UNIT 9

PHOTOGRAMMETRY

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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

Fiducial marks

Negative format

Photo scale

Map scale

Contour interval

Large scale

Small scale

Ratio scale

Flight height

C-factor

Terrain height

Datum height

Base sheets

National Map Accuracy Standards

Neat model

Overlap

Sidelap

Ground control

Premark

Flight line

Crab

Stereovision

Block

Halation

Spot elevations

Plannimetrics

Areotriangulation

Photo identification

Video Presentation Outline

Photography

- Cameras
- Focal length

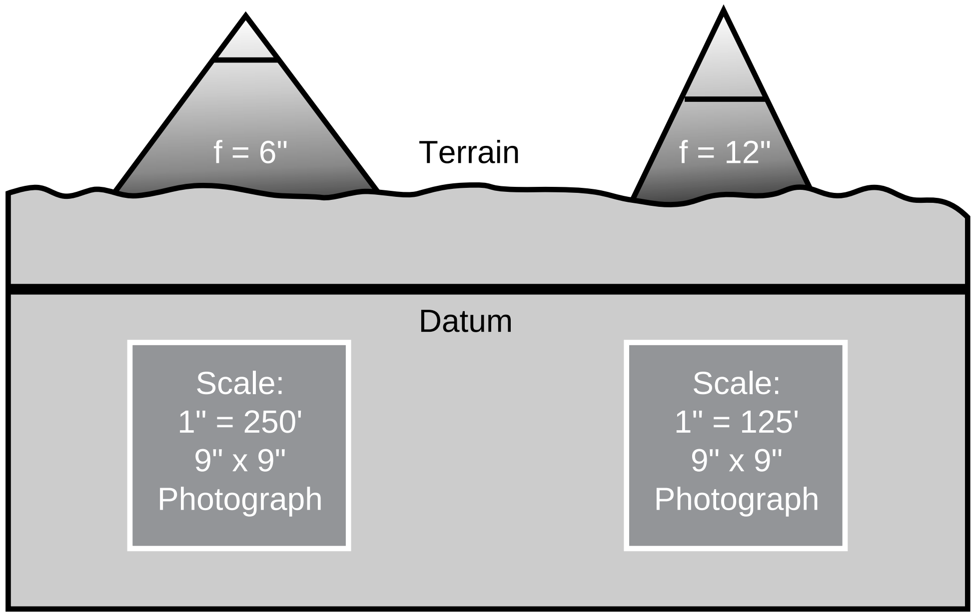


Figure 9-1. *Relation of focal length to area coverage.*

- Aerial photographs

Scale

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

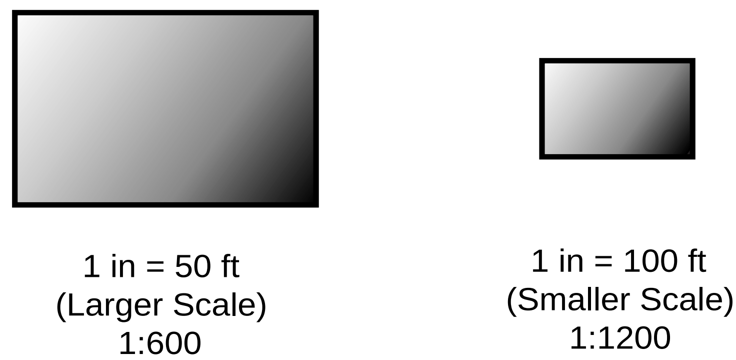


Figure 9-2. *Large scale/small scale.*

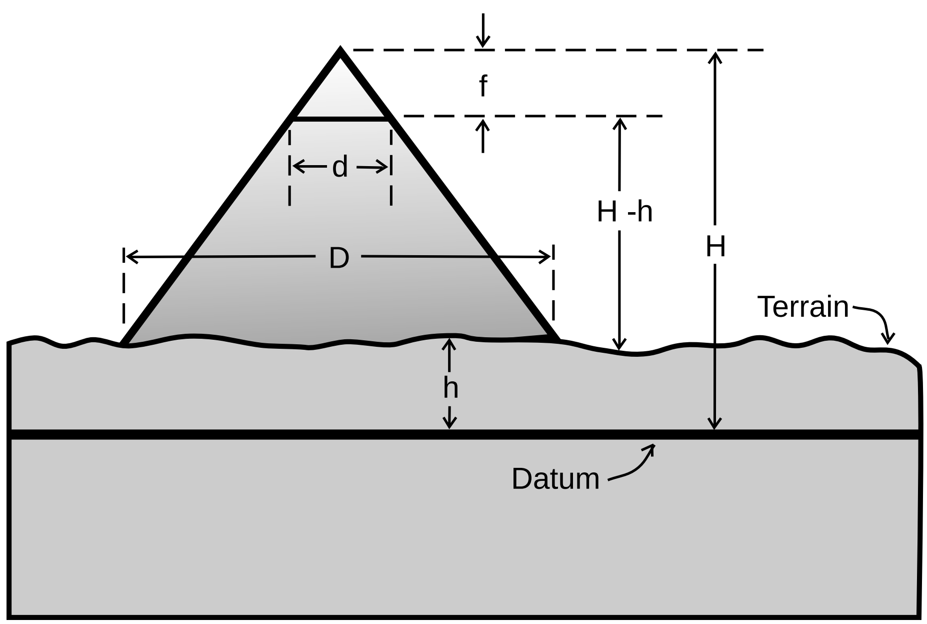


Figure 9-3. *Determining photo scale.*

- Basic formulas

$$S = \frac{f}{H\text{-}h}$$

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 $$S = \frac{f}{H\text{-}h} = \frac{d}{D} = \frac{1}{x}$$

Where:

x = ft/in on photograph

- C-factor

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

Where:

H = flying height above datum

h = average terrain elevation

C.I. = contour interval

- Flying tolerances

Models

- Overlap

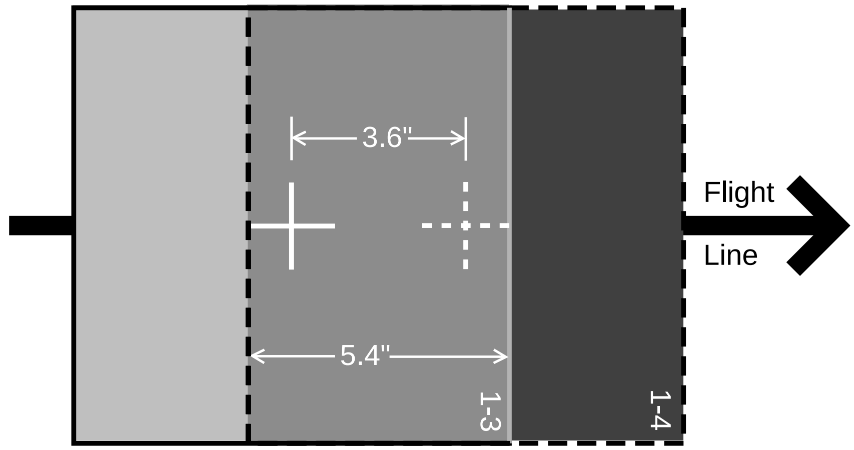


Figure 9-4. *Overlap of two successive photos.*

- Sidelap

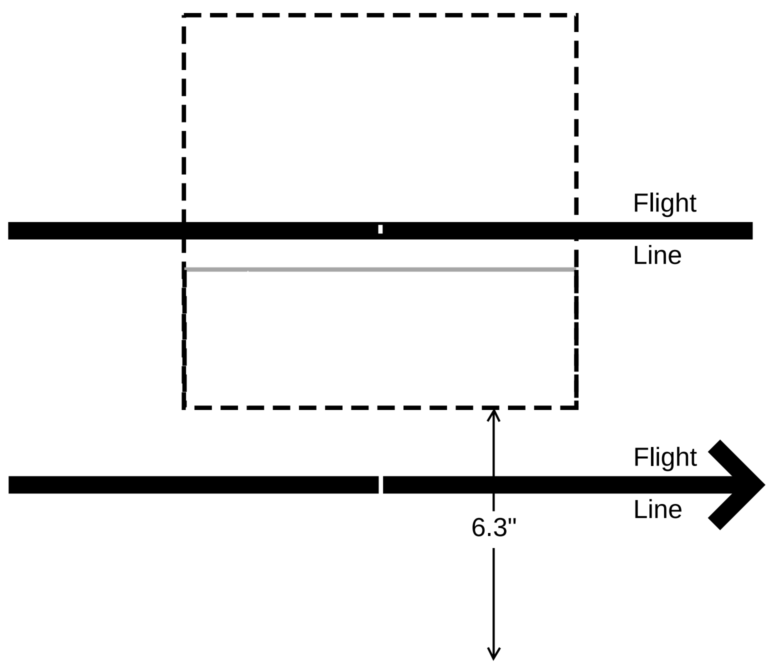


Figure 9-5. *Sidelap of two flight lines.*

- Neat model

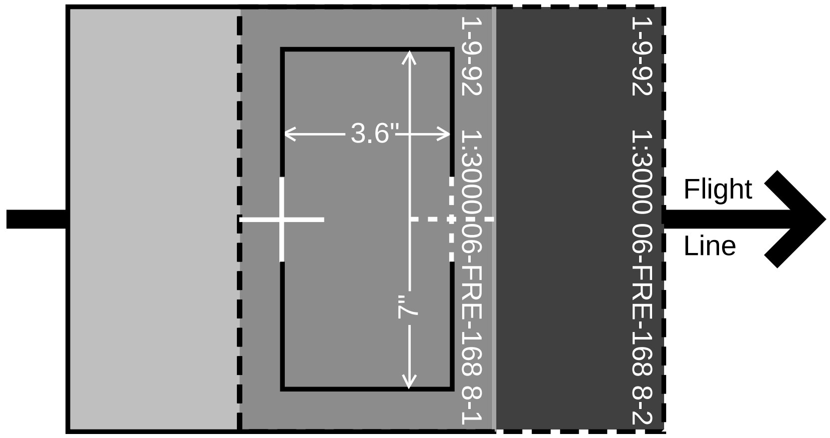


Figure 9-6. *Relationship of neat model to successive photos.*

- Flight line and models

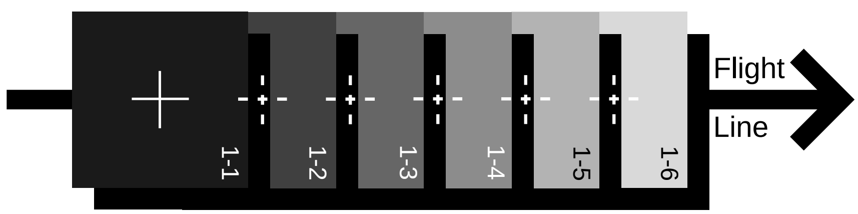


Figure 9-7. *Flight line and neat models.*

- Blocks

Photo Control

- Neat model (fully controlled)

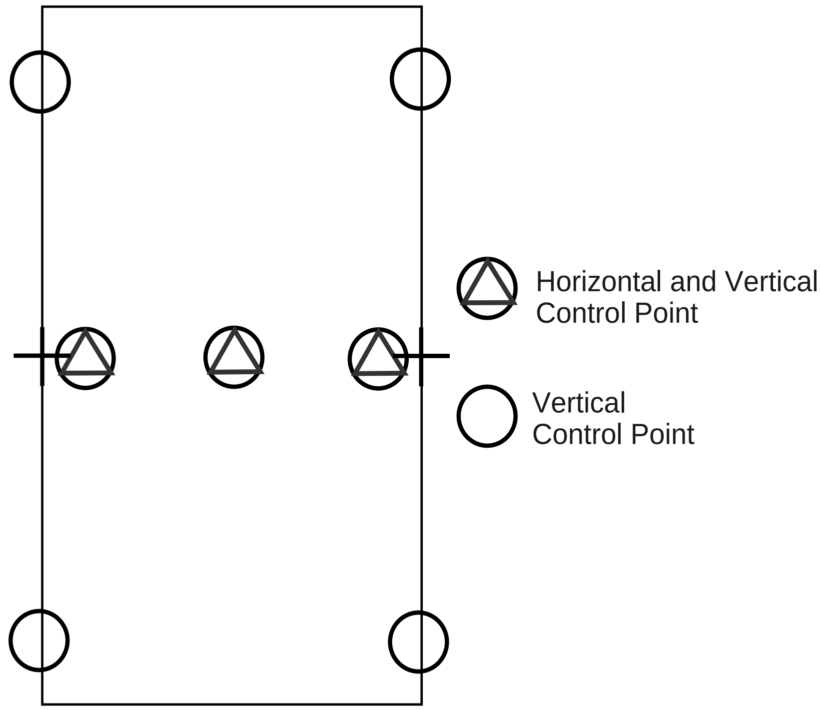


Figure 9-8. *Control for neat model.*

- Aerotriangulation

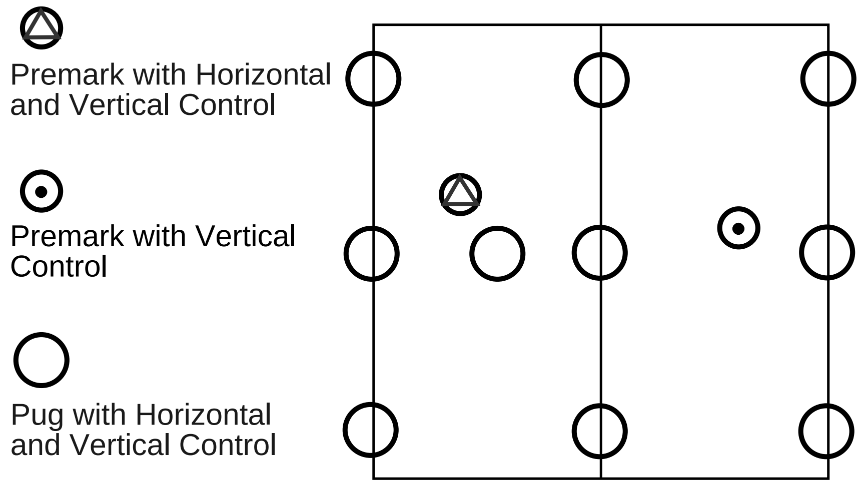


Figure 9-9. Neat models with control.

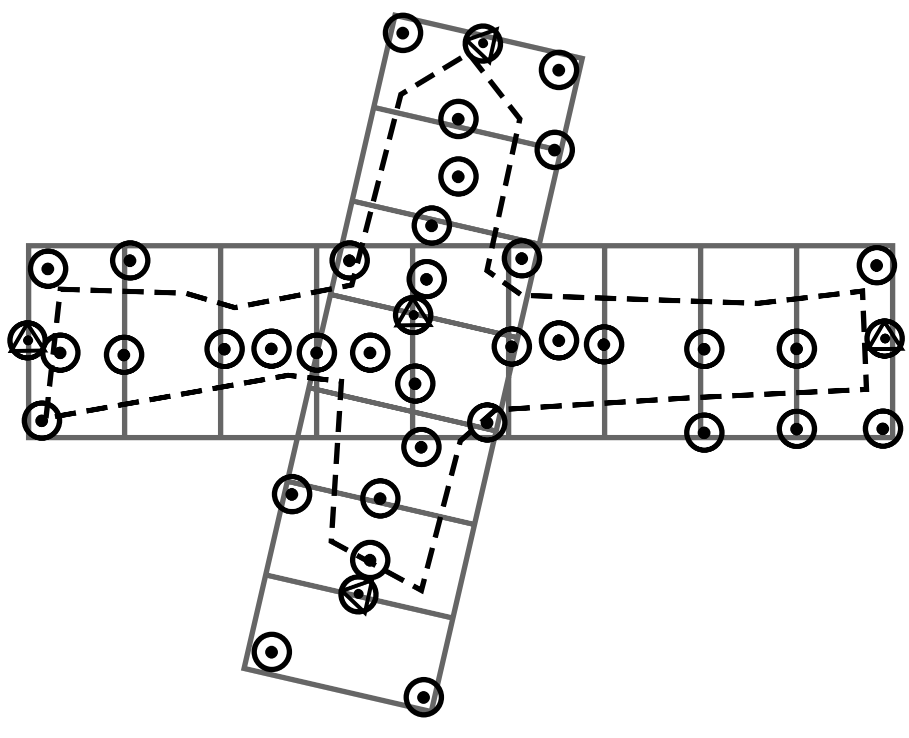
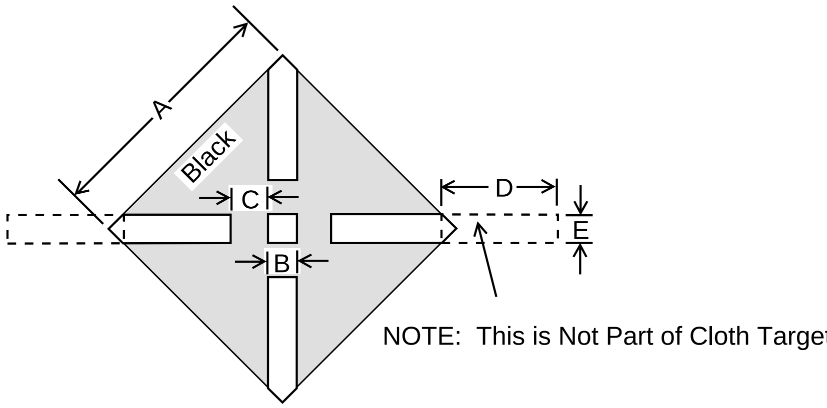


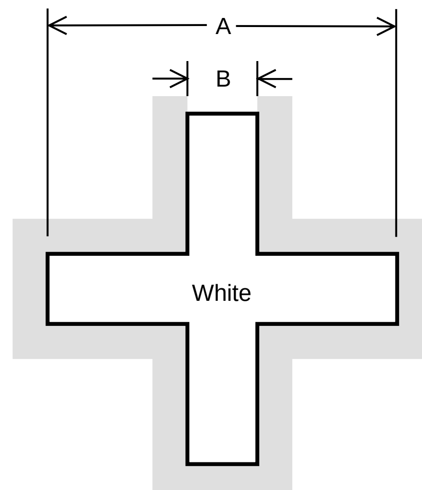
Figure 9-10. Two flight lines with control.

- Premarks

Quick Reference Table for Planning of Photogrammetric Mapping

Plotting Scale/C.I.	1 in = 50 ft / 2 ft	1 in = 100 ft / 5 ft	1 in = 200 ft / 10 ft	1 in = 400 ft / 20 ft	*Comments*
Photo Scale	1 in = 250 ft	1 in = 500 ft	1 in = 1000 ft	1 in = 2000 ft	Nominal. Will vary with relief.
Flying Height	1500 ft	3000 ft	6000 ft	12000 ft	*Above average ground elevation.*
Max. Range of Relief/Flight Line	300 ft	700 ft	1400 ft	2800 ft	*For mapping area – exceptions can be made if more relief outside mapping area but within photocoverage, special instructions to photographer necessary.*
Nominal Mapping Width/Flight Line	1400 ft	3000 ft	6000 ft	12000 ft	*Nominal - may be reduced 15% - 20% with maximum relief range. May be extended after aerial photography is received.*
Length of One Model	900 ft	1800 ft	3600 ft	7200 ft	*Nominal with 60% forelap, will vary with relief.*
No. Models/Mile	6	3	1.5	.75	*Approximate, for estimating purposes.*
Horizontal Control Premark Size	cloth or painted replica	cloth or painted replica with extensions	cross premark 12 ft x 1 ft	cross premark 24 ft x 2 ft	
Horizontal Control Premark Interval	see control diagram	see control diagram	planned for specific projects	planned for specific projects	*For aerotriangulation.*
Vertical Control Premark Interval	see control diagram	see control diagram	planned for specific projects	planned for specific projects	*For aerotriangulation.*
Supplemental Horizontal Control Accuracy	3rd order	3rd order	3rd order	3rd order	
Project Horizontal Control Accuracy	2nd order	2nd order	2nd order	2nd order	
Supplemental Vertical Control Accuracy	0.1 ft	0.2 ft	0.5 ft	1.0 ft	
Project Vertical Control Accuracy	2nd order	2nd order	3rd order	3rd order	





	Cloth Premark or Painted Replica		Cross	Premark
Photo Scale	1 in = 250 ft	1 in = 500 ft	1 in = 1000 ft	1 in = 2000 ft
A	45 in	45 in	12 ft	24 ft
B	4 in	4 in	1 ft	2 ft
C	7 in	7 in		
D	Not Required	24 in		
E	Not Required	6 in		

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 that 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 that 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

***Manual of Photogrammetry,* 4th Ed., American Society of Photogrammetry, 1980, page 372.

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.

E. The minimum number of horizontal and vertical control stations required to provide for adequate checks.

F. The negative scale.

G. The nominal map scale.

H. The minimum length and width of the target placed on the ground as a premark.

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

$$\text{Overall length} = 10{,}560 \text{ ft}$$
$$\text{Overall width} = 9{,}280 \text{ in}$$
$$\text{Model length} = 5{,}400 \text{ ft}$$
$$\text{Model width} = 10{,}500 \text{ ft}$$
$$\frac{9{,}280 \text{ ft}}{10{,}500 \text{ ft}} = 0.88 = 1$$

   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 - 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

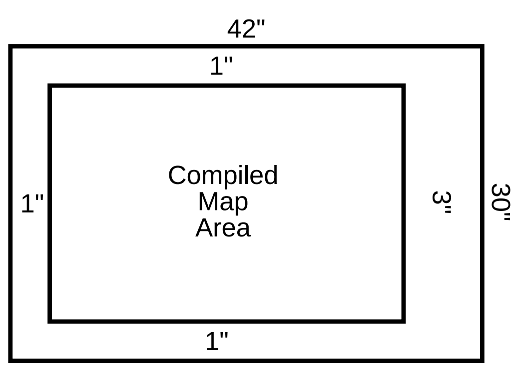
10. How many flight lines will be required?

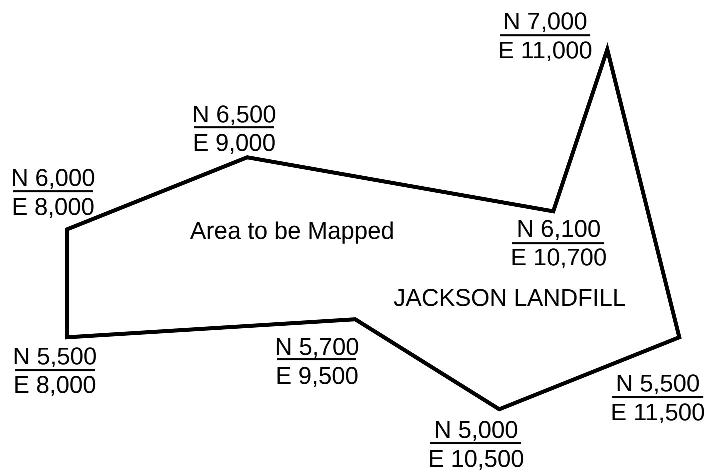
   A. 1
   B. 2
   C. 3
   D. 4

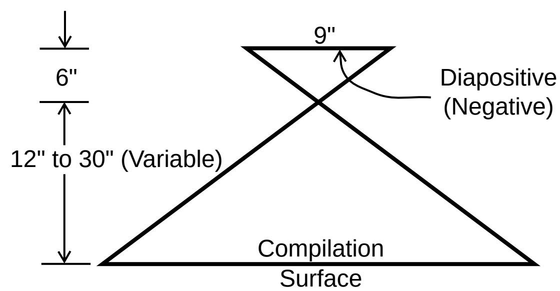
The following questions are from Problem B-5 1989 LS

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.

13. Maximum flying height above average terrain.

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 maximun height for maximum coverage that will not exceed the C-factor of the plotter.

$$\text{Maximum height} = \text{C-factor} \times \text{contour interval}$$

$$= 2000 \text{ ft} \times 1$$

$$= 2000 \text{ ft}$$

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.

$$\text{Mapping scale} = \frac{333}{2} - 166 \text{ ft to } \frac{333}{5} = 67 \text{ ft}$$

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

Forward = (1 - overlap) x photo scale x photo width

= (1 - .60) x 9 in x 333.3 ft = 1199 ft

Sidelap = (1 - .3) x 9 in x 333.3 ft = 2089 ft

Neat model = 1199 ft x 2089 ft 6.3 in x 3.6 in

B. Common practice

Forward = (1 - overlap) x photo scale x photo width

= (1 - .60) 9 in x 333.3 ft = 1199 ft

Sidelap = (1 - .222) 9 in x 333.3 ft = 2333 ft

Neat model = 1199 ft x 2333 ft, 7 in x 3.6 ft

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:

Width	Length	Width is adequate for a single strip
Neat model 8a or 8b	1199 ft	Models required = $\frac{3500}{1199}$ = 2.9 or 3 models
Area to map 2000 ft	3500 ft	

Problem A-3, 1992 LS

20.

$$S = \frac{f}{H-h}$$

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

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

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

________, *Manual of Photogrammetry*, Fourth Edition, American Society of Photogrammetry, Falls Church, VA, 1980.

Moffitt, Francis H., and Mikhail, *Photogrammetry,* Third Edition, International Textbook Co., Scranton, PA 1980.

Wolf, Paul R., *Elements of Photogrammetry*, McGraw Hill, New York, NY, 1983.