontal and Vertical Control} \]

**Figure 9-9.** Neat models with control.

**Figure 9-10.** Two flight lines with control.
**Quick Reference Table for Planning of Photogrammetric Mapping**

<table>
<thead>
<tr>
<th>Plotting Scale/C.I.</th>
<th>Photo Scale</th>
<th>Flying Height</th>
<th>Max. Range of Relief/Flight Line</th>
<th>Nominal Mapping Width/Flight Line</th>
<th>Length of One Model</th>
<th>No. Models/Mile</th>
<th>Horizontal Control Premark Size</th>
<th>Horizontal Control Premark Interval</th>
<th>Vertical Control Premark Interval</th>
<th>Supplemental Horizontal Control Accuracy</th>
<th>Project Horizontal Control Accuracy</th>
<th>Supplemental Vertical Control Accuracy</th>
<th>Project Vertical Control Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 in = 50 ft 2 ft</td>
<td>1 in = 100 ft 5 ft</td>
<td>1 in = 200 ft 10 ft</td>
<td>1 in = 400 ft 20 ft</td>
<td></td>
<td></td>
<td>cloth or painted replica</td>
<td>see control diagram</td>
<td>see control diagram</td>
<td>3rd order</td>
<td>2nd order</td>
<td>0.1 ft</td>
<td>2nd order</td>
</tr>
<tr>
<td></td>
<td>1 in = 250 ft</td>
<td>1 in = 500 ft</td>
<td>1 in = 1000 ft</td>
<td>1 in = 2000 ft</td>
<td></td>
<td></td>
<td>cloth or painted replica with extensions</td>
<td>see control diagram</td>
<td>see control diagram</td>
<td>3rd order</td>
<td>2nd order</td>
<td>0.2 ft</td>
<td>2nd order</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Nominal - may be reduced 15% - 20% with maximum relief range. May be extended after aerial photography is received.</td>
<td>Nominal with 60% forelap, will vary with relief.</td>
<td>Nominal - may be reduced 15% - 20% with maximum relief range. May be extended after aerial photography is received.</td>
<td>12 ft x 1 ft</td>
<td>planned for specific projects</td>
<td>planned for specific projects</td>
<td>2nd order</td>
<td>2nd order</td>
<td>0.5 ft</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>cross premark</td>
<td>planned for specific projects</td>
<td>planned for specific projects</td>
<td>24 ft x 2 ft</td>
<td>2nd order</td>
<td>1.0 ft</td>
<td>3rd order</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>For aerotriangulation.</td>
<td>For aerotriangulation.</td>
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<td>For aerotriangulation.</td>
<td>For aerotriangulation.</td>
<td>For aerotriangulation.</td>
</tr>
</tbody>
</table>

- **Premarks**
NOTE: This is Not Part of Cloth Target

Figure 9-11. Sizing premarks.
National Map Accuracy Standards*

- “Photogrammetry for Highways Committee, 1968”

  Contours: 90% of elevations determined from solid line contours must be within 1/2 contour interval (C.I.) and all within 1 C.I.

  Spot elevations: 90% of spot elevations must be within 1/4 C.I. and all within 1/2 C.I.

  Planimetric Features: 90% of well defined features must be within 1/40 in and all within 1/20 in.

- “Office of Management and Budget”

  Horizontal accuracy: Maps with publication scales larger than 1:20,000 can have no more than 10% of well defined points with an error of more than 1/30 in as measured on the publication scale; for maps with a publication scale of 1:20,000 or smaller 1/50 in.

  Vertical accuracy: No more than 10% of elevations tested can be in error by more than 1/2 C.I.

Mapping

- Instruments
- Base sheets

Steps to Completion of a Photogrammetric Project

1. Determination of mapping limits
2. Select scale and contour interval
3. Plan flight
4. Plan the ground control
5. Place premarks
6. Survey premarks
7. Aerial photography
8. Survey calculations
9. Check aerial photography
10. Aerotriangulation

11. Base sheets
12. Map compilation
13. Map checking
14. Map corrections
15. Map acceptance

Example Problem

Problem A-3 1991 LS

Your client owns Sections 9 and 16, and the westerly 4000 ft of Sections 10 and 15, T4S, R23W, S.B.M. You have been asked to provide horizontal and vertical control for the topographic mapping that is to be used for planning purposes. Vertical photography, taken with a 6-in focal length camera on a 9-in x 9-in focal plane, is to be used. Analytical bridging is not to be considered.

The following factors control the project. Make no assumptions.

1. A 5-ft contour interval is required.
2. Model size is 3.6 x 7.0 in for a single flight line and 3.6 x 6.3 in for two or more adjacent flight lines.
3. The C-factor to be used for this project is 1,800 ft.
4. The map is to be compiled at a 5 to 1 ratio.
5. The average terrain elevation is 2,500 ft above sea level.
6. The minimum target size to be used for premarking the ground is not to be less than 0.001 x 0.01 in at the photo scale.
7. Per a recent Record of Survey, each section has been found to be standard dimensions.

Required:

1. Based on the above specifications, determine the following. Show all work.
   A. The minimum number of flight lines required.
   B. The required flying height above sea level.
   C. The minimum number of models required.
   D. The minimum number of photographs required.
2. Give the accuracy requirements for each of the following based on requirements of the National Map Accuracy Standards:

A. Contours
B. Spot elevations
C. Planimetric features

Solution:

1. A. Minimum number of flight lines required = 1
   
   Overall length = 10,560 ft
   Overall width = 9,280 in
   Model length = 5,400 ft
   Model width = 10,500 ft
   \[ \frac{9,280}{10,500} = 0.88 = 1 \]

   B. Flying height above sea level = 11,500 ft
   
   C-factor x C.I. + elevation
   
   1800 ft x 5 ft + 2,500 ft = 11,500 ft

   C. Minimum number of models required = 2
   
   Terrain width ÷ model length = 10,560 ft ÷ 5,400 ft = 1.96 = 2

   D. Minimum number of photographs required = 3
   
   Photos required = models + flight lines
   
   2 models + 1 flight line = 3

   E. Minimum number of horizontal control stations required = 4
   
   Minimum number of vertical control stations required = 6
   
   Control for scale/model = 2 + 1 for check
   
   Control for elev./model = 3 + 1 for check
F. Negative scale = 1,500 ft
   C-factor x C.I. ÷ 6
   (1800 ft x 5 ft) ÷ 6 = 1500 ft or 1:18,000

G. Nominal map scale = 1 in = 300 ft
   Mapping scale = (Photo scale) (Ratio)
   Photo scale = flying/focal length
   Photo scale = (9,000/6) (1/5) = 300

H. Minimum length (180 in is acceptable) = 15.0 ft = 1500 x 0.01 ft
   Minimum width (18 in is acceptable) = 1.5 ft = 1500 x 0.001 ft

2. A. Accuracy = 90%
   Value = ±1/2 C.I.
   or
   Accuracy = not more than 10% exceed
   Value = ±2.50 ft

B. Accuracy = 90%
   Value = ±1/4 C.I.
   or
   Accuracy = not more than 10% exceed
   Value = ±1.25 ft

C. Accuracy = 90% of features
   Value = ±1/30 @ map scale
   or
   Accuracy = not more than 10% exceed
   Value = ±10 ft
Sample Test Questions

The following questions are from Problem A-1 1988 LS

You are asked by your client to prepare a topographic map for his proposed project. He tells you that he will use this map to design a subdivision (including grading plans and street plans). He also states that he wants this map at a scale of 1 in = 40 ft with a 1-ft C.I. and spot elevations to supplement contours when the contour lines are more than 2 in apart.

Project site is 217 acres more or less, being a parcel 2700 ft north-south by 3500 ft east-west. Terrain: moderate relief.

The photo control for this mapping project will be established by field surveys.

Camera to be used for obtaining the mapping photography is equipped with a 6-in focal length lens and a 9-in x 9-in format (negative size).

The map accuracy must comply with the U.S. Map Accuracy Standards.

Required:

Circle the correct answer.

1. U.S. Map Accuracy Standards are as follows:
   A. 90% of the contours shall be ±1/4 C.I.
   B. 90% of the spot elevations should be within 1/2 C.I.
   C. 80% of the spot elevations should be within 1/4 C.I.
   D. 90% of the spot elevations should be within 1/4 C.I.

2. The C-factor for a mapping system is determined by:
   A. Camera, aircraft, photo lab equipment, and stereo plotting equipment.
   B. Ground control, flying height, camera, and photo lab equipment.
   C. Flying height, weather, relief displacement, and camera.
   D. Stereo plotter operator, camera, ground control, and airplane altitude.
3. It was determined that a mapping system with a C-factor of 1500 will be used in the above project. This system is considered:
   A. A first order system
   B. A second order system
   C. A third order system
   D. A fourth order system

4. What is the altitude from which the photography must be obtained?
   A. 4200 ft ASL (above sea level)
   B. 3000 ft AGL (above ground level)
   C. 1500 ft AGL
   D. 1500 ft ASL

5. The scale of the photography is:
   A. 1 in = 200 ft
   B. 1:3000
   C. 1 in = 100 ft
   D. 1:1500

6. The enlargement ratio from photography to final map is:
   A. 10
   B. 40
   C. 7.50
   D. 6.25

Assume for the following questions that the flight path is east-west.

7. How many photographs will be required to obtain complete stereoscopic coverage of the area?
   A. 10
   B. 8
   C. 11
   D. 7

8. How many models will be required to map the parcel?
   A. 10
   B. 8
   C. 11
   D. 7
9. How many control points will be required to fully control the mapping photography?
   A. 10
   B. 4
   C. 15
   D. 18

10. How many flight lines will be required?
   A. 1
   B. 2
   C. 3
   D. 4

The following questions are from Problem B-5 1989 LS

Your client has requested that you provide a topographic map of the Jackson landfill by photogrammetric methods. In so doing, you are required to use the following criteria and equipment.

- The map must fit on a single mylar sheet with borders as specified in the diagram below.
- The common engineering map scale that allows the entire project to be compiled at the maximum size that will fit on the specified single sheet.
- The camera focal length is 6 in; the film format is 9 x 9 in.
- The plotter has 9-in x 9-in diapositive plate carriers and a C-factor of 2000, as shown in the diagram below.
- A forward photo overlap of 60% and a sidelap of 30% or an accepted common practice are required.
- The terrain varies from 1500 ft to 2100 ft above sea level.
- The C.I. is 1 ft.
Determine the following:

11. Usable map sheet dimensions.
12. East-west, north-south limits (length and width) of area to be mapped.
14. Flying height above sea level.
15. Photo scale.
16. Compilation scale that will fit on one map sheet (see diagram) and be drawn in one of the following common engineering scales (10, 20, 30, 40, 50, 60, 100).
17. Definition of the “neat model.”
18. Dimensions of the “neat model.”
19. Number of models required to map the given area.
The following questions are from Problem A-3, 1992, LS

The following are intended to measure your knowledge of basic photogrammetry. Keep answers short, to the point, and in the correct sequence.

Required:

20. What is the scale of vertical photography if taken with a 6-in focal-length camera at an altitude of 4,500 ft above mean terrain?

21. What is the absolute minimum number of exposures required for a single flight line?

22. What is the minimum number of horizontal stations required to control a single model? Explain.

23. What is the minimum number of vertical stations required to control a single model? Explain.

24. Define a “neat model.”

25. The mean elevation of the terrain being mapped is 1,600 ft above sea level (ASL). Vertical photography is taken with a 6-in focal-length camera at an ASL elevation of 4,000 ft. What is the nominal map scale utilizing an 8 to 1 plotting ratio?

Answer Key

Problem A-1, 1988 LS

1. D

2. A is the best answer. Aircraft is a questionable term for a list that should include: camera, film, photo lab, plotting equipment, and operator.

3. A

4. C

5. B

6. D

7. A

8. B

9. D

10. B
Problem B-5, 1989, LS

11. Available dimension is the sheet size less the border dimensions. Therefore:

\[
\text{North-south} = 30 \text{ in} - (2 \times 1 \text{ in}) = 28 \text{ in} \\
\text{East-west} = 42 \text{ in} - (1 \text{ in} + 3 \text{ in}) = 38 \text{ in}
\]

12. Area to be mapped is the east-west and north-south limits.

\[
\text{North-south} = 7000 - 5000 = 2000 \\
\text{East-west} = 11500 - 8000 = 3500
\]

13. Flying height above average terrain must be maximum height for maximum coverage that will not exceed the C-factor of the plotter.

\[
\text{Maximum height} = C\text{-factor} \times \text{contour interval} \\
= 2000 \text{ ft} \times 1 \\
= 2000 \text{ ft}
\]

14. Flying height above sea level is the flying height plus the elevation of average terrain above sea level.

\[
\text{Avg. terrain elevation} = \frac{\text{highest elevation} + \text{lowest elevation}}{2} \\
= \frac{2100 \text{ ft} + 1500 \text{ ft}}{2} \\
= 1800 \text{ ft}
\]

\[
\text{Flying height above sea level} = \text{Flying height} + \text{elevation of average terrain} \\
= 2000 \text{ ft} + 1800 \text{ ft} \\
= 3800 \text{ ft above sea level}
\]

15. Photo scale for maximum coverage

\[
\text{Photo scale} = \frac{\text{camera focal length}}{\text{flying height}} \\
\]

\[
= \frac{6 \text{ in}}{2000 \text{ ft}} = \frac{0.5 \text{ ft}}{2000 \text{ ft}} \\
= 1:4000 \text{ or } 1 \text{ in} = 333.3 \text{ ft}
\]
16. Final mapping scale may vary depending on the projection distance set off in the plotter. The variation is related to photo scale divided by projection ratio; for plotters capable of ratios between 2 and 5.

\[
\text{Mapping scale} = \frac{\frac{333}{2} \times 166 \text{ ft}}{5} = 67 \text{ ft}
\]

The most appropriate listed common scale is required; therefore, final mapping scale is 1 in = 100 ft.

17. A “neat model” is the maximum compiling limits of a single stereo model.

18. Dimensions of the neat model are based on the forward and sidelaps relative to the flight line. (Note: Either A or B are acceptable solutions.)

A. Common text reference

\[
\begin{align*}
\text{Forward} & = (1 - \text{overlap}) \times \text{photo scale} \times \text{photo width} \\
& = (1 - .60) \times 9 \text{ in} \times 333.3 \text{ ft} = 1199 \text{ ft} \\
\text{Sidelap} & = (1 - .3) \times 9 \text{ in} \times 333.3 \text{ ft} = 2089 \text{ ft} \\
\text{Neat model} & = 1199 \text{ ft} \times 2089 \text{ ft} 6.3 \text{ in} \times 3.6 \text{ in}
\end{align*}
\]

B. Common practice

\[
\begin{align*}
\text{Forward} & = (1 - \text{overlap}) \times \text{photo scale} \times \text{photo width} \\
& = (1 - .60) \times 9 \text{ in} \times 333.3 \text{ ft} = 1199 \text{ ft} \\
\text{Sidelap} & = (1 - .222) \times 9 \text{ in} \times 333.3 \text{ ft} = 2333 \text{ ft} \\
\text{Neat model} & = 1199 \text{ ft} \times 2333 \text{ ft}, 7 \text{ in} \times 3.6 \text{ ft}
\end{align*}
\]

19. The required number of models is based on the neat model dimensions related to the dimension of the area to be mapped. If the flight line runs east-west, then:

<table>
<thead>
<tr>
<th>Width</th>
<th>Length</th>
<th>Width is adequate for a single strip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neat model 8a or 8b</td>
<td>1199 ft</td>
<td>Models required = (\frac{3500}{1199}) = 2.9 or 3 models</td>
</tr>
<tr>
<td>Area to map 2000 ft</td>
<td>3500 ft</td>
<td></td>
</tr>
</tbody>
</table>
Problem A-3, 1992 LS

20. 
\[ S = \frac{f}{H-h} \]

\[ 1 \text{ in} = 750 \text{ ft or } \frac{1}{9,000} \]

\[ \frac{4,500 \text{ ft}}{6 \text{ in}} = 750 \text{ ft} \text{ in}, \quad 1 \text{ in} = 750 \text{ ft}, \quad \frac{6 \text{ in}}{4,500 \text{ ft}} = \frac{1}{9,000} \]

21. The total number of models plus one.
   or
   A minimum of two exposures.

22. A. Two or three
   B. Two points are required to establish scale.
   or
   Two points are required to establish scale plus one additional point for check.

23. A. Three or four
   B. Any three points not in a straight line are required to establish a plane.
   or
   Any three points not in a straight line are required to establish a plane plus one additional point for check.

24. Examples of acceptable answers are:
   - The stereoscopic area between adjacent principal points and extending out sideways in both directions to the middle of the sidelap. (The mapping area of each stereopair.)
   - 3.6 x 7 in
   - 3.6 x 6.8 in

25. 
\[ 4,000 - 1,600 = 2,400 \]

\[ \frac{2,400}{6} = 400 \]

\[ \frac{400}{8} = 50 \]

Answer: 1 in = 50 ft or 1:600
References

