DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
Washington, DC 20314-1000

EM 1110-1-1000

CECW-EE

Manual
No. 1110-1-1000

31 July 2002

Engineering and Design
PHOTOGRAMMETRIC MAPPING

1. Purpose. This manual presents procedural guidance, technical specifications, and quality control (QC) criteria for performing aerial photogrammetric mapping activities.

2. Applicability. This manual applies to all major subordinate commands, districts, and laboratories performing and/or contracting for aerial photography and photogrammetric mapping services in support of planning, engineering and design, construction, operation, maintenance, and/or regulation of civil works or military construction projects. This manual is also applicable to U.S. Army Corps of Engineers (USACE) functional areas having responsibility for environmental investigations and studies, archeological investigations, historical preservation studies, hazardous and toxic waste site restoration, structural deformation monitoring investigations, regulatory enforcement activities, and support to Army installation maintenance and repair programs and installation master planning functions. Waivers from applicability should be requested by written memorandum to Headquarters, USACE (ATTN: CECW-EE).

3. Discussion. The purpose of mandatory requirements is to assure that geospatial data developed from photogrammetric methods meet accuracy requirements and corporate direction for Geospatial data collection. **Mandatory requirements pertaining to the guidance contained in a particular chapter are summarized at the end of each chapter.** No mandatory requirements are identified in the appendices. Instead, any mandatory requirements pertaining to information contained in Appendices A through F are cited in chapters which reference those appendices.

FOR THE COMMANDER:

JOSEPH SCHROEDEL
Colonel, Corps of Engineers
Chief of Staff

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Appendix A - References
Appendix B - Planimetric and Topographic Feature Depiction Specifications
Appendix C - Guide Specification Guide Specification for Photogrammetric Mapping and Aerial Photography Services
Appendix D - ASPRS Accuracy Standards for Large-Scale Maps
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Appendix F - Sample SOW
Glossary

This manual supersedes EM 1110-1-1000, 31 March 1993.

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Chapter 1
Introduction

1-1. Purpose

This manual presents procedural guidance, technical specifications, and quality control (QC) criteria for performing aerial photogrammetric mapping activities.

1-2. Applicability

This manual applies to all major subordinate commands, districts, and laboratories performing and/or contracting for aerial photography and photogrammetric mapping services in support of planning, engineering and design, construction, operation, maintenance, and/or regulation of civil works or military construction projects. This manual is also applicable to U.S. Army Corps of Engineers (USACE) functional areas having responsibility for environmental investigations and studies, archeological investigations, historical preservation studies, hazardous and toxic waste site restoration, structural deformation monitoring investigations, regulatory enforcement activities, and support to Army installation maintenance and repair programs and installation master planning functions. Waivers from applicability should be requested by written memorandum to Headquarters, USACE (ATTN: CECW-EE).

1-3. Distribution

Approved for public release, distribution is unlimited.

1-4. References

Required and related publications are listed in Appendix A.

1-5. Mandatory Requirements

The purpose of mandatory requirements is to assure that geospatial data developed from photogrammetric methods meet accuracy requirements and corporate direction for Geospatial data collection. . **Mandatory requirements pertaining to the guidance contained in a particular chapter are summarized at the end of each chapter**. No mandatory requirements are identified in the appendices. Instead, any mandatory requirements pertaining to information contained in Appendices A through G are cited in chapters which reference those appendices.

1-6. Scope

a. This manual provides standard procedures, minimum accuracy requirements, instrumentation and equipment requirements, product delivery requirements and QC criteria for photogrammetric mapping. This includes aerial photography and standard line mapping (topographic or planimetric) products, including digital spatial data for use in computer-aided design and drafting (CADD) systems and Geographic Information Systems (GIS). The manual is intended to be a primary reference specification for contracted photogrammetric services. It should be used as a guide in planning mapping requirements, developing contract specifications, and preparing cost estimates for all phases of aerial photography and photogrammetric mapping. It may also be used as general guidance in executing some phases of photogrammetric mapping with USACE hired-labor forces.

b. This manual is intended to cover primarily those large-scale (i.e., greater than 400 feet (ft) per inch (in.)) photogrammetric mapping products that support typical USACE construction projects. These products include detailed site plan (or planimetry) feature mapping, topographic (vertical terrain) mapping, air photo enlargement plan drawings, and orthophotography mapping. The manual focuses primarily on the preparation of design drawings and other documents associated with these products, including related contracted construction performance activities.

c. Computer Automated Drafting and Design (CADD) vs. Geographic Information System (GIS). Photogrammetric mapping data collection is generally a necessary but costly process. The decision regarding final formats (CADD vs GIS) of spatial data is not always clear cut. Organization, storage, manipulation, and updating of data in a CADD system are efficient and appropriate for many engineering and mapping purposes. The decision to move from CADD to GIS stems from the requirement or desire to spatially analyze the data. While analysis capabilities are becoming increasingly more desirable, GIS databases can be more expensive to develop than CADD data. A portion of the time and cost in photogrammetric map production is the final format of the data sets. Factors that may affect the decision regarding CADD vs GIS include:

(1) Immediate and future uses of the spatial data sets collected.

(2) Immediate and future data analysis requirements for spatial data sets.

(3) Costs and time for each format requested.

(4) Project cost sharing and ownership.

d. Every attempt should be made to collect spatial data sets in the formats that will provide the most use and utility. GIS formatting costs can be minimized if the Contractor is aware of the request at the time of initial data collection. Many engineering, planning, and environmental projects can make use of and may require GIS capability in spatial data analysis. When planning a photogrammetric mapping project, both CADD and GIS formats may be required. Collection of the spatial data in both CADD and GIS will provide for the most utility of the spatial data sets and should be the first recommendation.

1-7. Standards

The use of geospatial data standards is good (sharing data, reliable decsions, etc.)

a. Throughout the manual, photogrammetric mapping criteria standards are in specific terms and are normally summarized in tables. Guidance is in more general terms where methodologies are described in readily available references or survey instrumentation operating manuals. Where procedural guidance is otherwise unavailable, it is provided herein.

b. One of the most important types of standards critical to geospatial data exchange is a data content standard. Data content standards define and organize the data captured in a geospatial database. A data content standard provides a list of “real-world” objects (e.g., roads, buildings, trees, etc.) for a given area of interest, their semantic definitions, and a logical data model to organize and encode “instances” of geospaital phenomena in a geospatial database. The Spatial Data Standards for Facilities, Infrastructure, and Environment (SDSFIE) is the USACE data content standard, and geospatial databases shall be developed using this standard. A mapping of features that USACE traditionally collects to the SDSFIE is included in Appendix B.

c. Geospatial metadata provide descriptive information in a standard format about geospatial data sets. Metadata describe the content, quality, fitness for use, access instructions, and other characteristics about the geospatial data. Geospatial metadata increase the longevity of geospatial data by maximizing the its use. All

USACE photogrammetric mapping projects shall include metadata fully compliant with the "Content Standard for Digital Geospatial Metadata (CSDGM)," FGDC-STD-007-1998. The USACE guidance on implementing FGDC-STD-007-1998 can be found in EM 1110-1-2909. A sample metadata file for photogrammetric mapping data is presented in Appendix E of this manual.

d. Accuracy specifications, procedural criteria, product delivery requirements, and QC requirements contained in this manual shall be directly referenced in the scopes of work for Architect-Engineer (A-E) survey services or other third-party survey services. This is intended to ensure that uniform and standardized procedures are followed by contract service sources throughout USACE. The "American Society for Photogrammetry and Remote Sensing (ASPRS) Standards for Large-Scale Mapping" (ASPRS 1990) and the Federal Geographic Data Committee (FGDC), "Geospatial Positioning Accuracy Standards, Part 4: Standards for Architecture, Engineering, Construction (A/E/C) and Facility Management" (FGDC 1998), shall be considered the USACE accuracy standards. ASPRS Standards have three accuracy classes for photogrammetric mapping products. The three accuracy classes are defined in this manual, together with the detailed criteria, instrumentation, and procedures necessary to meet these accuracy classifications. For each class of map, procedural specifications and limitations are defined, such as allowable types of photographic or mensuration instruments, QC criteria, limiting flight altitude, photo enlargement criteria, and recommended development scales based on project functional requirements. The ASPRS, as it is applied to USACE projects, is explained in Chapter 2, and the entire ASPRS standard is in Appendix D of this manual.

1-8. Life Cycle Project Management Integration of Photogrammetric Mapping Throughout the Project Life

a. Prior to contracting for photogrammetric services, USACE is required to ensure that there are no existing data (to include aerial photography and elevation data) that would meet project requirements. The following resources for geospatial data must be checked prior to contracting for photogrammetric services:

(1) National Digitital Orthophoto Program – The U.S. Geological Survey (USGS) participates in the National Digital Orthophoto Program (NDOP) in cooperation with U.S. Department of Agriculture agencies. The effects of camera tilt and terrain relief are removed through a rectification process to create a computer file referred to as a digital orthophoto. A digital orthophoto is uniform scale photographic image and can be considered a photographic map. (Chapter 10). Orthophotoquads are distortion-free aerial photographs that are formatted and printed as standard 7.5-min, 1:24,000-scale quadrangles (15-min in Alaska) or as quarter quadrangles at a scale of 1:12,000. Prior to contracting for photogrammetric services, check the availability of NDOP products at http://mcmcweb.er.usgs.gov/status/doq_stat.html and determine whether existing orthophotoquads will meet project requirements.

(2) National Aerial Photography Program (NAPP) – Aerial photographs archived and distributed by the USGS include the repository of multiagency National Aerial Photography Program (NAPP) photos at 1:40,000 scale in color infrared or black and white; National High Altitude Aerial Photography Program (NHAP) photos at 1:58,000 scale for color infrared and 1:80,000 for black and white; and aerial photos at various scales from USGS mapping projects and other Federal agencies such as the Bureau of Reclamation, Environmental Protection Agency, and the USACE. Prior to contracting for photogrammetric services, check the availability of NAPP products at http://mcmcweb.er.usgs.gov/status/napp_stat.html and determine whether existing Aerial Photography will meet project requirements.

(3) National Spatial Data Infrastructure (NSDI) Clearinghouse Site – The Clearinghouse Activity, sponsored by the Federal Geographic Data Committee (FGDC), is a decentralized system of servers located on the Internet which contain field-level descriptions of available digital spatial data. These descriptive information, known as metadata, are collected in a standard format to facilitate query and consistent presentation across multiple participating sites. Prior to contracting for photogrammetric services, check the

availability of existing products at http://www.fgdc.gov/clearinghouse/clearinghouse.html and determine whether existing data can be used to meet project requirements.

b. USACE should also verify with Federal field offices any state and local government's potential plans to develop orthophoto, etc that may meet project requirements. In many cases, this can be done through a regional GIS User's Group or Consortia. It is important that the USACE take advantage of existing data or partner with interested parties to develop the data to reduce overall project costs.

c. Most engineering projects require some degree of surveying and mapping during each stage (i.e., planning, acquisition, design, construction, operation, and maintenance). Therefore, in the early phases of a project, a comprehensive plan should be developed to integrate the surveying and mapping requirements throughout the various stages of the life of the project. This plan shall be consistent with the Districts Geospatial Data and Systems (GD&S) Implementation Plan as outlined in EM 1110-1-2909. Development of a comprehensive surveying and mapping plan consistent with the District's overall GD&S goals will eliminate duplicate surveys performed for different purposes, of different accuracy, for different organizations, and/or at different times, and ensure that these data generated will be of maximum use to the District.

1-9. Metrics

Both metric (SI) and English (non-SI) systems of measurement in this manual are used because of the common use of both systems throughout the surveying, mapping, and photogrammetric professions. The photogrammetric industry uses both English and metric units. English units of measure are more common for some parameters such as flight altitudes in feet, and aerial film/photo dimensions in inches. Camera focal lengths are measured in either inches or millimeters (mm), with "6-in. camera" normally used rather than its 153-mm equivalent.

a. Metric scale ratios are generally required for civil works or military construction. Both English and metric scales are expressed throughout this manual. English units are generally expressed as "1 in. = x ft" notation, or more commonly, "x ft/in." Unit ratio (i.e., 1:x) scale measures may also be used for English units and are used throughout this manual for metric units.. For example, a 100-scale photo represents a 100-ft/in.-scale photo, or 1 in. = 100 ft, or 1:1,200. However, when creating a map in metric units the map scales are generally in increments evenly divided by 10 (i.e., 1:500, 1:1,000, or 1,20,000). Direct conversion from English units to metric units (i.e., 1"=100' to 1:1,200) should not be a common map scale for a mapping project intended to be metric in scale. The map scale should be the nearest common metric map scale (i.e., Converting to metric for an English map scale of 1"=100' should be 1:1,000).

b. Minimum scale limitations given in the manual for either photography or mapping imply that a scale cannot be less (i.e., smaller ratio) than the prescribed scale (e.g., a 100-ft/in. scale is smaller than a 50-ft/in. scale). Common scales in both English and metric are shown throughout the manual. Other scales may be calculated by the user.

In all cases, metric conversions are based exclusively on the U.S. Survey Foot, which equals exactly 1,200/3,937 meters (m).

1-10. Trade Name Exclusions

The citation in this manual of trade names of commercial firms, commercially available mapping products, or photogrammetric instruments does not constitute their official endorsement or approval.

1-11. Manual Development and Proponency

The Headquarters, USACE, proponent for this manual is the Technology Integration Branch, Engineering and Construction Division, Civil Works Directorate. Primary technical authorship and/or review were provided by USACE District, St Louis. Recommended corrections or modifications to this manual should be directed to:

HQUSACE-CW-EE
441 G Street, N.W.
Washington, DC 20314

1-12. Using the Manual

Digital photogrammetry is a professional specialty which is becoming more complex as time passes. In the not too distant past, all mapping was accomplished by employing a combination of manual and optical/mechanical efforts to produce a hardcopy product. Today mapping is predominantly a digital and electro/optical procedure to produce a geospatial database. Although there are several chapters devoted to technical procedures herein, it is not the intent of this manual to educate the reader to the proficiency level of a photogrammetric technician. The uninitiated user would be wise to seek technical assistance when embarking on a photogrammetric project. One such source is the Directory of Expertise for Photogrammetry in the USACE District, St. Louis.

a. Chapter 2. This chapter states the limits of allowable inaccuracy for large-scale maps and orthophotos. It contains tables that list the allowable errors for the map classes. It also contains tables to aid in determining flight altitude and photo scale which should maintain these accuracies. An appreciation of accuracy standards is vital to the mapping project planning stage, because it controls the integrity of the final product. Since mapping projects are usually costly, a flawed product equates to significant wasted time and funds. This chapter also includes discussion regarding quality control for photogrammetric mapping.

b. Chapter 3. This chapter is a prelude to some of the technical procedures addressed in successive chapters. It presents some of the basic geometric principles of aerial photographs and discusses coordinates datums and reference systems. This chapter also addresses QC procedures for all phases of a typical photogrammetric mapping project.

c. Chapter 4. This chapter discusses planning and estimating the effort and budgetary cost of a typical photogrammetric mapping project. The true cost of a project depends on many factors to include time of year, schedule, final products required, and accuracy requirements. This chapter also provides a sample scope of work and budgetary cost for a typical project.

d. Chapters 5 through10. These chapters identify and describe the successive progression of functions that are accomplished in photogrammetric projects. The careful reader will recognize areas of potential pitfalls and can strive to avoid them in an ongoing project.

(1) Chapter 5 discusses the characteristics of film and types of cameras that are available for aerial photo missions.

(2) Chapter 6 contains a discussion of the field surveys that are necessary to reference the photo image to the terrain.

(3) Chapter 7 outlines the elements of a recent innovation to aerial photo control, airborne global positioning system (ABGPS).

(4) Chapter 8 introduces the reader to aerotriangulation, which is a process of using office methods to supplement a limited amount of field survey to control the photographs for mapping.

(5) Chapter 9 defines the instrumentation and procedures to compile planimetric and topographic maps. It also discusses map editing.

(6) Chapter 10 discusses orthophotography, which is becoming more popular as a image tool to replace or enhance planimetric line mapping, especially for GIS/LIS/AM/FM projects.

e. *Appendices.* To facilitate contracting photogrammetric mapping services, the following appendicies have been developed to accompany this manual:

(1) Appendix B, Planimetric and Topographic Feature Depiction Specifications.

(2) Appendix C, Guide Specification for Photogrammetric Mapping and Aerial Photography Services and a sample "typical" Section C for a photogrammetric contract.

(3) Appendix D, ASPRS Accuracy Standards for Large-Scale Mapping.

(4) Appendix E, Sample Metadata.

(5) Appendix F, Sample Scopes of Work.

f. This manual is designed to be used in conjunction with the guide specification as a QC and quality assurance (QA) aid in administering contracts for photogrammetric mapping and surveying services.

1-13. Explanation of Abbreviations and Terms

Photogrammetry terms and abbreviations used in this manual are defined in the Glossary.

1-14. Mandatory Requirements in this Chapter

Chapter 2
Photogrammetric Accuracy Standards and Classifications

2-1. General

This Engineer Manual presents USACE photogrammetric mapping standards that have been established to specify the quality of the spatial data product (i.e., map) to be produced. These standards are drawn largely from the 31 March 1990 ASPRS Standards for Large-Scale Maps (ASPRS 1990). Parts 3 and 4, FGDC Geospatial Positioning Accuracy Standard (FGDC 1998) recognize the use of the ASPRS Standards for Large- Scale Mapping when mapping is larger than 1:20,000 scale. When mapping smaller than 1:20,000, Part 3, FGDC Geospatial Positioning Accuracy Standard (which is an update of the National Map Accuracy Standards (NMAS) 1947) shall be used.

a. Minimum accuracy standards. This chapter sets forth the accuracy standards to be used in USACE for photogrammetrically derived maps and related spatial data products. Map accuracies will follow guidelines established in the current FGDC Standards. Suggested requirements to meet these accuracy standards are given for critical aspects of the photogrammetric mapping and mensuration process, such as maximum flight altitudes, maximum photo enlargement ratios, C-Factor ratio limitations, and aerotriangulation adjustment criteria.

b. Map scales. Mapping accuracy standards are associated with the final development scale of the map or compilation scale, both the horizontal scale and vertical relief components. The use of CADD and GIS software allows the ready separation of planimetric features and topographic elevations to various layers, along with depiction at any scale. Problems arise when source scales are increased beyond their original values, or when the image is subjected to so-called "rubber sheeting." *It is therefore critical that these spatial data layers contain descriptor information (Metadata) identifying the original source target scale and designed accuracy*. **All USACE photogrammetric mapping projects shall include metadata fully compliant with the FGDC metadata requirements.** Sample metadata files are shown in Appendix E of this manual.

c. CADD vs GIS. Photogrammetric mapping data collection is generally a necessary but costly process. The decision regarding final formats (CADD vs GIS) of spatial data is not always clear cut. A portion of the time and cost in photogrammetric map production is the final format of the data sets. Factors that may affect the decision regarding CADD vs GIS include:

(1) Immediate and future uses of the spatial data sets collected.

(2) Immediate and future data analysis requirements for spatial data sets.

(3) Costs and time for each format requested.

(4) Project cost sharing and ownership.

Every attempt should be made to collect spatial data sets in the formats that will provide the most use and utility. GIS formatting costs can be minimized if the Contractor is aware of the request at the time of initial data collection. Many engineering, planning, and environmental projects can make use of and may require GIS capability in spatial data analysis. When planning a photogrammetric mapping project, both CADD and GIS formats may be required. Collection of the spatial data in both CADD and GIS will provide for the most utility of the spatial data sets and should be the first recommendation.

d. Mapping requirements. The specified accuracy of a geospatial data collection effort shall be sufficient to ensure that the map can be reliably used for the purpose intended, whether this purpose is an immediate or a future use. However, the accuracy of a map shall not surpass that required for its intended functional use. Specifying map accuracies in excess of those required for project design, construction, or condition reports is all too often performed. This could result in increased costs to USACE, local sponsors, or installations, and it may delay project completion. It is absolutely essential that mapping accuracy requirements originate from the functional and realistic accuracy requirements of the project. Photogrammetric mapping design criteria such as flight altitude, ground control survey accuracy, types of features typically collected, elevation model post spacing and optimum scanning resolution are determined from the design map scale and minimum contour interval. These requirements should be part of the Government and contractor project planning and cost estimate. The contract technical provisions (or delivery order Statement of Work (SOW) for indefinite delivery order contracts) should not be overly prescriptive and should not preclude contractor expertise and knowledge. USACE Commands should make the maximum use of **performance based specifications** for procuring photogrammetric mapping related services. These specifications should indicate desired end results and final products. Performance specifications for USACE photogrammetric projects should not mandate design criteria used to achieve the end results. Contract negotiations should establish actual project design criteria that will achieve the required map accuracy and end products. These criteria should be based upon final map accuracy requirements and mutually agreed upon design criteria that will achieve the map accuracy. **Prescriptive (procedural) specifications** should only be used for highly specialized or critical projects where only one method and/or unique equipment will be required to perform the work and create acceptable final products. **General guidance** on project-specific accuracy requirements is contained in this and later chapters.

e. Feature location tolerances. **Photogrammetric mapping accuracy is a function of the accuracy of a point on a map to its location on the earth.** Feature location tolerance is the positional accuracy of selected features relative to each other within the confines of a specific area and not the overall project or installation boundaries.. For example, two catch basins 60 m (200 ft) apart might need to be located 25 mm (0.1 ft) relative to each other, but need only be known to +30 m (+100 ft) relative to another catch basin 10 km (6 miles) away. Planning, design, and construction of typical USACE projects may require multiple feature location tolerances for project mapping requirements. In many instances, a feature may need to be located to a feature location tolerance well in excess of its plotted/scaled accuracy. Table 2-1 indicates recommended feature location tolerances of planimetric features. These feature tolerances are defined relative to adjacent points within the confines of a specific area, map sheet, or structure and not to the overall project or installation boundaries. **Photogrammetric map accuracy specifications should consider the functional requirements of the mapping and not feature location tolerance.**

f. Chapter precedence. The standards set forth in this chapter shall have precedence over numbers, figures, references, or guidance presented in other chapters of this manual.

2-2. Photogrammetric Mapping Standards

a. There are three recognized industry standards that can be used for specifying spatial mapping products and resultant accuracy compliance criteria:

(1) American Society for Photogrammetry and Remote Sensing (ASPRS). "ASPRS Accuracy Standards for Large-Scale Maps" (ASPRS 31 March 1993).

(2) Federal Geographic Data Committee (FGDC). "Geospatial Accuracy Standards, Part 3: National Standard for Spatial Accuracy (1998)," which is an update of Office of Management.

(3) Federal Geographic Data Committee (FGDC). "Geospatial Accuracy Standards, Part 4: Standards for Architecture, Engineering, Construction (A/E/C) and Facility Management (2001)."

Table 2-1
Recommended Surveying and Mapping Specifications for Military Construction, Civil Works, Operations, Maintenance, Real Estate, and Hazardous, Toxic, and Radioactive Waste (HTRW) Projects

Project or Activity	Equivalent Target (Plot) Map Scale[1] SI Ratio/ 1 in. = x ft	Feature Location Tolerance[2] mm/ft, RMS	Horiz Control Survey type[3]	Feature Elevation Tolerance[4] mm/ft, RMS	Vertical Control Survey Type[3]	Typical Contour Interval mm/ft
MILITARY CONSTRUCTION (MCA, MCAF, OMA, OMAF):						
Design and Construction of New Facilities: Site Plan Data for Direct Input into CADD 2-D/3-D Design Files						
General Construction Site Plan Feature and Topo Detail	1:500/40 ft	100mm/0.1-0.5 ft	3rd-I	50mm/0.1-0.3ft	3rd	250mm/1ft
Surface/Subsurface Utility Detail	1:500/40 ft	100mm/0.2-0.5 ft	3rd-I	50mm/0.1-0.2ft	3rd	N/A
Building or Structure Design	1:500/40 ft	25mm/0.05-0.2 ft	3rd-I	50mm/0.1-0.3ft	3rd	250mm/1ft
Airfield Pavement Design Detail	1:500/40 ft	25mm/0.05-0.1 ft	3rd-I	25mm/0.05-0.1ft	2nd	250mm/0.5-1ft
Grading and Excavation Plans (Roads, Drainage, etc.)	1:500/30-100 ft	250mm/0.5-2 ft	3rd-I/II	100mm/0.2-1ft	3rd	500mm/1-2ft
Maintenance and Repair (M&R), or Renovation of Existing Structures, Roadways, Utilities, etc., for Design/Construction/ Plans and Specifications (P&S)	1:500/30-50 ft	100mm/0.1-0.5 ft	3rd-I	50mm/0.1-0.5ft	3rd	250mm/1ft
Recreational Site P&S (Golf Courses, Athletic Fields, etc.)	1:1000/100 ft	500mm/1-2 ft	3rd-II	100mm/0.2-2ft	3rd	500mm/2-5ft
Training Sites, Ranges, Cantonment Areas, etc.	1:2500/100-200 ft	500mm/1-5 ft	3rd-II	1,000mm/1-5ft	3rd	500mm/2ft
Installation Master Planning and Facilities Management Activities (Including AM/FM and GIS Feature Applications)						
General Location Maps for Master Planning Purposes	1:5000/100-400 ft	1,000mm/2-10 ft	3rd-II	1,000mm/1-10ft	3rd	1,000mm/ 2-10ft
Space Management (Interior Design/Layout)	1:250/10-50 ft	50mm/0.05-1 ft	Relative to Structure	N/A	N/A	N/A

Note: Footnotes 1 through 4 are repeated in headings on each page. Other footnotes are numbered sequentially through Table 2-1.

[1] Target map scale is that contained in CADD, GIS, and/or AM/FM layer, and/or to which ground topo or aerial photography accuracy specifications are developed. This scale may not always be compatible with the feature location/elevation tolerances required. In many instances, design or real property features are located to a far greater relative accuracy than that which can be scaled at the target (plot) scale, such as property corners, utility alignments, first-floor or invert elevations, etc. Coordinates/elevations for such items are usually directly input into a CADD or AM/FM data base.

[2] The map location tolerance (or precision) of a planimetric feature is defined relative to two adjacent points within the confines of a structure or map sheet, not to the overall project or installation boundaries. Relative accuracies are determined between two points that must functionally maintain a given accuracy tolerance between themselves, such as adjacent property corners; adjacent utility lines; adjoining buildings, bridge piers, approaches, or abutments; overall building or structure site construction limits; runway ends; catch basins; levee baseline sections; etc. The tolerances between the two points are determined from the end functional requirements of the project/structure (e.g., field construction/fabrication, field stakeout or layout, alignment, locationing, etc.).

[3] Horizontal and vertical control survey accuracy refers to the procedural and closure specifications needed to obtain/maintain the relative accuracy tolerances needed between two functionally adjacent points on the map or structure, for design, stakeout, or construction. Usually 1:5,000 Third-Order control procedures (horizontal and vertical) will provide sufficient accuracy for most engineering work, and in many instances of small-scale mapping or GIS mapping, Third-Order, Class II methods and Fourth-Order topo/construction control methods may be used. Base- or area-wide mapping control procedures shall be specified to meet functional accuracy tolerances within the limits of the structure, building, or utility distance involved for design or construction surveys. Higher order control surveys shall not be specified for area-wide mapping or GIS definition unless a definitive functional requirement exists (e.g., military operational targeting or some low-gradient flood control projects).

[4] (See note 2.) Some flood control projects may require better relative accuracy tolerances than those shown.

(Sheet 1 of 5)

Table 2-1 (Continued)

Project or Activity	Equivalent Target (Plot) Map Scale[1] SI Ratio/ 1 in. = x ft	Feature Location Tolerance[2] mm/ft, RMS	Horiz Control Survey type[3]	Feature Elevation Tolerance[4] mm/ft, RMS	Vertical Control Survey Type[3]	Typical Contour Interval mm/ft
MILITARY CONSTRUCTION (Continued)						
Installation Surface/Subsurface Utility Maps (As-builts; Fuel, Gas, Electricity, Communications, Cable, Storm Water, Sanitary, Water Supply, Treatment Facilities, Meters, etc.)	1:1000/50-100ft (DA) 1:500/50ft (USAF)	100mm/0.2-1ft	3rd-I	100mm/0.2ft	3rd	250mm/1ft
Architectural Drawings: Customary Inch-Pound Scale	Equivalent SI Ratio	N/A	N/A	N/A	N/A	N/A
Site Plans: 1” = 20 ' (Landscape Planting Plans)	1:250 1:500					
Floor Plans: 1/4” = 1' - 0"	1:50					
1/8” = 1' - 0"	1:100					
1/16” = 1' - 0"	1:200					
Roof Plan: (no smaller than) 1/16" = 1' - 0"	1:200					
Exterior Elevations:						
1" or 1-1/2" = 1' - 0"	1:10					
1/8" = 1' - 0"	1:100					
1/16" = 1' - 0"	1:200					
Interior Elevations: 1/4" = 1' - 0"	1:50					
1/8" = 1' - 0"	1:100					
Cross Sections: 1/4" = 1' - 0"	1:50					
1/8" = 1' - 0"	1:100					
1/16" = 1' - 0"	1:50					
Wall Sections:						
1/2" or 3/4" = 1' - 0"	1:20					
Stair Details:						
1" or 1-1/2" = 1' - 0"	1:10					
Detail Plans:						
3" = 1' - 0"	1:5					
1" or 1-1/2" = 1' - 0"	1:10					
Area-/Installation-/Base-Wide Mapping Control Network to Support Overall GIS and AM/FM Development[5]	N/A	varies	3rd-I or 2nd-II	varies	2nd or 3rd	250-1000mm 1-10ft
Housing Management (Family housing, Schools, Boundaries, and Other Installation Community Services)	1:5000/100-400ft	10,000mm/ 10-50ft	4th	N/A	4th	N/A
Environmental Mapping and Assessments	1:5000/200-400ft	10,000mm/ 10-50ft	4th	N/A	4th	N/A
Emergency Services (Military Police, Crime/Accident Locations, Emergency Transport Routes, Post Security Zoning, etc.)	1:10000/400-2000ft	25,000mm/ 50-100ft	4th	N/A	4th	N/A
Cultural, Social, Historical (Other Natural Resources)	1:5000/400ft	10,000mm/ 20-100ft	4th	N/A	4th	N/A
Runway Approach and Transition Zones; General Plans/Section[6]	1:2500/100-200ft	2,500mm/5-10ft	3rd-II	2 500mm/2-5ft	3rd	1 000mm/5ft

[5] GIS raster or vector features generally can be scaled or digitized from any existing map of the installation. Typically a standard USGS 1:24,000 (1 in. = 2,000 ft) scale quadrangle map is adequate given the low relative accuracies needed between GIS data features, elements, or classifications. Relative or absolute GPS positioning (1m to 100m) may be adequate to tie GIS features where no maps exist. In general, a basic area- or installation-wide Second- or Third-Order control network is adequate for all subsequent engineering, construction, real estate, GIS, and/or AM/FM control.

[6] Typical requirements for general approach maps are 1:50,000 (H) and 1:1,000 (V); detail maps at 1:5,000 (H) and 1:250 (V).

(Sheet 2 of 5)

Table 2-1 (Continued)

Project or Activity	Equivalent Target (Plot) Map Scale[1] SI Ratio/ 1 in. = x ft	Feature Location Tolerance[2] mm/ft, RMS	Horiz Control Survey type[3]	Feature Elevation Tolerance[4] mm/ft, RMS	Vertical Control Survey Type[3]	Typical Contour Interval mm/ft
CIVIL WORKS DESIGN, CONSTRUCTION, OPERATIONS AND MAINTENANCE ACTIVITIES						
Site Plan for Design Memoranda, Contract Plans and Specifications, etc. C for Input to CADD 2-D/3-DDesign Files						
Locks, Dams, Flood Control Structures; Detail Design Plans	1:500/20-50ft	25mm/0.05-1ft	2nd-II	10mm/ 0.01-0.5ft	2nd/3rd	250mm/0.5-1ft
Grading/Excavation Plans	1:1000/100ft	1 000mm/0.5-2ft	3rd-I	100mm/0.2-1ft	3rd	1 000mm/1-5ft
Spillways, Concrete Channels, Upland Disposal Areas	1:1000/50-100ft	100 mm/0.1-2ft	2nd-II	100mm/0.2-2ft	3rd	1 000mm/1-5ft
Construction In-place Volume Measurement	1:1000/40-100ft	500mm/0.5-2ft	3rd-I	250mm/0.5-1ft	3rd	N/A
River and Harbor Navigation Projects: Site Plans, Design, Operation, or Maintenance of Flood Control Structures, Canals, Channels, etc. C for Contract Plans or Reports						
Levees and Groins (New Work or Maintenance Design Drawings)	1:1000/100ft	500mm/1-2ft	3rd-II	250mm/0.5-1ft	3rd	500mm/1-2ft
Canals and Waterway Dredging (New Work Base Mapping)[7]	1:1000/100ft	1 000mm/2ft	3rd-II	250mm/0.5ft	3rd	250mm/1ft
Canals and Waterway Dredging (Maintenance Drawings)	1:2500/200ft	1 000mm/2ft	3rd-II	250mm/0.5ft	3rd	250mm/1ft
Beach Renourishment/Hurricane Protection Projects	1:1000/100-200ft	1 000mm/2ft	3rd-II	250mm/0.5-1ft	3rd	250mm/1ft
Project Condition Reports (Base Mapping for Plotting Hydrographic Surveys: line maps or air photo plans)	1:2500/ 200-1,000ft	10 000mm/ 5-50ft	3rd-II	250mm/0.5-1ft	3rd	500mm/1-2ft
Revetment Clearing, Grading, and As-built Protection	1:5000/100-400ft	2 500mm/2-10ft	3rd-II	250mm/0.5-1ft	3rd	500mm/1-2ft
Geotechnical and Hydrographic Site Investigation Surveying Accuracies for Project Construction						
Hydrographic Contract Payment and P&S Surveys	1:2500/200ft	2 000mm/6ft (2DRMS)	N/A	250mm/0.5ft	N/A	250mm/1ft
Hydrographic Project Condition Surveys	1:2500/200ft	5 000mm/16ft (2DRMS)	N/A	500mm/1.0ft	N/A	250mm/1ft
Hydrographic Reconnaissance Surveys	C	0.15km/500ft (2DRMS)	N/A	500mm/1.5ft	N/A	250mm/1ft
Geotechnical Investigative Core Borings/Probings/etc.	C	5 000mm/5-15ft	4th	50mm/0.1-0.5ft	3rd or 4th	N/A
General Planning and Feasibility Studies, Reconnaissance Reports, Permit Applications, etc.	1:2500/100-400ft	1 000mm/2-10ft	3rd-II	500mm/0.5-2ft	3rd	1 000mm/ 2-10ft
GIS Feature Mapping--Civil Works Projects						
Area/Project-Wide Mapping Control Network to Support Overall GIS Development	N/A	Varies 1:5000	2nd-I or 2nd-II	Varies	2nd	1 000mm/ 1-10ft
Soil and Geologic Classification Maps, Well Points	1:5000/400ft	10 000mm/ 20-100ft	4th	N/A	4th	N/A

[7] Table refers to base maps upon which subsurface hydrographic surveys are plotted, not to hydrographic survey control.

(Sheet 3 of 5)

Table 2-1 (Continued)

Project or Activity	Equivalent Target (Plot) Map Scale[1] SI Ratio/ 1 in. = x ft	Feature Location Tolerance[2] mm/ft, RMS	Horiz Control Survey type[3]	Feature Elevation Tolerance[4] mm/ft, RMS	Vertical Control Survey Type[3]	Typical Contour Interval mm/ft
CIVIL WORKS DESIGN, CONSTRUCTION, OPERATIONS AND MAINTENANCE ACTIVITIES ACTIVITIES (Continued)						
Cultural and Economic Resources, Historic Preservation	1:10000/1,000ft	10 000mm/ 50-100ft	4th	N/A	4th	N/A
Land Utilization GIS Classifications; Regulatory Permit General Locations	1:5000/400-1,000ft	10 000mm/ 50-100ft	4th	N/A	4th	N/A
Socio-economic GIS classifications	1:10,000/1,000ft	20 000mm/ 100ft	4th	N/A	4th	N/A
Land Cover Classification Maps	1:5000/400-1,000ft	10 000mm/ 50-200ft	4th	N/A	4th	N/A
Archeological or Structure Site Plans & Details (Including Non-topographic, Close Range, Photogrammetric Mapping)	1:10/0.5-10ft	5mm/0.01-0.5ft	2nd I/II	5mm/ 0.01-0.5fft	2nd	100mm/0.1-1ft
Structural Deformation Monitoring Studies/Surveys[8]						
Reinforced Concrete Structures (Locks, Dams, Gates, Intake Structures, Tunnels, Penstocks, Spillways, Bridges, etc.)	Large-scale vector movement diagrams or tabulations	10mm/0.03ft (long term)	N/A[9]	2mm/0.01ft	N/A[9]	N/A
Earth/Rock Fill Structures (Dams, Floodwalls, Levees, etc.) (slope/crest stability & alignment)		30mm/0.1ft (long term)	N/A	15mm/0.05ft	N/A	N/A
Crack/joint & deflection measurements (precision micrometer)	tabulations	0.2mm/0.01inch	N/A	N/A	N/A	N/A
Flood Control and Multipurpose Project Planning, Floodplain Mapping, Water Quality Analysis, and Flood Control Studies	1:5000/400-1,000ft	10 000mm/ 20-100ft	3rd-I	100mm/0.2-2ft	2nd or 3rd	1 000mm/2-5ft
Federal Emergency Management Agency Flood Insurance Studies	1:5000/400ft	10 000mm/20ft	3rd-I	250mm/0.5ft	3rd	1 000mm/4ft
REAL ESTATE ACTIVITIES (ACQUISITION, DISPOSAL, MANAGEMENT,AUDIT)[10]						
Tract Maps, Individual, Detailing Installation or Reservation Boundaries, Lots, Parcels, Adjoining Parcels, and Record Plats, Utilities, etc.	1:1000/50-400ft[11]	10mm/0.05-2ft	3rd-I/II	100mm/0.1-2ft	3rd	1 000mm/1-5ft
Condemnation Exhibit Maps	1:1000/50-400ft	10mm/0.05-2ft	3rd-I/II	100mm/0.1-2ft	3rd	1 000mm/1-5ft
Guide Taking Lines (for Fee and Easement Acquisition) Boundary Encroachment Maps	1:500/20-100ft	50mm/0.1-1ft	3rd-I/II	50mm/0.1-1ft	3rd	250mm/1ft
Real Estate GIS or LIS General Feature Mapping Land Utilization and Management Forestry Management Mineral Acquisition	1:5000/200-1,000ft	10 000mm/ 50-100ft	4th	N/A	4th	N/A
General Location or Planning Maps	1:24,000 (USGS)	10 000mm/ 50-100ft	N/A	5 000mm/5-10ft	3rd	2 000mm/ 5-10ft
Easement Areas and Easement Delineation Lines	1:1000/100ft	50mm/0.1-0.5ft	3rd-I/II	50mm/0.1-0.5ft	3rd	C

[8] Long-term structural movements measured from points external to the structure may be tabulated or plotted in either X-Y-Z or by single vector movement normal to a potential failure plane. Reference EM 1110-2-4300, EM 1110-2-1908, and EM 1110-1-1004 for stress-strain, pressure, seismic, and other precise structural deflection measurement methods within/between structural members, monoliths, cells, embankments, etc.

[9] Accuracy standards and procedures for structural deformation surveys are contained in EM 1110-1-1004. Horizontal and vertical deformation monitoring survey procedures are performed relative to a control network established for the structure. Ties to the National Geodetic Reference System or National Geodetic Vertical Datum of 1929 are not necessary other than for general reference, and then need only USACE Third-Order connection.

[10] Real property surveys shall conform to local/state minimum technical standards and/or recognized practices, and where prescribed by law or code.

[11] A 1:1,200 (1-in. = 100-ft) scale is recommended by ER 405-1-12. Smaller scales should be on even 30-m (100-ft) increments.

(Sheet 4 of 5)

Table 2-1 (Concluded)

Project or Activity	Equivalent Target (Plot) Map Scale[1] SI Ratio/ 1 in. = x ft	Feature Location Tolerance[2] mm/ft, RMS	Horiz Control Survey type[3]	Feature Elevation Tolerance[4] mm/ft, RMS	Vertical Control Survey Type[3]	Typical Contour Interval mm/ft
HAZARDOUS, TOXIC, & RADIOACTIVE WASTE (HTRW) SITE INVESTIGATION, MODELING, AND CLEANUP						
General Detailed Site Plans (HTRW Sites, Asbestos, etc.)	1:500/5-50ft	100mm/0.2-1ft	2nd-II	50mm/ 0.1-0.5ft	2nd or 3rd	100mm/0.5-1ft
Subsurface Geotoxic Data Mapping (Modeling)	1:500/20-100ft	1 000mm/1-5ft	3rd-II	500mm/1-2ft	3rd	500mm/1-2ft
Contaminated Ground Water Plume Mapping (Modeling)	1:500/20-100ft	1 000mm/2-10ft	3rd-II	500mm/1-5ft	3rd	500mm/1-2ft
General HTRW Site Plans, Reconnaissance Mapping	1:2500/50 - 400	5 000mm/2-20ft	3rd-II	1 000mm/ 2-20ft	3rd	1 000mm/2-5ft
EMERGENCY OPERATION MANAGEMENT ACTIVITIES						
(Use basic GIS database requirements defined above)						
(Sheet 5 of 5)						

Each of these standards has application to different types of functional products, ranging from wide-area small-scale mapping (FGDC Geospatial Accuracy Standards, Part 3 (FGDC 1998)) to large-scale engineering design (ASPRS Accuracy Standards for Large-Scale Maps and FGDC Geospatial Accuracy Standards, Part 4 (FGDC 1998)). Their resultant accuracy criteria (i.e., spatial errors in X-Y-Z), including QC compliance procedures, do not differ significantly from one another. In general, use of any of these standards for a photogrammetric mapping contract will result in a quality product. The operational philosophy of many photogrammetric mapping offices is oriented toward ASPRS and National Map Accuracy Standards, Office of Management and Budget (OMB). Notwithstanding, Contractors are obligated to meet accuracies referenced in this document as USACE Photogrammetric Mapping Standards if specified in a contract.

b. OMB Circular No. A-119, “Federal Participation in the Development and Use of Voluntary Standards,” prescribes that Federal agencies maximize use of industry standards and consensus standards established by private voluntary standards bodies, in lieu of Government-developed standards. Voluntary industry standards shall be given preference over nonmandatory Government standards. When industry standards are nonexistent, inappropriate, or do not meet a project's functional requirement, DoD, Army, USACE, or FGDC standards may be specified as criteria sources. Specifications for surveying and mapping shall use industry consensus standards established by national professional organizations, such as the ASPRS, the American Society of Civil Engineers (ASCE), the American Congress on Surveying and Mapping (ACSM), or the American Land Title Association (ALTA). Technical standards established by state boards of registration, especially on projects requiring licensed surveyors or mappers, shall be followed when legally applicable. Commands shall not develop or specify local surveying and mapping standards where industry consensus standards or Army standards exist.

2-3. USACE Photogrammetric Mapping Standard

The USACE accuracy standard for photogrammetric mapping is modeled after the ASPRS Accuracy Standards for Large-Scale Maps and Part 4 of the Federal Geographic Data Committee (FGDC) Geospatial Positioning Accuracy Standards (1998). When applicable to a specific photogrammetric mapping process or product, ASPRS standard will be the USACE standard. This standard was developed for the production mapping products with spatial accuracies typically required for engineering projects designed by the USACE. This standard is intended for site plan development work involving mapping scales larger than 1:20,000, usually in the range of 1 in. = 40 ft to 1 in. = 1,667 ft. Its primary advantage over other standards is that it contains more definitive statistical map testing criteria, which, from a contract administration standpoint, is desirable. It also is applicable to conventional surveying topographic site development work. This standard, like most other mapping standards, defines map accuracy by comparing the mapped location of selected well defined points to their "true" location, as determined by a more accurate, independent field survey. When no independent check is feasible or practicable, a map's accuracy may be estimated based on the accuracy of the technique used to locate mapped features (e.g., GPS, total station, plane table, etc.) For small-scale general location mapping work (i.e., scales smaller than 1:20,000), the "United States National Map Accuracy Standards" (Bureau of the Budget 1947) and "U.S. National Cartographic Standards for Spatial Accuracy" are perhaps the most widely used standards and are recommended for USACE small-scale mapping.

a. Application of standards. The objective of the USACE photogrammetric standards is twofold:

(1) To help ensure that the topographic map accuracy standards or geospatial database accuracy will be met during the production process.

(2) To help ensure that contractual deliverables other than maps, such as aerial photographs, ground control, etc., will possess quality of the required degree.

b. Map accuracy subclassifications. The ASPRS Standard classifies a map as statistically meeting a certain level of accuracy. Its primary advantage over other standards for large-scale mapping is that it contains more definitive statistical map testing criteria. Using guidance in Tables 2-2 and 2-3, specifications for site plans need only indicate the ASPRS map class, target scale (horizontal map scale), and contour interval. Three map accuracy classifications are prescribed in the ASPRS Standards. These classes are discussed in paragraph 2-4a. Lower classifications will be more economical, albeit less accurate. The project engineer/manager coupled with the USACE photogrammetric mapping specialist must determine the specific map accuracy requirement and class for a given project based on the functional requirements. The accuracy class must be shown on all final drawings/design files.

Table 2-2
ASPRS Planimetric Feature Coordinate Accuracy Requirement (Ground X or Y) for Well-Defined Points

Target Map Scale	ASPRS Limiting RMSE in X or Y (Meters)			Target Map Scale		ASPRS Limiting RMSE in X or Y (Feet)		
Ratio m/m	Class 1	Class 2	Class 3	1"=x ft	Ratio, ft/ft	Class 1	Class 2	Class 3
1:500	0.125	0.25	0.375	40	1:480	0.4	0.8	1.2
1:1,000	0.25	0.50	0.75	50	1:600	0.5	1.0	1.5
1:2,000	0.50	1.00	1.5	60	1:720	0.6	1.2	1.8
1:2,500	0.63	1.25	1.9	100	1:1,200	1.0	2.0	3.0
1:3,000	0.75	1.5	2.25	200	1:2,400	2.0	4.0	6.0
1:4,000	1.0	2.0	3.0	300	1:3,600	3.0	6.0	9.0
1:5,000	1.25	2.5	3.75	400	1:4,800	4.0	8.0	12.0
1:8,000	2.0	4.0	6.0	500	1:6,000	5.0	10.0	15.0
1:9,000	2.25	4.5	6.75	600	1:7,200	6.0	12.0	18.0
1:10,000	2.5	5.0	7.5	800	1:9,600	8.0	16.0	24.0
1:16,000	4.0	8.0	12.0	1,000	1:12,000	10.0	20.0	30.0
1:20,000	5.0	10.0	15.0	1,667	1:20,000	16.7	33.0	50.0

c. Use of ASPRS Standards for ground survey mapping. The ASPRS Standards are also applicable to large-scale site plan mapping performed by plane table or electronic total station techniques. This work may either supplement the aerial mapping work (e.g., surface or subsurface utility details) or be of a scale too large for aerial mapping (generally larger than 1 in. = 40 ft).

d. Compliance tests. Tests for compliance with the ASPRS and other map accuracy standards are discussed in more detail in Chapter 2, paragraph 2-4*d*, and Chapter 3, paragraph 3-7. Maps found compliant with a particular standard shall have a statement indicating that standard. The compliance statement shall refer to the data of lowest accuracy depicted on the map. As a result of the high cost of field testing, not all deliverables should be tested. In such cases, the statement should clearly indicate that the procedural mapping

Table 2-3
ASPRS Topographic Elevation Accuracy Requirement for Well-Defined Points

ASPRS Limiting RMSE in Meters							ASPRS Limiting RMSE in Feet						
Target Contour Interval	Topographic Feature Points			Spot or Digital Terrain Model Elevation Points			Target Contour Interval	Topographic Feature Points			Spot or Digital Terrain Model Elevation Points		
Meters	Class1	Class 2	Class 3	Class 1	Class 2	Class3	Feet	Class 1	Class 2	Class 3	Class 1	Class 2	Class 3
0.5	0.17	0.33	0.50	0.08	0.16	0.25	1	0.33	0.66	1.0	0.17	0.33	0.5
1	0.33	0.66	1.0	0.17	0.33	0.5	2	0.67	1.33	2.0	0.33	0.67	1.0
2	0.67	1.33	2.0	0.33	0.67	1.0	3	1.0	2.0	3.0	0.50	1.00	1.50
							4	1.33	2.67	4.0	0.67	1.33	2.0
4	1.33	2.67	4.0	0.67	1.33	2.0	5	1.67	3.33	5.0	0.83	1.67	2.5
5	1.67	3.33	5.0	0.83	1.67	2.5	10	3.33	6.66	10.0	1.67	3.33	5.0

specifications were designed and performed to meet a certain ASPRS map classification but that a rigid compliance test was not performed. Published maps and geospatial databases whose errors exceed those given in a standard should indicate in their legends or metadata files that the map is not controlled and that dimensions are not to scale. This accuracy statement requirement is especially applicable to databases compiled from a variety of sources containing known or unknown accuracy reliability. Generally, overall map accuracy is affected by each of the main processes used in photogrammetric map production. Aerial photography, supporting ground control, aerotriangulation, and feature collection are the main processes. Deviation from standard guidance in subsequent chapters in this manual regarding these processes can result in degradation of map accuracy. The effect of noncompliance is not always intuitive and is often map scale- and/or process-dependent. Map accuracy should begin in the scope of work development. The scope of work should follow the guidelines established in this manual without being overly prescriptive. Quality Assurance (QA) testing should involve review for compliance of each process as the project proceeds. Accuracy testing of mapping products should be performed within a fixed time period after delivery. The contractor selection process should consider contractor's QC processes. The Government should only perform minimal, selected QA testing. QA should focus on whether the contractor meets the required performance specification (e.g., map accuracy). In accordance with the ASPRS Standard and class, the horizontal and vertical accuracies of a map are checked by comparing measured coordinates or elevations from the map (at its intended target scale) with spatial values determined by a check survey of higher accuracy. The check survey should be at least twice as accurate as the map feature tolerance given in the ASPRS tables.

2-4. ASPRS Accuracy Standards for Large-Scale Maps

In March 1990, the Professional Practicing Division, ASPRS, approved a set of standards as guidelines for large-scale mapping (Appendix D). These standards have been designed for large-scale planimetric and topographic maps prepared for engineering applications and other special purposes. ASPRS standards defines map accuracy by comparing the mapped location of selected well-defined points to their Aactual@ location as determined by a more accurate, independent field survey. Its primary advantage over other standards is that it contains more definitive statistical map testing criteria, which, from a contract administration standpoint, is desirable. The ASPRS standard has application to different types of mapping, ranging from wide-area, small-scale, GIS mapping to large-scale construction site plans. The ASPRS standards shall be used for USACE large-scale mapping projects. The ASPRS standards are synopsized below.

a. Map classes. Three map accuracy classes are defined. Class 1 maps are the most accurate. Class 2 maps have twice the root mean square error (RMSE) of a Class 1 map; Class 3 maps have thrice the RMSE of a Class 1 map. RMSE is defined to be the square root of the average of the squared discrepancies. The discrepancies are the differences in coordinate or elevation values as derived from the map and as determined by an independent survey of higher accuracy (check survey). The RMSE is defined in terms of feet or meters at ground scale rather than in inches or millimeters at the target map scale. This results in a linear relationship between RMSE and target map scale; as map scale decreases, the RMSE increases linearly. The RMSE is the cumulative result of all errors including those introduced by the processes of ground control surveys, map compilation, and final extraction of ground dimensions from the target map.

b. Horizontal accuracy criteria. The planimetric standard makes use of the RMSE. The limiting horizontal RMSEs shown in Table 2-2 are the maximum permissible RMSEs established by this standard. These limits of accuracy apply to well-defined points only.

c. Vertical accuracy criteria. Vertical accuracy is defined relative to the required contour interval (CI) for a map. In cases where only digital terrain models (DTM) or digital elevation models (DEM) are being generated, an equivalent CI must be specified based on the required digital point (spot) elevation accuracy. The contours themselves may be generated later using CADD software routines. The vertical standard also uses the RMSE, but only for well-defined features between contours containing interpretative elevations, or spot elevation points. Contours in themselves are not considered as well-defined feature points. The RMSE for Class 1 contours is one-third of the CI. The RMSE for Class 1 spot heights is one-sixth of the CI. Class 2 and Class 3 accuracies are twice and thrice those of Class 1, respectively. Testing for vertical map compliance is also performed by independent, higher accuracy ground survey methods, such as differential leveling. Table 2-3 summarizes the limiting vertical RMSEs for well-defined points, as checked by independent surveys at the full (ground) scale of the map.

d. Map accuracy testing. Map accuracy testing can be costly and time consuming. One or more sheets (or segments of a design file) may be tested for compliance. The decision whether to check photogrammetric mapping products rests with the Contracting Officer or his designated representative and is dependent on numerous factors, such as intended design work, available personnel, known contractor capabilities, and personnel resources available for the test. Every attempt should be made to review and check major phases of the mapping process (i.e., project planning, ground control, aerotriangulation, and compilation) as they are completed. Additional ground survey checks of map feature accuracy should be limited and in most cases eliminated. The Government should rely heavily on the Contractor's QC program and procedures to check for and catch blunders. **When it becomes necessary to perform independent QA checks for map accuracy, the USACE will follow the ASPRS standards for map accuracy tests.** Horizontal and vertical accuracy is to be checked by comparing measured coordinates or elevations from the map (at its intended target scale) with coordinates determined by a check survey of higher accuracy. The check survey should be at least twice as accurate as the map feature tolerance given in the ASPRS tables, with a minimum of 20 points tested. Maps and related geospatial databases complying with a required standard shall have a statement indicating that standard. The compliance statement shall refer to the data of lowest accuracy depicted on the map, or, in some instances, to specific data layers or levels. The statement shall clearly indicate the target map scale at which the map or feature layer was developed. Because of the high cost of field testing, not all deliverables will be physically tested. In such cases, the statement shall clearly indicate that the procedural mapping specifications were designed and performed to meet a certain ASPRS map classification, but that a rigid compliance test was not performed. Published maps and geospatial databases with errors exceeding those given in a standard shall indicate in their legends or metadata files that the map is not controlled and that dimensions are not to scale. This accuracy statement requirement is especially applicable to GIS databases that may be compiled from a variety of sources containing known or unknown accuracy reliability.

(1) For horizontal points, the check survey should produce a standard deviation equal to or less than one-third of the limiting RMSE selected for the map. This means that the relative distance accuracy ratio of the check survey must be less than one-third that of the limiting RMSE, expressed as a function of the distance measured across an agreed upon typical map sheet or digital file equivalent (not overall project or design file) diagonal. **For example,** given a 1-in. = 50-ft target scale with a required horizontal feature accuracy of 0.5 ft (i.e., Table 2-2, Class 1 accuracy) and a typical diagonal distance of 40 in. across a typical map sheet, the check survey should have a relative accuracy of 1:12,000, or Second-Order, Class 2 (50 ft/in. by

40 in./0.5 ft/3). This accuracy level is constant for all scales plotted on a standard drawing sheet with approximately a 40-in. dimension.

(2) Only the dimensions of a typical sheet or digital file equivalent, not the overall project or design file dimensions, are used to compute relative line accuracies. This is true regardless of whether or not the data are contained in an overall digital design file. The critical parameter for engineering and construction is relative to the accuracy of map features within the range of a drawing/sheet.

(3) For vertical points, the check survey (i.e., Global Positioning System (GPS), differential leveling, or electronic total station trig elevations) should produce an RMSE not greater than 1/20th of CI, expressed relative to the longest diagonal dimension of a standard drawing sheet. The map position of the ground point may be shifted in any direction by an amount equal to twice the limiting RMSE in horizontal position. Ground survey techniques considered acceptable for check surveys should include GPS, differential leveling, or total station trig elevations. The RMSE requirement for the check survey should direct the survey techniques utilized. Again, as with horizontal evaluation, vertical check survey accuracies are relative to the area on a given map sheet, <u>not</u> to the overall project dimension.

(4) The same survey datums must be used for both the mapping and check surveys. Care should be taken to ensure that datums are consistent and that any datum conversion was calculated properly.

(5) Refer to Chapter 3, paragraph 3.7, Quality Control/Quality Assurance, for additional details on map testing criteria.

e. Checkpoints. As mentioned earlier, checkpoints should be confined to well-defined features. Depending upon map scale, certain features will be displaced for the sake of map clarity. These points should not be used unless the rules for displacement are well known and can be counteracted. Test points should be well distributed over the map area. Any checkpoint whose discrepancy exceeds three times the limiting RMSE should be corrected before the map is considered to meet the standard.

f. Compliance statement. Maps (or the appropriate digital design file descriptor level) produced to meet the USACE standard shall include the following statement:

THIS MAP WAS COMPILED TO MEET THE USACE STANDARD FOR CLASS *[__] MAP ACCURACY

If the map was field checked and compliant, the following additional statement shall be added:

THIS MAP WAS CHECKED AND CONFORMED TO THE USACE STANDARD FOR CLASS *[__] MAP ACCURACY

For digital products, the descriptor level should also contain the original target mapping scale along with the absolute horizontal and vertical accuracies intended or checked.

2-5. Typical Mapping Scales, Contour Intervals, and Accuracy Classifications for USACE Functional Applications

Table 2-1 depicts typical mapping parameters for various USACE engineering, construction, and real estate mapping applications. The table is intended to be a general guide in selecting a target scale for a specific project; numerous other project-specific factors may dictate variations from these general values. The table does not apply exclusively to photogrammetric mapping activities. Some of the required surveying and mapping accuracies identified exceed those obtainable from photogrammetry and may need to be obtained using conventional surveying techniques. Selection of an appropriate CI is extremely site-dependent and will directly impact the mapping costs since the photo negative scale (and resultant model coverage and ground survey control) is determined as a function of this parameter. Table 2-1 may be used as general guidance in selecting a CI (or DTM elevation accuracy, as applicable). See also additional guidance in subsequent chapters dealing with photo mapping planning and cost estimating.

2-6. Supplemental USACE Photogrammetric Mapping Criteria

The following criteria shall be followed (and/or referenced) in preparing contract specifications or delivery order scopes of work for photogrammetric mapping services.

a. Non-International System of Units (SI)/SI conversion. Conversions between non-SI units and SI units of measure shall be as follows:

(1) 1 in. = 25.4 mm exactly

(2) 1 International Foot = 0.3048 m exactly

(3) 1 U.S. Survey Foot = 1,200/3,937 m exactly

b. Maximum enlargement for map compilation from negative to map scale. Enlargement factors are used during the planning phases of a project to establish an acceptable flight height that will produce an expected photogrammetric map horizontal accuracy. These enlargement factors are based on assumptions regarding the photogrammetric mapping process used by a specific mapping office. These assumptions are based on equipment used, climatic conditions during the flight, and expertise of personnel performing the processes. The maximum enlargement from original negative scale to final map scale shall conform to Table 2-4.

Table 2-4
Maximum Enlargement Ratios from Photographic Scale to Map Scale

	Maximum Enlargement Photo to Map	
Instrument Type	Map Class	Planimetric Map Enlargement
Analytical Stereoplotter	1	7
	2	8
	3	9
Softcopy Workstation	1	7
	2	8
	3	9

Note: Topographic enlargement limitations are a function of the contour interval and C-Factor.

c. C-Factor ratios. C-Factor (Contour Factor) has been a concept of determining appropriate flight altitude for vertical mapping from aerial photography for at least half a century. It is an empirical concept and subject to wide latitude of bias based on a number of variables, major among which are:

(1) Resolution and image definition of the aerial photograph affected by such factors as silver grain size, altitude, haze, sun angle, and brightness.

(2) Photographic lab processing of negatives and film transparencies.

(3) Sophistication and precision of the optical and mechanical system of the stereo mapping instrumentation.

(4) Integrity of a combination of ground control (GPS and/or conventional surveys), number and spacing of ground control points, airborne GPS hardware and post processing software, and aerotriangulation procedures and software.

(5) Reliability of digital data collection based on experience and visual depth perception of the stereoplotter operator.

C-Factor = Height of flight above mean terrain / Contour Interval

An **assumed C-Factor ratio** is used during the planning of a photogrammetric project to establish an acceptable flight height for an expected map vertical accuracy. Each office that produces photogrammetric maps has a different mix of equipment, personnel, and experience. **Assumed C-Factor ratios** are based on experience developed from similar projects. Photogrammetric maps produced with similar equipment and personnel and under the same general climatic circumstances should produce an ***actual C-Factor*** within a fairly tight range. The same final map vertical accuracy may be achieved with different equipment, personnel, and processes, and the *actual C-Factor* would fall within a broader range as shown in Table 2-5. The *actual C-Factor* can only be known after a project is completed and the accuracy tested. Planning of a photogrammetric mapping project should consider the **Assumed C-Factor Ratio Ranges** indicated in Table 2-5. Table 2-6 indicates photographic negative scales and flight altitudes that are compatible with the low end of the Assumed C-Factor Ratio Ranges for a specific map class as shown in Table 2-5.

Table 2-5
Assumed C-Factor Ratio Ranges (Denominator)

Stereoplotter	Class 1	Class 2	Class 3
Analytical	2,000	2,200	2,500
Softcopy	2,000	2,200	2,500

d. Minimum negative scales for planimetry. Table 2-7 depicts the minimum allowable negative scale (and related flight altitude for a 6-in. focal length camera) for a given target mapping scale. These minimum scales are based on the enlargement ratio for a given map class prescribed Table 2-4, and the Assumed C-Factor Ratio indicated for a map class in Table 2-5. The minimum scales are intended for large-scale engineering and design site plan mapping work. Enlargement factors are related to and dependent upon photogrammetric equipment, expertise, and personnel utilized throughout the photogrammetric mapping process. These variables may differ with different contractors. The Government should make use of individual contractor's experience as it relates to negative scale appropriate C-Factor on final map accuracy. The photographic negative scale and flight altitude used for a project should be established based on an individual contractor's experience and fall within the ranges noted in Table 2-4. The design negative scale may be computed by multiplying the target scale times the maximum allowable enlargement ratio prescribed in Table 2-4. Once it is decided which enlargement factor will be used in the project design, Table 2-7 should be checked to ensure agreement.

e. Minimum negative scale for topographic development. The negative scales and flight altitudes shown in Table 2-6 are based on the Assumed C-Factors shown in Table 2-5. The minimum negative scales in Table 2-6 shall be used relative to the vertical contour accuracy intended for the product. These negative scales, along with limitations based on the planimetric component, will be used in determining the optimum negative scale for a project. The limiting negative scales are computed based on the prescribed Assumed C-factor ratio chosen from Table 2-5 (multiplied by the CI and divided by 6).

Table 2-6
Minimum Negative Scale and Maximum Flight Altitudes for Topographic Development Negative Scale in English Feet and Flight Height in English Feet Above Mean Terrain Assumed C-Factor = 2,000

	Negative Scale in Inches to Feet (Altitude Above Mean Terrain in Feet)		
Contour Interval	**Class 1**	**Class 2**	**Class 3**
1 ft	330 (2,000)	370 (2,200)	420 (2,500)
0.5 m	550 (3,300)	600 (3,600)	680 (4,100)
2 ft	670 (4,000)	730 (4,400)	830 (5,000)
1 m	1,100 (6,600)	1,200 (7,200)	1,370 (8,200)
3 ft	1,000 (6,000)	1,110 (6,600)	1,250 (7,500)
4 ft	1,330 (8,000)	1,470 (8,800)	1,670 (10,000)
5 ft	1,670 (10,000)	1,830 (11,000)	2,390 (12,500)
2 m	2,170 (13,000)	2,400 (14,400)	2,730 (16,400)
10 ft	3,333 (20,000)	3,667 (22,000)	4,167 (25,000)

Table 2-7
Minimum Negative Scales and Maximum Flight Altitudes for Planimetric Mapping in English Feet (C-Factor assumed = 2,000)

	Negative Scale in Inches to Feet (Altitude Above Mean Terrain in Feet)		
TargetMap ScaleRatio	**Class 1**	**Class 2**	**Class 3**
1:500	292 (1,750)	333 (2,000)	375 (2,250)
1:600	350 (2,100)	400 (2,400)	450 (2,700)
1:1,000	583 (3,500)	667 (4,000)	750 (4,500)
1:1,200	700 (4,200)	800 (4,800)	900 (5,400)
1:2,000	1,167 (7,000)	1,333 (8,000)	1,500 (9,000)
1:2,400	1,400 (8,400)	1,600 (9,600)	1,800 (10,800)
1:2,500	1,458 (8,750)	1,667 (10,000)	1,875 (11,250)
1:4,800	2,800 (16,800)	3,200 (19,200)	3,600 (21,600)
1:5,000	2,917 (17,500)	3,333 (20,000)	3,750 (22,500)
1:9,600	5,600 (33,600)	6,400 (38,400)	7,200 (21,600)
1:10,000	5,833 (35,000)	6,667 (40,000)	7,500 (45,000)
1:12,000	7,000 (42,000)	8,000 (48,000)	9,000 (54,000)
1:16,000	9,333 (55,998)	10,667 (64,002)	12,000 (72,000)
1:20,000	11,667 (70,000)	13,333 (80,000)	15,000 (90,000)

Notes:
1. Minimum negative scale in feet per inch shown above maximum flight altitude in feet shown in brackets.
2. Capturing aerial photography above 22,000 ft may require specially equipped aircraft. The additional equipment and time required may equate to significant additional costs. When target map scales above 1:5,000 are required, consideration should be given to flying at an altitude below 22,000 ft.

f. ***Photo control survey standards and specifications.*** Ground survey control for photogrammetry can become a costly portion of a mapping project. Conventional traversing and level loops through difficult terrain can drastically affect the cost and time to establish ground control. Every attempt should be made to keep these costs and subsequent time frames to a minimum without jeopardizing the mapping quality and accuracy. The unique circumstances of a particular project should be considered in planning the tools that will be used to establish required ground control. Conventional traversing, levels, and GPS and Airborne GPS should all be considered as viable tools to establish ground control. Generally a combination of these tools will be required. The decision to use each of the tools should be based on accuracy required, time, cost and project specific conditions. Generally, industry standards should be used in deciding amount and placement of ground control. The tools and methods to be used in a photo control survey project should be the decision of the survey contractor. Ground survey contracts, task orders, and subsequent scopes of work should be performance oriented (i.e., survey control will be compatible with final map scale accuracy) and should not unnecessarily mandate procedures. Contractors are selected based partially on technical competence and when having full understanding of the intended use of the survey data requested should be able to plan and produce a product that meets the requirements. The accuracy requirement for the mapping project should be specified and the contractor should propose a minimum control plan that will achieve the required accuracy. Recommended horizontal and vertical control survey accuracy requirements are stated in Table 2-1. **In general, GPS technology should be able to achieve these results for both horizontal and vertical ground control.** The decision to check GPS derived horizontal and or vertical positions for a specific project should be project specific and not be mandated in the contract by a specified checking procedure. Ground survey requirements and planning information is addressed in other chapters in this manual. Detailed guidance regarding ground survey accuracy requirements and procedures is provided in Chapter 6 of this manual.

g. Aerotriangulation accuracy standards. Aerotriangulation may be accomplished with diapositives and stereoplotters, total softcopy workstation/scanning methods, or a combination of the two methods. The requirement and criteria will be the horizontal and vertical accuracy achieved. See Chapter 8 for more information regarding methods and processes involved in aerotriangulation. Aerotriangulation accuracy for each class of map and orthophotograph shall conform to Table 2-8.

Table 2-8
Aerotriangulation Accuracy Criteria

Map Class	Aerotriangulation Method	Allowable Error at Control and Test Points: Horizontal RMSE	Horizontal Max.	Vertical RMSE	Vertical Max.
1	**Fully Analytical or Softcopy Workstation**	**H/10,000**	**3 RMSE**	**H/9,000**	**3 RMSE**
2	**Fully Analytical or Softcopy Workstation**	**H/8,000**	**3 RMSE**	**H/6,000**	**3 RMSE**
3	**Fully Analytical or Softcopy Workstation**	**H/6,000**	**3 RMSE**	**H/4,000**	**3 RMSE**

2-7. USACE Orthophoto and Orthophoto Map Accuracy Standards

This section sets forth the standards for orthophotos and orthophoto maps. Orthophoto production is generally achieved by digital processes. High resolution scanning of diapositives or negative film coupled with the merging of DEM or DTM data utilizing acceptable rectification algorithms are the main processes involved in digital orthophoto production. **Photo enlargements, simply rectified images and rubber sheeting are photographic products and do not comply with the basic procedures involved in photogrammetry that produce accurate maps from aerial photography.** Items that affect digital orthophoto accuracy include: scanner quality and geometric accuracy, scanning pixel size, photography negative scale, and DTM resolution and accuracy. Each orthophoto shall meet the quality and precision specified in the contract. USACE standards for digital orthophoto mapping will conform to the accuracy standards specified below. Additional orthophoto mapping criteria are found in Chapter 10.

a. Photographic detail. The ground surface, vegetation, culture, planimetry, and all other details shall be clearly discernable. The photography scale must be designed for maximum feature discernability. The level of discernible detail is dependant on the pixel resolution of the scanned imagery and the desired final plot scale of the orthophoto.

b. Accuracy. Digital orthophotographs can have both a relative and absolute accuracy. The design plot scale (i.e., 1=500 planimetric feature scale) of the digital orthophotograph determines the relative accuracy. Enlargement of source photography for orthophotographs is dependent upon orthophoto design plot scale requirements and the type of terrain and shall meet requirements stated in Table 2-9. The planimetric (horizontal) accuracy of USACE orthophotos shall meet the ALimiting RMSE in X and Y@ stated in Table 2-2 for Classes 1 through 3. Acceptable "Photo Negative Scales" for Classes 1 through 3 will correspond with those indicated in Table 2-7. The pixel size in the image must be appropriate for showing the necessary ground details at the desired plot scale. Table 2-10 summarizes recommended pixel sizes for final map scales of digital orthophotographs. Orthophotos shall depict all visible image features in the correct planimetric position to the accuracy specified in subparagraph *c* below. Image displacements caused by ground relief and tilt shall be removed. Image displacement resulting from height of structures is inherent in typical orthophoto production processes and may not be removed without significant additional effort and time. When requested as an orthophoto overlay, topographic line and point data shall meet the topographic map standards previously set forth in this chapter.

Table 2-9
Digital Orthophoto Enlargement Factor From Photo Negative Scale

Class	Enlargement
1	4X TO 6X
2	7X TO 8X
3	9X TO 10X

c. Orthophoto accuracy statement. Specifications for USACE orthophotos shall state the accuracy in terms of ASPRS Standards for planimetric accuracy. Specifications shall also state the acceptable flight height and ground pixel resolution according to Tables 2-7 and 2-10.

Example

Aerial photography for orthophoto maps shall be flown at a photo negative scale of _____. Orthophoto maps shall meet or exceed the horizontal accuracy for ASPRS Class __ maps at 1:1,200 scale with a ground pixel resolution of _____ .

d. Compliance statement. Orthophoto maps in compliance with the USACE Standards shall include the following statement:

THIS ORTHOPHOTO MAP COMPLIES WITH ASPRS Class ____ Standards for 1:________ map scale with a Ground Pixel Resolution of ___________.

(1) The compliance statement shall refer to the data of lowest accuracy depicted on the orthophoto.

(2) Digital orthophoto maps with errors exceeding those aforestated shall omit from their legends all mention of standard accuracy.

e. Scan lines. The final orthophoto (map) shall not contain scan lines and mismatched imagery that interfere with the interpretability of ground features or the intended use of the images as specified.

2-8. Photogrammetric Mapping Coverage

Table 2-11 depicts various aerial photo mapping parameters that may be used for mission planning purposes. For more information regarding mission planning and cost estimation see Chapter 4. The Government should consider the expertise of the Contractor when planning a project. Some projects may be more economically

Table 2-10
Recommended Approximate Pixel Sizes for Selected Digital Orthophotograph Map Plot Scales

Final Map Plot Scale	Approximate Ground Pixel Resolution Required to meet USACE Accuracy Standards
1:500	0.0625 m
1"= 50 ft	0.25 ft
1:1,000	0.125 m
1"= 100 ft	0.5 ft
1:1,500	0.250 m
1:2,000	0.375 m
1"= 200 ft	1.0 ft
1:2500	0.5 m
1"= 400 ft	2.0 ft
1"= 500 ft	2.5 ft
1”= 1,000 ft	5.0 ft
1"= 2,000 ft	10.0 ft

Table 2-11
Standard Photogrammetric Mapping Coverage Parameters

Photo	9- by 9-in. Full Photo Width in feet	9- by 9-in. Full Photo Coverage Acres	Flight Line Spacing, ft	Lineal Gain Per Exposure, ft	Net Model Gain Acres
300	2,700	167	1,890	1,080	46
400	3,600	297	2,520	1,440	83
500	4,500	465	3,150	1,800	130
600	5,400	669	3,780	2,160	187
1,000	9,000	1,860	6,300	3,600	520
1,200	10,800	2,678	7,560	4,320	750
1,667	15,000	5,165	10,500	6,000	1,446
2,000	18,000	7,438	12,600	7,200	2,082.00

Notes:
1. Coverage parameters based on standard 6-in. camera, 9- by 9-in. negative size, 60 percent end lap, and 30 percent side lap. Net Model Gain = 28 percent (i.e., 0.4 by 0.7) of full photo coverage.
2. 1 acre = 43,560 square feet (sq ft)
3. 1 square mile (or section) = 640 acres

produced with deviation from the recommendations provided in Tables 2-4 through 2-11without sacrificing accuracy.

2-9. Mandatory Requirements in Chapter 2.

Mandatory requirements in Chapter 2 include paragraphs 2-3, 2-4, 2-6*d*, and 2-6*g*, and Table 2-8.

Chapter 3
Photogrammetric Processes

3-1. Photogrammetry

Photogrammetry is generally defined as the art and science of making accurate measurements from aerial photography. For the purposes of this manual, aerial photography will be limited to near vertical photography taken from a conventional fixed-wing or rotary-winged aircraft of satellite. Aerial photographs, as they are initially exposed, do not provide for accurate measurements. Distortions in the camera systems coupled with the curvature of the earth must be accounted for and eliminated in a series of techniques and processes in order to make measurements at a predicted accuracy across the area of coverage of an aerial photograph. These photogrammetric processes allow the user to view three dimensions from a two-dimensional surface (aerial photograph). Review Chapters 5 through 10 or a current surveying, photogrammetry, or remote sensing textbook for additional information regarding photogrammetric principles.

3-2. Photogrammetric Processes

a. Photogrammetric mapping is achieved through four general processes (Figure 3-1). The four processes are as follows:

(1) Imagery Acquisition.

(2) Ground Control Acquisition.

(3) Accurate Adjustment of the Imagery to the Earth.

(4) Feature Collection.

b. Generally, each photogrammetric project is unique. Each project is defined by spatial data collection for a unique piece of the earth with specific feature collection requirements. Feature collection requirements include accuracy and feature types. The general processes listed above may involve several significant sub-processes based on the feature collection requirements for a specific project.

3-3. Imagery Acquisition

Imagery for photogrammetric mapping (Table 3-1) may be broken into two general areas. Imagery for feature vertical and horizontal location and shape detail may be captured with the use of panchromatic (black and white) or natural color near vertical aerial photography or from digital satellite imagery. Other types of imagery such as color infrared aerial photography, thermal scanner imagery, and microwave imagery, multispectral and hyperspectral satillite imagery are generally used to detect unique feature data other than location and shape detail. These type images may be incorporated into a GIS and registered to other georeferenced data sets.

3.3.1 Vertical aerial photography

Near vertical aerial photography to be used for planimetric and topographic mapping is generally collected as stereo pairs. The photography is collected with forward overlap between each photograph as they are captured down a flight line. Mapping areas may require multiple flight lines in order to include all necessary mapping area within the imagery. In these cases, the imagery flight lines are flown so that they overlap (sidelap). Generally near vertical aerial photography is flown with a forward lap of 60 percent and side lap of

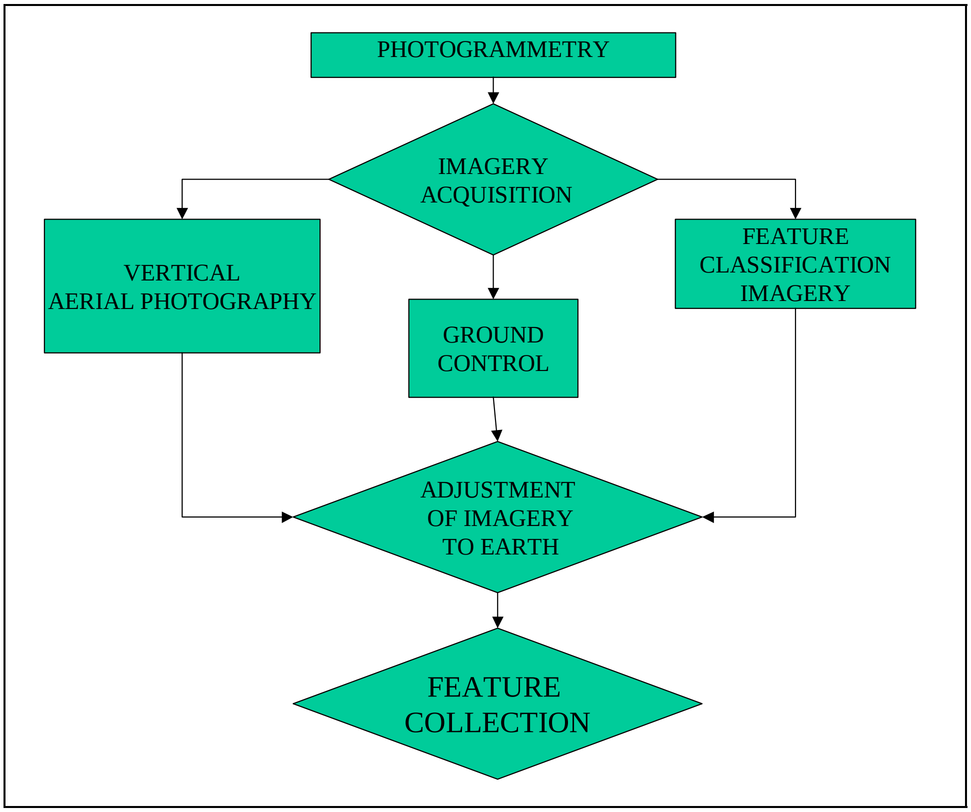


Figure 3-1. Photogrammatic mapping processes

Table 3-1
Imagery Types and Uses

Imagery Type	General Purposes
Black and White Aerial Photography	Topographic and Planimetric Mapping
Natural Color Aerial Photography	Topographic and Planimetric Mapping
Infrared Aerial Photography	Vegetation Analysis, Landuse/Land Classification
Satellite Imagery	Small-Scale Mapping, Vegetation Analysis, Land use/Land Classification
Microwave	Groundwater
Thermal	Heat Loss

30 percent. These parameters allow the pilot and photographer some latitude in the imagery collection and should provide enough overlap for the compiler to see stereo and map the required features. Generally, planimetric (buildings, roads, above ground utilities, etc.) and topographic features (mass points, breaklines, and contours) are collected from either black and white or natural color near vertical aerial photography. Planimetric and topographic mapping are generally the base mapping data set in a GIS or engineering data set. The accuracy of computations and queries made from these base mapping data sets is based on their thoroughness and accuracy. Black and white and natural color aerial photography generally provide the clarity and spatial resolution required to achieve most large- and small-scale mapping accuracies (Figure 3-2).

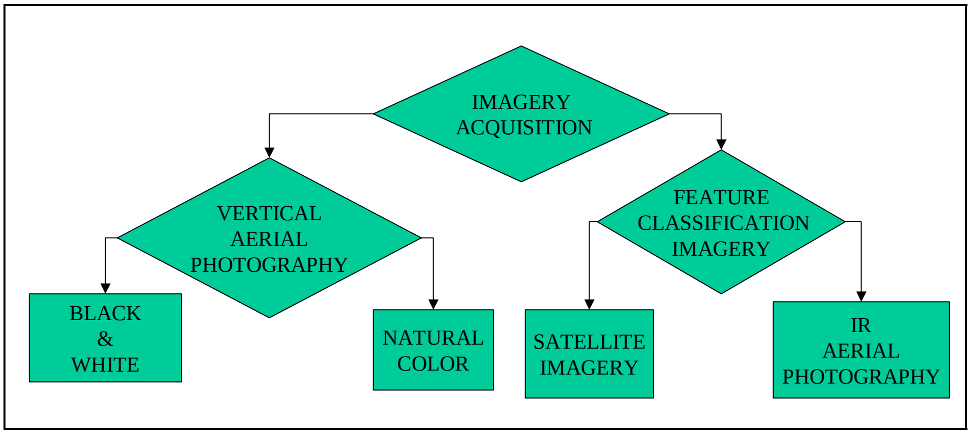


Figure 3-2. Imagery acquisition processes

3.3.2 Feature Classification Imagery

Feature classification imagery includes infrared (IR) aerial photography, satellite imagery (multispectral and hyperspectral) and digital scanners (thermal, microwave, etc). These types of imagery can be rectified to other base imagery or datums and used in various GIS analyses.

Primary uses of infrared imagery include the analysis of vegetation health and camoflaugh detection. Infrared imagery cannot detect thermal changes. Infrared imagery can be black and white or color. Black and white infrared has a relatively coarse imagery resolution compared to color infrared (CIR) and therefore is not used as frequently.

Satellite platforms operated by the United States, other countries, and private industry provide various sensors that can capture digital images of the earth. These sensors can provide panchromatic, color, and IR digital data at various spatial resolutions. Recently, private industry has launched satellites to provide high resolution digital imagery. These types of data may provide cost effective imagery over large portions of the earth. These types of spatial data are generally at a resolution far larger than that provided by aircraft platforms and may not be suitable for many large-scale mapping and GIS projects. However, high resolution satellite imagery may be an economical solution for some medium- to small-scale projects. The Corps of Engineers Topographic Engineering Center (TEC), Alexandria, VA, has staff trained to search out available data sets and contract vehicles to purchase the data for other USACE offices.

3-4. Ground Control

a. Ground control for photogrammetry is necessary to rectify the images to the earth prior to feature collection. Ground control accuracies must generally be greater than the accuracy required of the photogrammetric mapping. See Chapter 2, Table 2-1, for ground control accuracy requirements. Conventional traversing and level loops or GPS techniques, may be employed to obtain the necessary horizontal and vertical information (Figure 3-3).

b. Ground control must be planned based upon the method of image rectification to be used for the project. A team of a photogrammetrist familiar with the mapping requirements and a survey engineer should accomplish the planning of ground control or technician with unique experience in planning and establishing ground control for photogrammetry. Generally, the ground control must be around the perimeter of the mapping area. Some ground control points may be established on a portion of an existing ground feature that will be seen in the photography. Others will need to be established in a location with no existing suitable ground

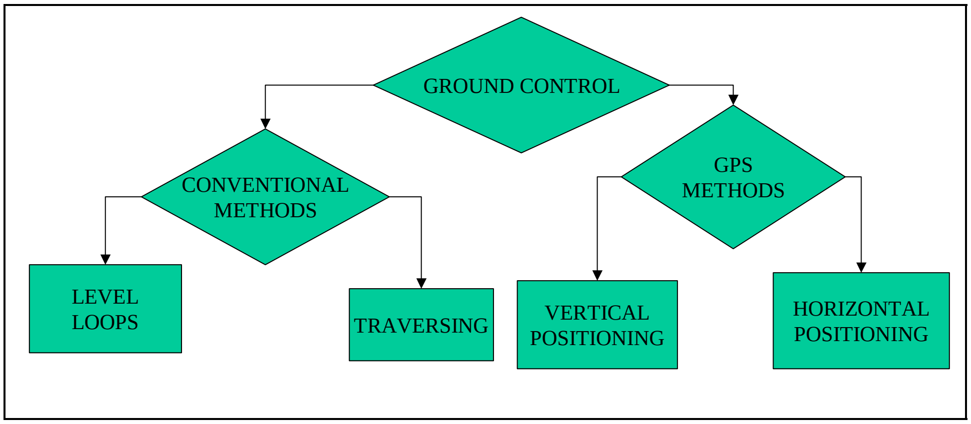


Figure 3-3. Ground control methods

feature. In these cases, a panel is placed on the ground that will be identifiable in the photography. The ground survey team can then establish the location of the panel.

c. Recent advancements in the GPS technology have provided for the collection of the horizontal and vertical location of the center of each photograph captured during a photography mission. This technology is referred to as airborne GPS (ABGPS). This technology can capture a large amount of ground control very efficiently and can supplement and in some cases reduce the amount of conventional ground control point collection. Again, planning for an ABGPS ground control project should be accomplished by an experienced team including photogrammetrists and survey engineers and/or technicians. See Chapter 7 for additional information regarding ABGPS technology.

d. The amount and location of ground control points is based upon the imagery rectification methods to be employed. Very small project areas (a few stereo models) may be economically rectified by convention methods. Conventional methods require a minimum of three horizontal points and four vertical points per stereo pair. Aerotriangulation is a mathematical process that allows for fewer ground points to be established. Aerotriangulation extends the horizontal and vertical control from a relatively few ground unknown points throughout a block of imagery. See Chapter 6, for additional information regarding ground control and aerotriangulation.

3-5. Adjustment of Imagery to the Earth

The process of adjusting the aerial photography to the earth is critical to the accuracy of final mapping products. Today most projects are adjusted using aerotriangulation methods. These methods require fewer ground control points than conventional adjustment methods. Aerotriangulation methods are accomplished with computer software. The software is very efficient and allows for quality control checks throughout the process. Aerotriangulation requires that the imagery be collected in blocks. Therefore, it is most efficient for large project areas. Unusually aerotriangulation of small areas or areas that have very irregular shapes looses efficiency and cost savings. However, the speed and quality control may still make this process acceptable for many small or irregularly shaped projects. Aerotriangulation accuracies should generally be greater than these required for the final mapping data sets. See Chapter 2, Table 2-8, for additional information regarding aerotriangulation accuracy criteria.

3-6. Feature Collection

a. Photogrammetric mapping feature collection can generally be divided into four categories (Figure 3-4).

(1) Topographic Features.

(2) Planimetric Features.

(3) Orthophotography.

(4) Landuse.

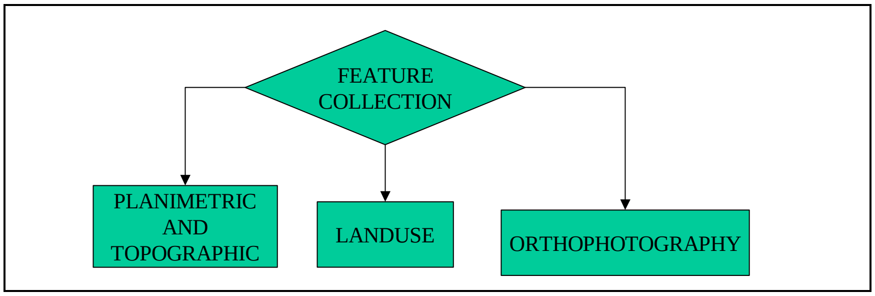


Figure 3-4. Feature collection processes

b. These feature types can be collected accurately using stereo imagery and stereo viewing equipment. Spatial data collection is expensive and it is important that the end user understand what his needs are regarding accuracy and format. Terminology between a photogrammetrist and the end user can often be confusing. Therefore, it is also important that a common understanding regarding data type, accuracy, and format be established prior to contract development.

3.6.1 Topographic features

a. Topographic features can generally be divided into two categories.

(1) Mass points

(2) Breaklines

b. Mass points define the horizontal and vertical location of specific points on the earth. These points generally define areas of change in elevation. Breaklines are lines that define an abrupt change in elevation such as a drainage feature, edge of roadway, etc. These two products are used to produce several elevation model types that are commonly requested by an end user.

(1) Together, mass points and breaklines are considered as a digital terrain model (DTM).

(2) An end user may require only mass points collected on an evenly spaced grid (every 10 m). This type of elevation model is considered a digital elevation model (DEM).

(3) A DTM is often imported into software that will generate a Triangulated Irregular Network (TIN) model. A TIN is often referred to as a surface model.

(4) A TIN model can be processed through software to generate contour lines (lines of equal elevation). TIN models can also be used to lay out and produce cross-section data across an area of interest (i.e., stream crossings for hydraulic analysis).

3.6.2 Planimetric features

a. Planimetric features include buildings, roads, railroads, utilities, etc. These features are generally collected as polygons denoting the perimeter of the feature. The features collected must be seen in the aerial imagery. Underground features cannot be photogrammetrically collected. However, utility data from another data source are often added to a photogrammetric mapping data set. The level of planimetric detail to be collected is generally determined by the scale of the photography. For example:

(1) 1:600-scale mapping would generally provide side walks, utility poles, fences, roads and curbs, manholes, catch basins, and shapes of individual structures.

(2) 1:16,800-scale mapping would not show sidewalks, most utility poles, fences, manholes, and catch basins. Structures would be symbolized and not drawn as unique feature shapes.

b. Large-scale photogrammetric mapping requires compatible large-scale aerial photography. See Chapter 2, Tables 2-6 and 2-7. The larger the photogrammetric mapping scale the more planimetric feature detail that can be seen and plotted. However, some features that may be seen in very large-scale mapping (1:600 and greater) may not normally be collected (i.e., parking lot strips, roof detail, mail boxes, moveable features). If these features are required, they should be specified in the SOW and will require extra time and cost.

3.6.3 Orthophotography

a. Obviously, planimetric feature collection can be time- and cost-consuming. Orthophotography can be an economical compromise for many projects. Orthophotography is not a simple scan and rubber sheeting process. A simple aerial photograph has distortions because of various mechanical and optical features in the camera system. The errors are not linear and therefore not uniform across a photograph. Horizontal measurements taken from a simple rubber-sheeted digital photograph are not accurate or consistent. Orthophotography involves a process (Figure 3-5) that eliminates the distortions in original aerial photography because of the camera system and distortion because of the elevation change.

b. It is very important to plan an orthophoto project properly. The aerial photography scale must be compatible with the final expected orthophoto horizontal scale and accuracy and the final ground pixel resolution. Generally, a four-times enlargement from the aerial photography will produce a suitable “ASPRS Class 1” orthophoto. See Chapter 2, Table 2-9.

c. The photography must be scanned at a resolution that is compatible with the final map scale and expected ground pixel resolution. See Chapter 2, paragraph 2-6, and Table 2-10. The scan should be accomplished with a high resolution (capable of scanning to resolutions as small as 7 microns) transmissive metric scanner. The end user should be aware of the final file sizes when requesting Orthophotography. It is often tempting to get as high a resolution orthophoto as possible. However, the file sizes can be prohibitive in some view software. Color orthophotos create file sizes that are three times as large as black and white orthophotos. If very high-resolution orthophotos are required, the end user may have to request that the Contractor also provide the data in a compression format with a viewer that allows for speedy viewing of large digital orthophoto files.

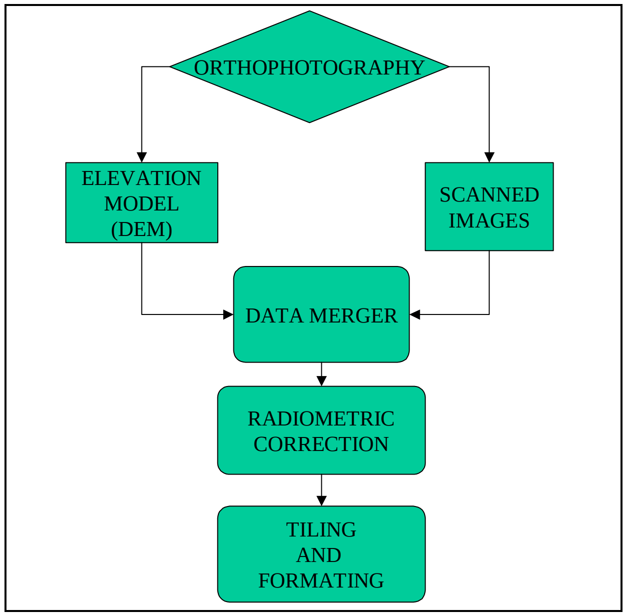


Figure 3-5. Orthophoto processes

d. The course digital elevation model (DEM) must be obtained from the aerial photography to be scanned. The DEM for orthorectification does not require as many points as a DEM to be used for the generation of a surface model or contour file. In some instances, a DEM that was developed from another imagery source of the project area may be used. However, review of the DEM must be accomplished prior to utilization in the orthophoto process to ensure that it was captured with compatible aerial photography (time period, photo scale, datum, and accuracy). Often USGS DEM data can be obtained, checked, and used to rectify an orthophoto.

e. Once a suitable scan and DEM are collected, orthophoto software can be used to merge the DEM with the scanned image and create the orthophoto image files. The image files are then reviewed and checked for scratches, dust, blemishes, and radiometric anomalies that can be corrected. A quality final orthophoto may not appear seamless throughout the total area. However, if the source photography was captured under the same general weather conditions and during the same general time period, the files' radiometric correction work should correct most anomalies and provide a near seamless image file. Additional work may also be required at bridges and overpasses to provide additional corrections necessary because of the elevation change between the bridge and the earth. The SOW should be clear regarding this correction work when necessary. Correction of tall building tilt is generally not required in an orthophoto mapping project unless specifically requested. This work can be time-consuming and the value may be questionable.

f. The overall file may then need to be tiled and formatted as per the SOW. Tile size may be a function of the equipment that will be used to view and work with the orthophotos. Resampled and/or compressed file formats may be necessary for the end user. The end user should discuss these requirements with the Contractor prior to negotiations and address the issue in the SOW.

3-7. Quality Control / Quality Assurance

The USACE generally obtains photogrammetric mapping products through Architect – Engineer type contracts. The selection criteria for photogrammetric mapping contractors are qualifications-based contracting. Therefore, demonstrated quality procedures must be in place to ensure that contractors are producing photogrammetric mapping products that meet the specifications requested. QC is procedures and processes that a contractor performs during the generation of photogrammetric mapping products to ensure that the products meet the intent of the contract. QA is procedures and processes that the Government performs during photogrammetric map production and or after delivery of final photogrammetric mapping products to ensure that the products meet the intent of the contract.

3.7.1 Quality control

General QC procedures (performed by the Contractor) for a photogrammetric mapping project should be part of the contractor selection process. Quality control should include project management as well as checking all interim and final products to insure compliance with the SOW. Quality control should be performed and documented on all required processes. A typical photogrammetric mapping project may include aerial photography acquisition, ground survey data collection, planimetric and topographic feature collection, and orthophoto production. Proper design and planning of a photogrammetric mapping project is critical in obtaining quality final products. A clear and concise SOW is vital to proper planning, design, and quality. Listed below are some of the QC steps that should be taken by a Contractor in a typical photogrammetric mapping project.

a. Aerial photography acquisition.

(1) The film type, flight height, and overlap should be designed to meet the requirements of a project and should be stated in the SOW.

(2) The current camera calibration report for the camera actually used for a project should be submitted with the processed film.

(3) Processed film negatives should be checked for aerial coverage and overlaps, scratches, and blemishes.

(4) Aerotriangulation. An aerotriangulation report should be generated and independently reviewed by qualified staff within the firm to ensure that procedures were followed that will ensure the final mapping accuracy stated in the SOW. The report should include an explanation of the procedures used, what ground points were not used in the solution (with an explanation), and a listing and discussion of the final results. The report should be signed and dated by the responsible aerotriangulation technician.

b. Feature compilation. Feature compilation should be checked for accuracy and completeness. This review process may involve resetting selected stereo models for accuracy checks against data withheld from the original compilation staff. Review may also include checking models in the stereo plotting system for thoroughness of planimetric and topographic feature compilation.

c. Final digital and hardcopy formatting. Final data sets (hardcopy and digital) should be review to insure compliance with the SOW. Marginalia, titles, symbology, line weights, etc should be reviewed on all hardcopy maps submitted. Digital files should also be reviewed for marginalia, titles, symbology, line weights, etc. Review of GIS maps should include a review of topology and annotation as requested in the SOW. When multiple copies of digital data are requested, the Contractor should insure that the copies have been accomplished accurately and completely on all digital storage media.

3.7.2 Quality assurance

a. Quality assurance is review of photogrammetric mapping products to ensure compliance with the SOW. Generally, a photogrammetric mapping project SOW should be end product oriented. Example: Fly and photograph the project area using a black and white aerial film at 1:3,600 negative scale with a 6-in. focal length camera. Produce planimetric and topographic mapping that meets or exceeds ASPRS Class 1 Standards for 1:600-scale mapping. The final products shall fully comply with the Tri-Service Spatial Data Standards (TSSDS) for Engineering and GIS mapping.

b. Quality assurance should involve checking deliverables for completeness and accuracy.

(1) Accuracy is generally accomplished by comparing data points to other known ground survey data in the same general area. This method of quality assurance can be costly. Every attempt should be made to minimize these types of checks. Existing ground survey data should be located and used to compare to final mapping products. Photogrammetric mapping projects generally require some ground survey data to be collected as part of the overall process. Minimal ground survey check data (individual points or short profiles) may be economically collected by the contractor staff at this time and submitted only to the Government to be used as a check of the final mapping.

(2) Quality assurance for completeness and thoroughness can be accomplished by comparing the final mapping with the aerial photographs or existing mapping. Field checks should be kept to a minimum when cost is a factor. Digital data files should be opened and reviewed for completeness and thoroughness also.

c. Contractors are obligated to provide products as specified in a SOW. Quality assurance should be accomplished immediately after receipt of the products. Errors or omissions are noted and agreed upon with a Contractor. Corrections should be made and revised data submitted in a timely manor. Contractors do not want to submit bad data. They do want to ensure a good reputation. Many errors and omissions are a result of a poorly written SOW. The SOW should be thoroughly understood, reviewed, and agreed upon by both the Government and the Contractor. Negotiation sessions should insure understanding of the intent of the SOW and correct any misunderstandings. When possible sample files or maps should be provided to the Contractor prior to negotiations and SOW review. Technically knowledgeable staff should be an integral part of the project planning, SOW development, cost estimating, and negotiations as well as QA checking of the final products.

Chapter 4
Photogrammetric Mapping Planning and Cost Estimating Principles

4-1. General

This chapter contains guidance for USACE project engineers, project managers, or project engineering technicians who are required to plan and develop cost estimates for negotiated qualification-based Architect-Engineer (A-E) contracts for photogrammetric mapping projects.

a. *Section I* provides guidance on the elements of project planning and estimating costs for all phases of a photogrammetric mapping project.

b. *Section II* provides the elements of a general costing procedure.

c. *Section III* presents a sample scope of work and estimate for a typical project.

Section I

4-2. Photogrammetric Mapping Project Planning

a. In order to estimate photogrammetric mapping costs, it is necessary to visualize production procedures that must be accomplished. The project manager should design a specific procedural scheme before a Government cost estimate is formulated. With a logical project plan in mind, it is possible to estimate man-hour and material needs and apply cost factors. Since hourly labor rates, equipment rental rates, overhead, and profit margins vary widely, it is necessary to estimate costs for contract negotiations based on a specific production system.

b. Digital mapping projects require several basic operations:

(1) Aerial photography, which may or may not involve ABGPS, with appropriate film types.

(2) Field control surveys using conventional and/or GPS procedures.

(3) Aerotriangulation utilizing a workstation or an analytical stereoplotter.

(4) Collection and editing of digital planimetric and/or topographic data with an analytical stereoplotter or a workstation.

(5) Orthophoto images generated with a workstation.

c. Some production items are rather straightforward to determine. For instance, once the relevant photo scale is selected, it is relatively easy to calculate the number of photos, which is a determining factor for a number of production parameters. Other costs may be rather difficult to determine and will vary from one project site to another, depending on the ground conditions and product requirements of the specific project. Many unit item timeframes can be estimated only with a fairly thorough understanding of the equipment and production procedures, generally termed "experience." Unfortunately, these difficult items usually form the bulk of the project costs. This is coupled with the fact that most USACE commands cannot afford the time and money to train experienced photogrammetrists to estimate mapping costs.

d. During the estimating process of a project, it is essential to include every item that could be required. The estimator must include overhead expenses and, when working through a private contractor, a reasonable profit for the contractor.

e. One of the principal objectives of planning is the assessment of risk that may be inherent in a project. There are several types of risk: programmatic, technical, schedule, and cost. Risk should be identified whenever possible, and the project plan should include actions to mitigate their possible impact.

f. USACE Commands contract most of their photogrammetric work to commercial mapping firms. The relationship between the USACE project manager and the private contractor should not be adversarial. Rather, it must be a cooperative effort to produce a product of legitimate quality for a reasonable price. Both the USACE representative and the private contractor should cooperate toward this end. Since digital mapping is a dynamic discipline, USACE cost estimators should make a positive effort to visit the map production facilities of private contractors in order to enhance familiarity with state-of-the-art equipment and procedures. Private mapping contractors are deservedly proud to display their facilities and share their technical expertise, especially if it contributes to the collective understanding of project requirements. It is recognized that the USACE project manager and a private contractor will not necessarily approach cost estimating from a singular perspective. However, if both have a similar understanding of the specifications and a common knowledge of production procedures, their independent cost estimates should provide a basis for negotiating a reasonable fee that will provide a quality product.

g. Before specific cost estimating can be addressed, the project manager should study the procedures discussed in other chapters of this manual to gain a technical knowledge with regard to issues of practical photogrammetric production. The project manager and the Contractor may consider developing a production flow diagram noting all major tasks and associated schedules.

4-3. Photo Scale, Contour Interval, and Target Map Scale Determination

Photo scale, contour interval (CI), and target mapping scale are integrally related and directly affect the cost of a spatial data product.

a. Photo scale selection. Planimetric and topographic detailing are the two main factors that must be considered in selecting a photo scale for digital mapping. Usually one or the other will govern the final photo scale.

(1) Planimetric (cultural) features. On larger-scale mapping projects, a great deal of finite features (poles, street signs, inlets, traffic signs, sidewalks, manholes, etc.) are drawn. As map scale gets smaller, progressively more of this finite detail is omitted (by reason that it may not be visible and/or identifiable on the photos or to reduce map clutter), and some features may be symbolized because of minimum size limitations. This dictates that large-scale planimetric mapping requires large-scale photos. In most cases, the enlargement factor from photo to map for USACE mapping should not exceed the *maximum* factors in Table 2-4 for determining maximum enlargement ratios for a specific map class. Tables in Chapter 2 should be used as a guide for appropriate flight heights and photo negative scales required to achieve specified map scales and accuracies.

(2) Topographic (terrain) features. Flight height determines the attainable accuracy of the vertical data and also regulates photo scale. Tables in Chapter 2 should be used as a guide for appropriate flight heights and photo negative scales for topographic feature detail required to achieve specified map scales and accuracies.

Sample photo and map target scale applications. Figures 4-1 through 4-8 may an aid in selecting optimum photo negative scales and map target scales based on specific engineering and planning applications. Figures 4-1 through 4-7 depict typical planning, engineering, and real estate mapping applications, showing a portion of the manuscript (digital database) at various target scales. The aerial photographs in Figure 4-8 show the varying detail available at different flying heights.

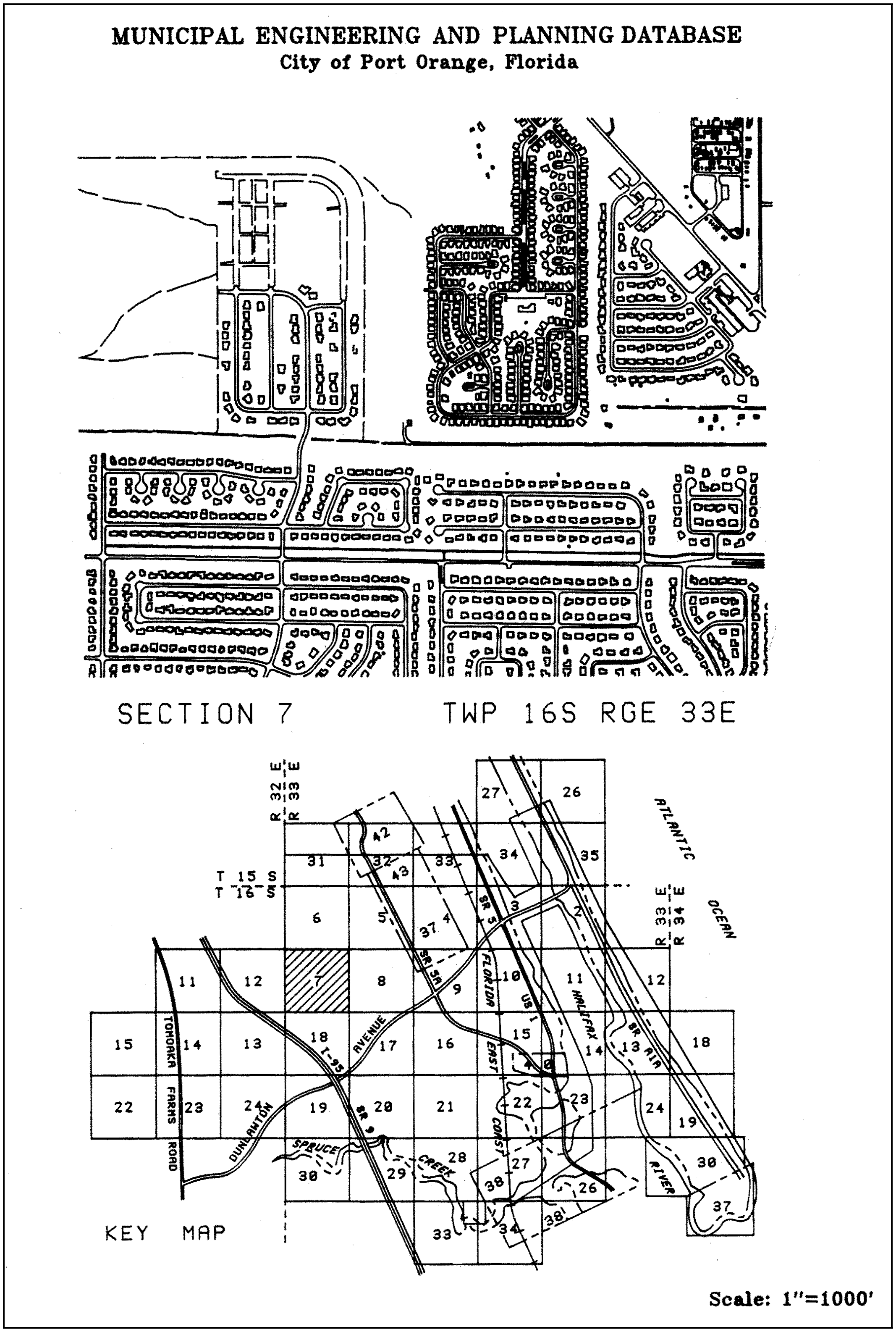


Figure 4-1. General planimetric feature mapping, 1-in. = 1,000-ft scale, with small-scale index map (Courtesy of Southern Resource Mapping Corporation)

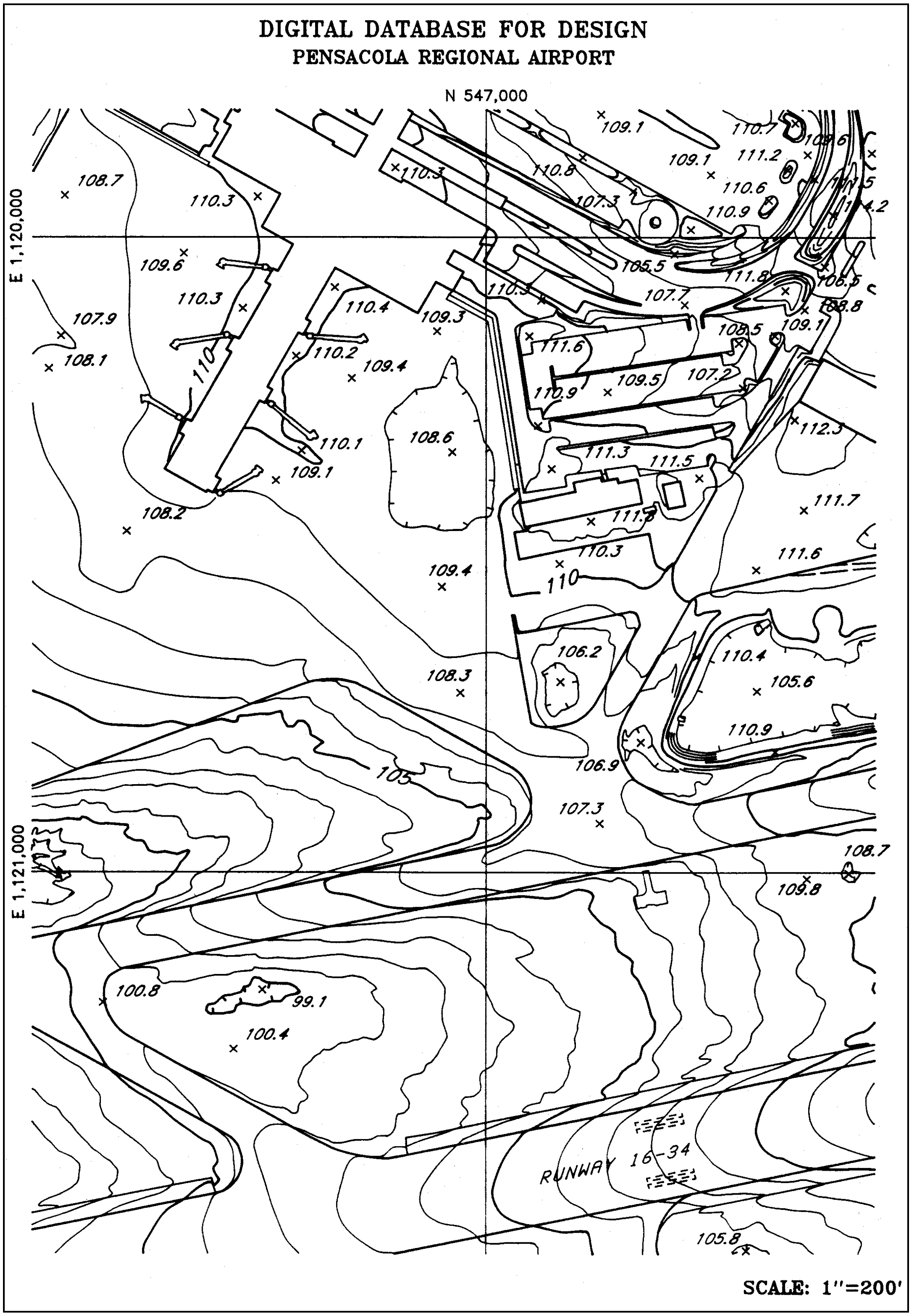


Figure 4-2. Topographic map with 1-ft contours, 1-in. = 1,000-ft scale, for general airfield drainage study/design uses (Courtesy of Southern Resource Mapping Corporation)

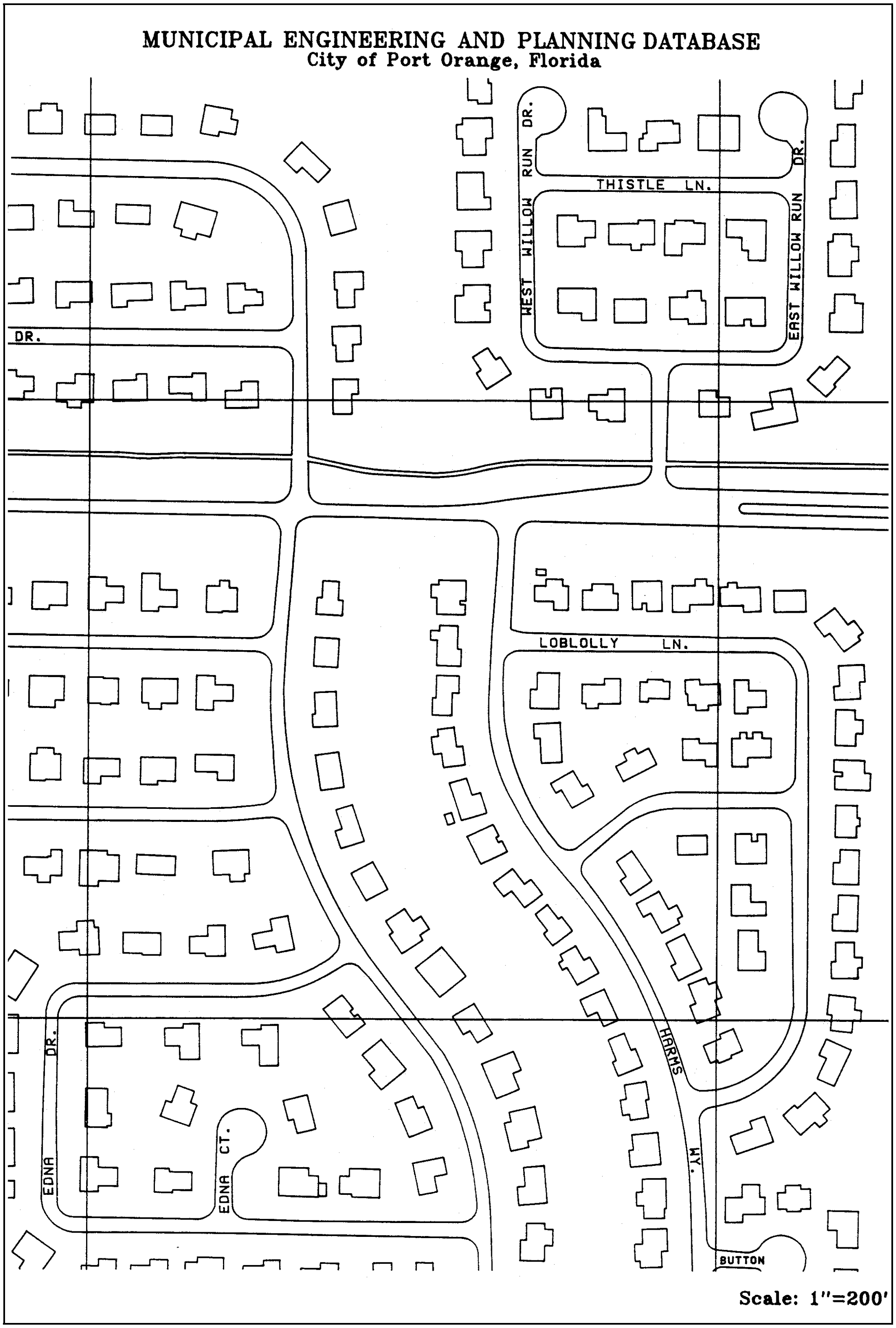


Figure 4-3. Planimetric map of residential area, 1-in. = 200-ft scale, for general planning purposes (Courtesy of Southern Resource Mapping Corporation)

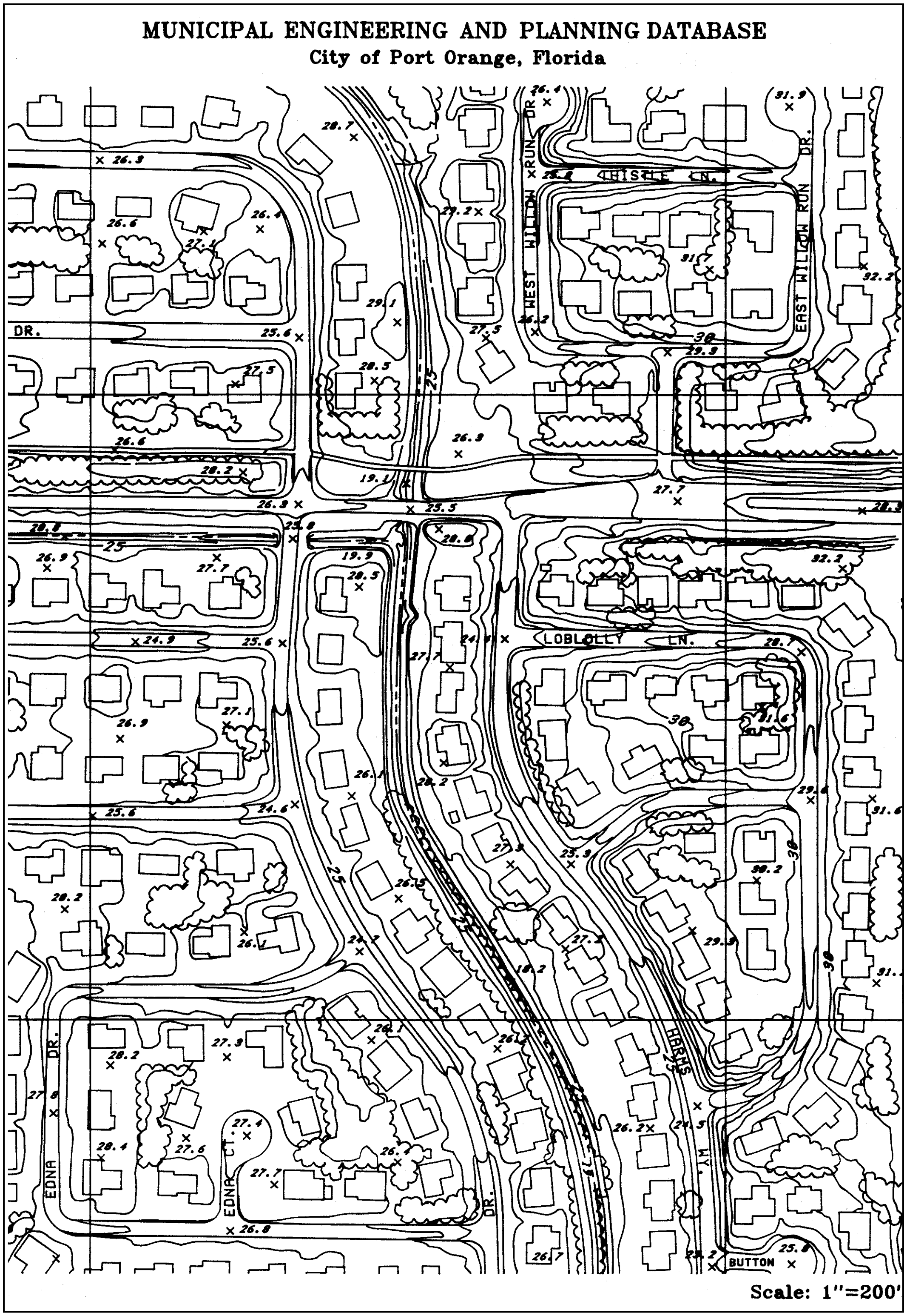


Figure 4-4. Topographic and vegetation layers added to Figure 4-3, 1-in. = 200-ft scale (Courtesy of Southern Resource Mapping Corporation)

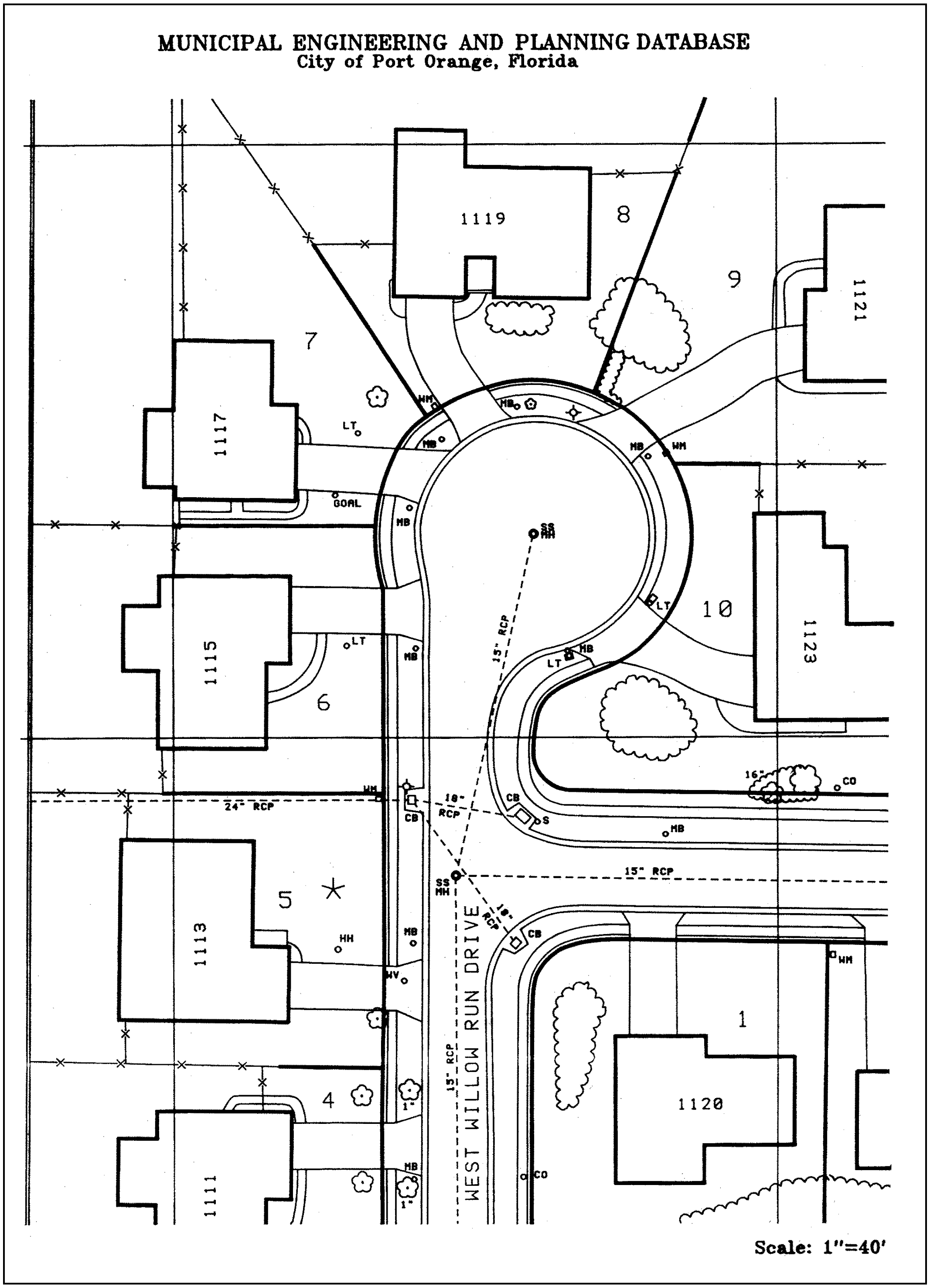


Figure 4-5. Planimetric feature and selected utilities, 1-in. = 40-ft scale, for detailed design of typical civil works project (U.S. Army Engineer District, Jacksonville) (Courtesy of Southern Resource Mapping Corporation)

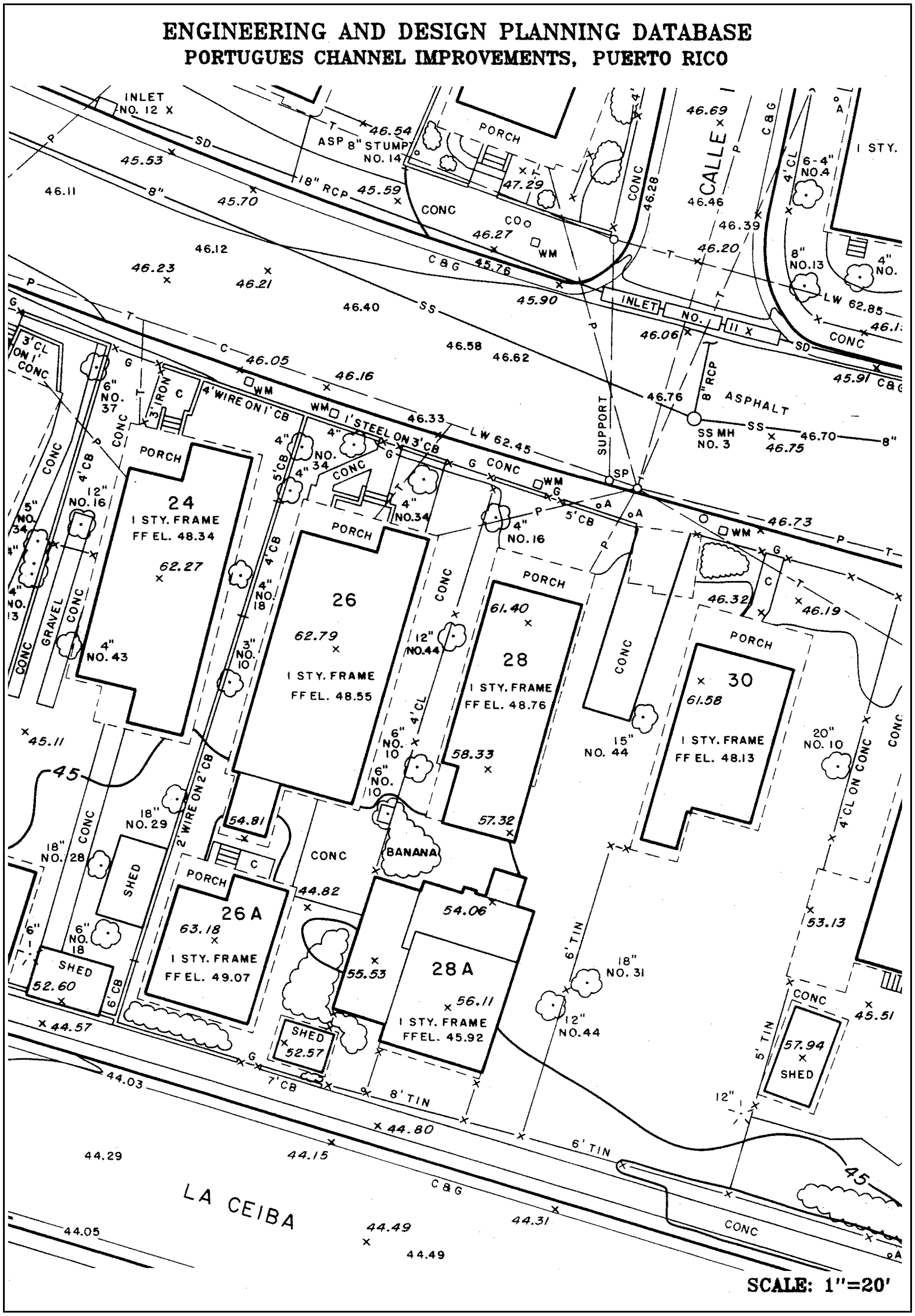


Figure 4-6. Full planimetric and topographic map, 1-in. = 20-ft scale, for detailed design use (Courtesy of Southern Resource Mapping Corporation)

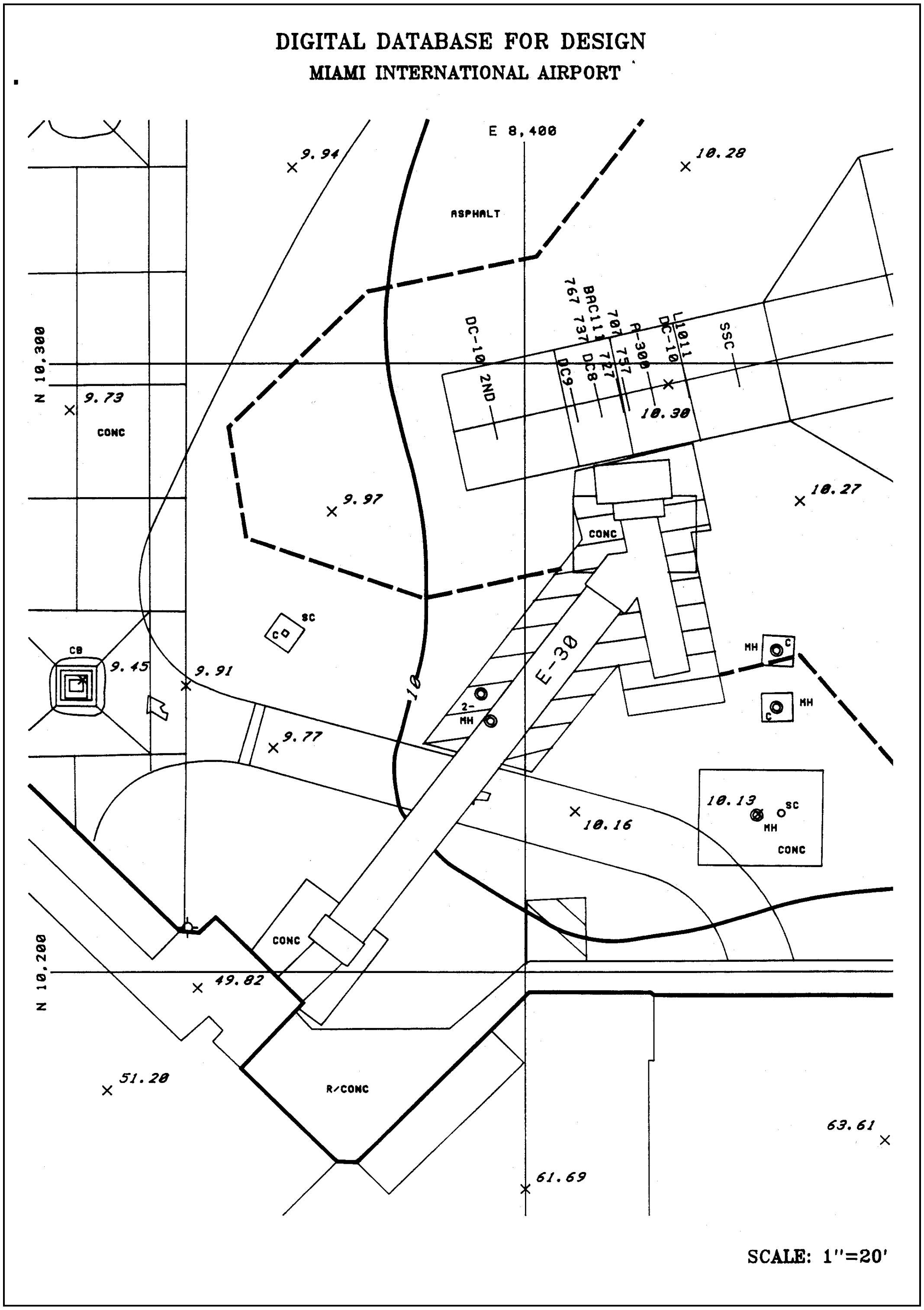


Figure 4-7. Full planimetric and topographic map of airfield, including drainage, 1-in. = 20-ft scale, for detailed design use (Courtesy of Southern Resource Mapping Corporation)

a. 1 in. = 166.6 ft

Figure 4-8. Photographic negative scales for various engineering applications (Courtesy of Southern Resource Mapping Corporation) (Sheet 1 of 11)

b. 1 in. = 200 ft

Figure 4-8. (Sheet 2 of 11)

c. 1 in. = 250 ft

Figure 4-8. (Sheet 3 of 11)

d. 1 in. = 300 ft

Figure 4-8. (Sheet 4 of 11)

e. 1 in. = 400 ft

Figure 4-8. (Sheet 5 of 11)

f. 1 in. = 500 ft

Figure 4-8. (Sheet 6 of 11)

g. 1 in. = 600 ft

Figure 4-8. (Sheet 7 of 11)

h. 1 in. = 1,000 ft

Figure 4-8. (Sheet 8 of 11)

i. 1 in. = 1,200 ft

Figure 4-8. (Sheet 9 of 11)

j. 1 in. = 1,666 ft

Figure 4-8. (Sheet 10 of 11)

k. 1 in. = 2,000 ft

Figure 4-8. (Sheet 11 of 11)

4-4. Data Compatibility

There can be no doubt that the advent of digital databases has been a boon to mapping and GIS/CADD applications; however, there are photogrammetric pitfalls. Perhaps the greatest hazard, though seemingly an apparent strong suit, stems from the ability of a computer, driven by proper software, to accept almost any block of X-Y-Z data and create a map to any scale or contour interval. A primary advantage of automated information systems is not simply aggregating various themes to draw a composite map. More important is the capability of the user to reach into the database, select particular portions of information, and formulate reliable alternative solutions to given situations. Automated information systems will generate hard copy maps, data tabulations, and reports.

a. Information from a multitude of diverse sources can be integrated into a single database, since these systems are capable of comparing various blocks of dissimilar data and presenting the viewer with a composite scenario based on given situation parameters. This allows the manager to manipulate variable parameters to compare multiple solutions with limited expenditure of time.

b. Collected data for various themes are placed on specific data layers for convenience in accessing the database. For this reason, individual layers must be georeferenced to a common ground reference (State Plane, Universal Transverse Mercator, Latitude/Longitude) so that data from various layers geographically match one another when composited. Digital data for many layers will have been collected from various existing map and aerial photo sources. This implies that not all data are compatible.

c. All features go into a database as a group of individual spatial coordinate points that are relational to each other through a common geographic positioning grid. However, not all information is collected to the same degree of accuracy! A map is as reliable only as its most inaccurate information layer. Serious thought must be given to the compatibility of information that resides in an integrated database.

d. As was stated previously, there are two accuracy factors to be considered, each as an autonomous parameter.

(1) Horizontal scale. Assume that digital line graphics (DLG) information is purchased economically from the USGS. This would include transportation, hydrographics, political boundaries, and land lines digitized from 1:24,000 quadrangles. These data conform to U.S. National Map Accuracy Standards, which translates to allowable inaccuracy tolerance of 50 ground feet on 1:24,000 quads. If these data are merged with other data to create a map to scale 1 in. = 100 ft, some features can be realistically misplaced by 0.5 in. at the map scale, far beyond the inaccuracy allowance of 1.0-ft horizontal vector error for ASPRS Class 1, 1 in. =100 ft mapping dictated by Table 2-2.

(2) Topographic relief. Assume that digital terrain model (mass points and breaklines) information is purchased economically from the USGS. This would include 10- or 20-ft contour information, depending on which is available for the project site, digitized from 1:24,000 quadrangles. These data conform to US National Map Accuracy Standards, which states that 9/10 of contours should be accurate to within half a contour interval. This translates to 5 ft for 10-ft contours and 10 ft for 20-ft contours. If these data were to be used to create contours at 2-ft vertical intervals, which DTM software can readily accomplish, each 2-ft contour could realistically vary by as much as 5 to 10 ft from its true vertical position. This by far exceeds the inaccuracy allowance of 0.67 ft prescribed by ASPRS Class 1 mapping in Table 2-3.

(3) A word to the wise. Do not "mix & match" data just because they are readily available and/or economical. All data layers must mesh into the overall accuracy of the final product. Metadata must be developed for all data and be fully compliant with the Content Standard for Digital Geospatial Metadata (CSDGM) FGDC-STD-007-1998 and shall fully document data sources and accuracies.

4-5. Project Design

Prior to cost estimating a mapping project, there must be a concept, mental or written, as to what is required to complete that project. Writing the general job specifications and outlining the project design can be helpful. Appendix F includes several sample Scopes of Work for typical Corps of Engineers type photogrammetric mapping projects. The following factors must be considered in performing this effort.

a. Parameters.

(1) Project site. It is usually best to outline the site on a USGS quadrangle or another equally suitable map of the site.

(2) Contour interval. This must be upon the function for which mapping is intended. A general consideration is that smaller contour intervals are for design purposes, while larger intervals are for planning studies. See Chapter 2 for additional guidance in determining contour intervals for typical USACE projects.

(3) Mapping scale. This is also dependent upon the user's functional requirements (see Chapter 2 for guidance). It must be kept in mind that after the information resides in the database, a map can be generated to any scale, which can be advantageous or disastrous.

b. Aerial photography.

(1) Photo flight parameters. Determine photo scale, film type, flight altitude, number of flight lines, and number of photographs based on the guidance in Chapter 2 and other chapters in this manual. It is good practice, once these items are calculated, to make a preliminary photo mission flight map, preferably on a USGS quadrangle map.

(2) Aircrew cross country. Determine the distance from the photographer's base airport to the project site. This influences cross-country time for the craft and crew.

(3) Special considerations. Make some assumptions as to whether there may be any special considerations to this flight. Is the project in an area where overflights will be restricted to specific time slots? Are there any chronic adverse atmospheric (lingering haze, consistent cloud cover) or ground (snow, vegetation) conditions that will interfere with or prolong the flight?

c. Field surveys.

(1) Travel time. Determine how far it is from surveyor's office to project site. This will influence labor travel costs and per diem expectations.

(2) Control reference. Collect information regarding nearest existing benchmarks and triangulation stations that must be used as geographic reference ties. Ground control references to distant established control is labor intensive and costly.

(3) Photo control density. Determine the pattern of horizontal and vertical field control points that will be needed. If a project requires preflight ground targets, it is helpful to arrange the layout on a USGS quadrangle. Ground control point selection should be done with some thought toward amenable survey routing. Final ground control plan should be planned and agreed upon with the mapping contractor prior to implemenatation.

d. Aerotriangulation.

(1) Aerotriangulation is the control extension link between a limited amount of strategic field survey points and the stringent pattern of photo passpoints that control the photos for mapping.

(2) Control extension can be accomplished either with a stereoplotter or a softcopy workstation. If a stereoplotter is used, a supplementary point marking (pugging) on diapositives is required also. Aerotriangulation in a totally softcopy environment is a self contained operation. Film or diapositive is scanned and loaded into the softcopy system. Pugging is not required.

(3) The photos to be used in mapping are to be employed in the control extension.

e. Digital mapping.

(1) Map detail density. Because of the planimetric and topographic variability specific sites, each project site exhibits its own characteristics. The government estimator must get some perception for the density of cultural features and terrain character on the site. This is normally a great variable between sites and often even within a site. It is probably the biggest labor-intensive item in the whole project. It takes a much longer time to digitize all of the congested cultural detail in an urban area than the few features in a rural setting. It also takes a longer time to digitize DEM data in rough, steep hills than in a flat river valley.

(2) Data edit. Once the data digitizing is complete, an edit of these data must be performed.

(3) Data translation. After data are compiled and edited, they must be translated into whatever format is compatible with the user's CADD system.

(4) Data plot. A line plot of the digital data should be generated to ensure that the data are complete and valid.

f. Orthophoto images.

(1) GIS/LIS projects increasingly demand orthogonal pictorial images to merge as a background for other data layers.

(2) Orthophotos are as accurate as line maps except in areas of sudden vertical change. It may be necessary in these areas to patch images from other photos.

(3) Relevant DEM data are required to generate an orthophoto image.

(4) Scan resolution must be as finite as is required to maintain pixel integrity at the image enlarged image scale.

g. Miscellaneous. Determine what other auxiliary items may be specifically required to complete this project.

(1) Does the project require any accessory photo reproduction items (contact prints, indexes, enlargements, mosaics)?

(2) Are there any supplementary field surveys (bridge surveys, cross sections, well or boring location) required?

(3) Are there any supplementary digital mapping items (cross sections, boring locations, volumetrics) required?

(4) What hidden utility data text attributes will the mapper be required to integrate into the mapping database?

4-6. Photogrammetric Mapping Production Flow

In order to bring the various photogrammetric mapping procedures together in a logical sequence, Figure 4-9 , parts a and b, depict a typical photogrammetric mapping and orthophoto production flow, respectively. Orthophoto production flow is generally a part of a photogrammetric mapping project and utilizes much of the same information collected for photogrammetric mapping to include aerial photography, ground control, aerotriangulation, and digital terrain model development. <u>However, when only orthophotos are required for a project the amount of digital elevation model collection can be reduced as well as vertical ground control</u>. The end user should be warned that a digital elevation model developed ONLY for orthophoto production will not be suitable for contour generation. This chapter presents the project elements that must be addressed when planning, specifying, and estimating costs for a digital mapping project.

Section II

4-7. Approach to Estimating Detailed Photogrammetric Mapping Project Costs

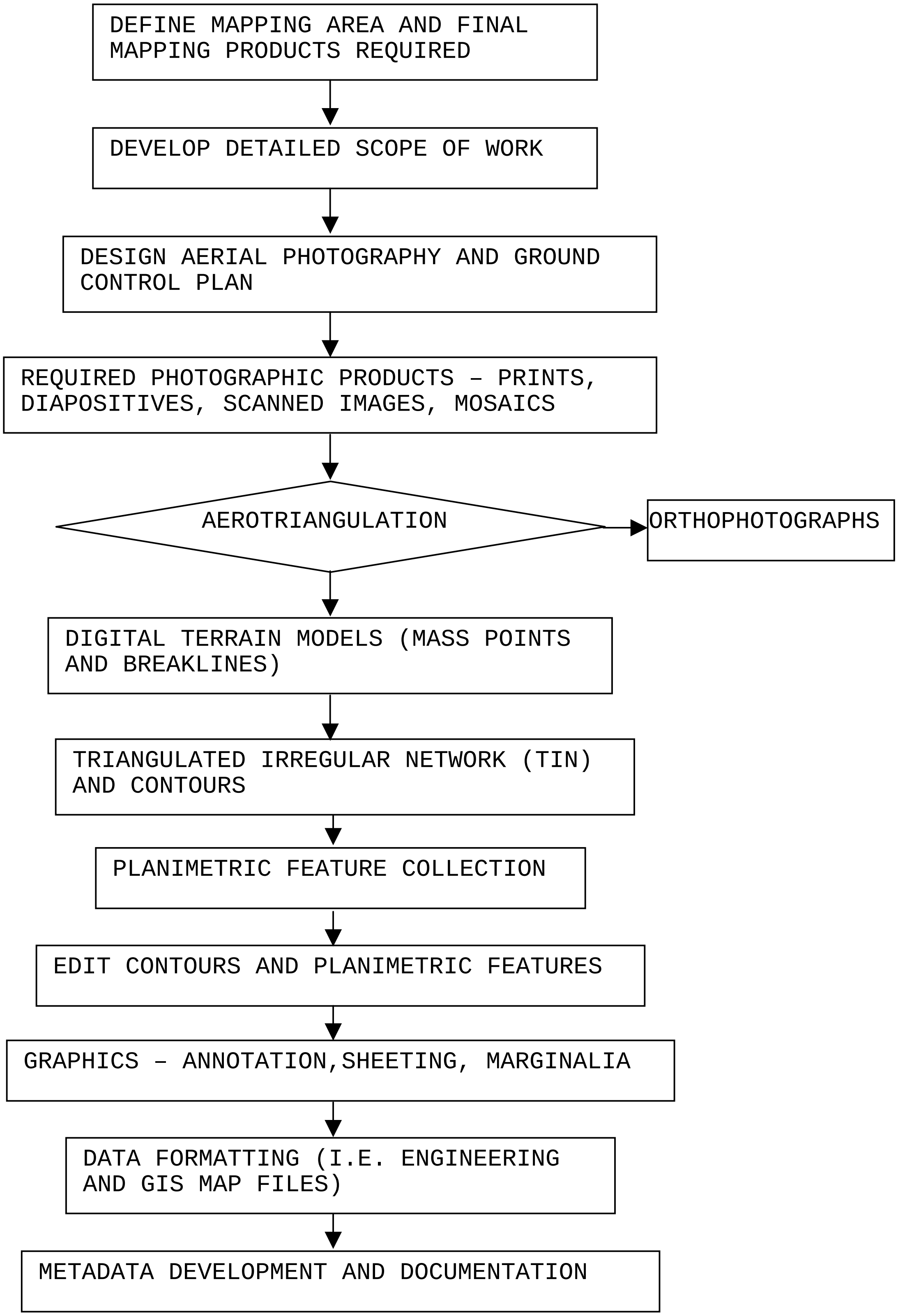
Detailed independent Government cost estimates are required for contract negotiation purposes and must specifically account for all significant cost phases of a digital mapping operation. This is necessary since these estimates (both the Government's and the Contractor's) may be subject to subsequent field audits and/or other scrutiny. Also, contract modifications must relate to the original estimate. Initially, it is important to specify which of the activities involved in making a map will be completed by the Contractor and which may be done by the Government. USACE and other agencies may do some portion of the work. Many USACE Commands, however, contract all the mapping work and participate in none of the actual production activities associated with the generation of digital mapping products.

a. General estimating procedure. The cost estimating procedures presented here can be used to estimate all or only certain parts of a mapping project. This approach allows each user to develop a cost estimating method that incorporates information needed in a specific locale. It allows for exclusion of portions of a mapping project to be conducted by USACE hired labor forces.

(1) Those using the following procedures should indicate which of these activities need to be estimated. As stated earlier, those steps in a cost estimating procedure for mapping include aerial photography, photo control surveying, aerotriangulation, map production, and orthophoto images. For each of these activities, the cost estimates have been further stratified into production elements.

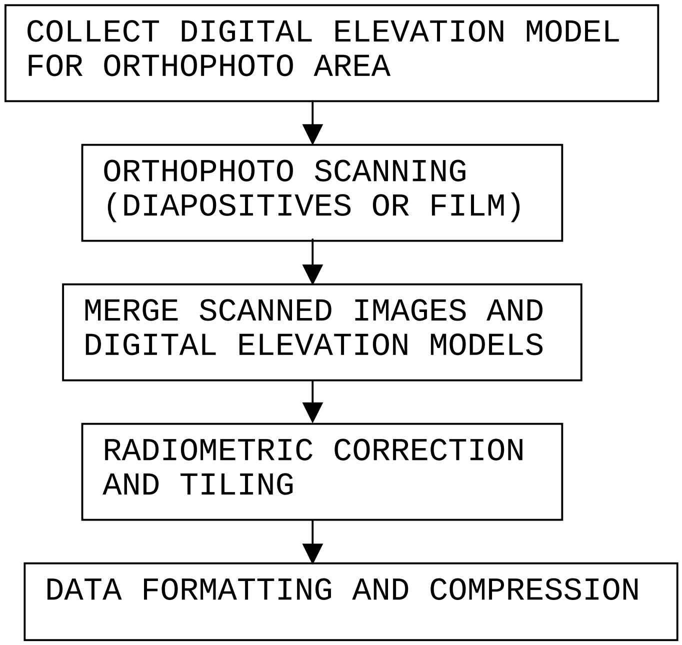
(2) Paragraphs 4-10 through 4-15 present the cost estimating procedure in its entirety. The procedure provides the individual production elements which can be summed with overhead and profit to arrive at estimated budgetary cost for a specific project.

b. Labor. One of the most significant production factors in a mapping project relates directly to hours expended by highly qualified technicians. Amount of work that personnel will conduct is characterized as Direct Labor. It is convenient to express work in hours because it provides a per unit cost basis for estimating purposes.



a. Photogrammetric mapping production flow diagram

Figure 4-9. Photogrammatic mapping processes (Continued)



b. Orthophoto Production Flow Diagram

Figure 4-9. (Concluded)

c. Capital equipment. Another significant factor in a mapping project relates to the capital equipment that technicians operate during production hours. Such sophisticated equipment as aircraft, airborne GPS, softcopy workstations, stereoplotters, scanners, computers, and film processors must be amortized through hourly rental during production phases.

4-8. Project Specifications

a. Variables. It is desirable to specify a number of variables to help best characterize the mapping project and to ensure that an accurate and precise cost estimate can be completed. A complete and accurate scope of work is paramount to a good Government estimate. See example scopes of work in Appendix F. Exact numbers and types of variables can be different for alternate approaches to cost estimating and may not be desirable in a scope of work. However, a complete list of possible needs (deliverables) can be provided, and the required specifications can be selected from the list to customize the content for each cost estimate. It is desirable to specify a set of variables that describes the project before a cost estimate is made. Such a list of variables is provided herein. It includes most required items that should be known along with other information deemed to be useful. The list of specifications presents a good example of what information needs to be supplied before a cost estimation is made. This list is not exhaustive and any effort may include other variables as determined by the Command employing this method.

b. Labor. Cost per hour of personnel can be obtained from regional wage rates or from negotiated information supplied by the Contractor. These can be applied to the estimated production hours to arrive at a project cost.

4-9. Contract Parameters

It is necessary to have information for the following items to best specify a project. Many of the items listed below are inputs to the cost estimating procedure and are used in calculations of parameters.

a. Area to be mapped. It is desirable to provide a firm definition of the area to be mapped. This may be delineated on large-scale topographic maps or 1:24,000 USGS quadrangles. Other descriptive and measurement information should be provided if available. Information may include details from surveys, deeds, or whatever other documents are available. Descriptions may also include gross north/south and east/west dimensions of project.

b. Parameters. Other mapping parameters should include the following:

(1) Final map scale consistent with data usage.

(2) Contour interval consistent with data usage.

(3) Photo scale based on enlargement factor and C-Factor.

(4) Flight height above mean ground level calculated from photo scale.

(5) Film type pertinent to data usage.

(6) Calibrated focal length of camera, usually 6-in. but may differ for special use.

(7) Assumed C-Factor (Chapter 2).

(8) Enlargement factor (Chapter 2).

(9) Nominal endlap, usually 60 percent but may differ for special usage.

(10) Nominal sidelap, usually 30 percent but may differ for special usage.

(11) Distance from aircraft base to project site measured on atlas.

(12) Number of flight lines based on calculations from project short dimension.

(13) Number of photos per flight line based on calculations from project long dimension.

(14) Distance from site to nearest established horizontal control reference measured from atlas.

(15) Distance from site to nearest established vertical control reference measured from atlas.

(16) Cruising speed of aircraft from equipment specifications.

(17) Terrain slope variability estimated from a 1:24,000 USGS quad.

(18) Cultural development variability estimated from a 1:24,000 USGS quad.

c. Deliverables. A list of delivery items should be supplied. This is necessary to clearly define the end products, which should ensure an accurate estimate of cost. The list below consists of a number of possible products that may be requested. Products should be specified in the contract. Also, the number of copies or sets to be furnished must be stated.

(1) Contact prints.

(2) Hardcopy map sheets.

(3) Digital data in CADD or GIS/LIS format (planimetric features, DEM, DTM, TIN, Contours).

(4) Photo enlargements.

(5) Photo index.

(6) Photo mosaics.

(7) Field surveys.

(8) Orthophotos.

(9) Aerotriangulation report.

(10) Field survey report.

(11) Aerial camera current USGS Calibration Report.

4-10. Calculation of Production Hours for Aerial Photography

PRODUCTION HOURS FOR AERIAL PHOTOGRAPHY

Direct labor

Project Mission:

Flight preparation = 1.5 hr

Takeoff/landing = 0.5 hr

Cross-country flight = miles to site H 2 ways / mph
= ______ H 2 / ______
= ______ hours

Photo flight =

End turns = lines H 0.08 hours = ______ hours

Photo Lab:

Develop film = ______ photos H 0.04 = ______ hours
Check film = ______ photos H 0.04 = ______ hours
Title film = ______ photos / 40 = ______ hours

Contact prints = ______ photos / 45 = ______ hours

Equipment rental

Aircraft = project mission hours = ______ hours

Airborne GPS = project mission hours = ______ hours
(if not included in aircraft rental)

Film processor = develop film hours = ______ hours

Film titler = title film hours = ______ hours

Contact printer = contact prints hours = ______ hours

4-11. Photo Control Surveying Cost Items

Offsite information. The following items are to be specified to assist in the calculations of costs associated with photo control surveying.

a. Distance from survey office to site.

b. Distance to horizontal reference.

c. Distance to vertical reference.

d. Time to complete horizontal photo control or number of points required.

e. Time to complete vertical photo control or number of points required.

No production estimating procedure is presented for ground surveys. This is best left to District survey branches once they are apprized of the number and location of required ground targets.

4-12. Aerotriangulation

PRODUCTION HOURS FOR AEROTRIANGULATION

Direct labor

Photo scan = ________ photos H 0.3 hours = ______ hours

Aerotriangulation (workstation):

Model orientation = ______ models H 0.2 hour
= ______ hours

Coordinate readings = ______ photos H 0.3 hour
= ______ hours

Computations = ______ models H 0.4 hours = ______ hours

Equipment rental

Scanner (for Softcopy Aerotriangulation) = scanning hours = ______ hours

Workstation = aerotriangulation hours = ______ hours

Computer = computations hours = ______ hours

4-13. Photogrammetric Compilation and Digital Mapping Cost Items

Site specific information. The following items are to be calculated, estimated, or measured to assist in the computing costs associated with digital mapping.

a. Number of stereomodels to orient.

b. Number of acres and or stereomodels to map.

c. Complexity of terrain character.

d. Complexity of planimetric culture.

e. Format translations of digital data.

PRODUCTION HOURS FOR STEREOMAPPING

Model Setup:

Model setup includes planning the collection procedures and setting models in the data collection system. Data collection may be accomplished by analytical stereoplotters or softcopy workstations. Analytical stereoplotters will require diapositives and softcopy workstations will require high resolution scans. For additional explanation and detail review portions of Chapters 5 through 10.

Model orientation = _______models H 0.1 hours = ______ hours

Photo scan = ________ photos H hours = ______ hours
(if not done previously)

Digital data capture:

Planimetry (cultural features) - The project planning map used to outline the mapping area should be overlain with a proposed flight line layout. The flight line layout should note the approximate location of each photo stereopair. The planimetric feature detail in each of the models should be assessed based on the amount of planimetric detail to be captured (full or partial stereomodel and the final map scale) and the density of planimetry to be captured in each stereomodel. As an example: Highly urban area stereomodels require more time to compile than rural area stereomodels. The following charts can be used as a guide for certain map scales.

CHART 1 **PLANIMETRY PRODUCTION**				APPROX. PLAN. **TIME (HOURS)/MODEL**			
				FINAL MAP SCALE			
DENSITY TYPE	MODELS/ TYPE	HOURS/ TYPE	TOTAL PLAN HRS	1"=40' TO 1"=60'	1"=100' TO 1"=150'	1"=200' TO 1"=300'	1"=400' TO 1"=1600'
LIGHT							
1				3.0	2.5	2.5	2.5
2				4.0	3.5	3.5	3.5
MEDIUM							
3				5.0	4.0	4.0	4.0
4				7.0	6.0	6.0	5.0
HEAVY							
5				10.0	8.0	7.0	6.0
TOTAL PLANIMETRY HOURS							
EDIT TIME: GENERALLY 30% OF TOTAL PLANIMETRIC COMPILATION HOURS							

Topography - The project planning map used to outline the mapping area should be overlain with a proposed flight line layout. The flight line layout should note the approximate location of each photo stereopair. The topographic feature detail in each of the models should be assessed based on the amount of planimetric detail to be captured (full or partial stereomodel and the final map scale). Topographic detail must consider the character of the land to be depicted. As an example: 1-ft contour development in a relatively flat terrain requires much less time than collection of 1-ft contours in very mountainous terrain. The chart below can be used as a guide for certain map scales.

CHART 2 **TOPOGRAPHY (TOPO) PRODUCTION** **COLLECTION OF MASS POINTS AND BREAKLINES FOR PRODUCTION OF CONTOURS**				APPROX. TOPOGRAPHY **TIME(HOURS)/MODEL**			
				FINAL MAP CONTOUR INTERVAL SCALE			
TERRAIN CHARACTER (SLOPE)	MODELS /TYPE	HOURS /TYPE	TOTAL TOPO HOURS	1 FT	2 FT	4 FT	5 FT TO 8 FT
FLAT				2.0	2.5	2.5	2.0
ROLLING				4.0	4.0	4.0	3.0
HILLY				6.0	6.0	5.0	4.0
STEEP				8.0	8.0	6.0	5.0
DISTURBED				10.0	10.0	8.0	7.0
TOTAL TOPO HOURS							
EDIT TIME: GENERALLY 30% OF TOTAL TOPO COLLECTION TIME							

4-14. Orthophoto Images

<u>PRODUCTION HOURS FOR ORTHOPHOTOS</u>

Current technology allows for total softcopy generation of orthophotos. See previous chapters for more detailed information. If a Contractor has collected the digital terrain model with an analytical stereoplotter and created diapositives then a clean set of diapositives must be made and scanned for orthophoto generation. However, if the Contractor uses softcopy stereo compilation for the elevation model collection then the same scanned images may by used to generate the orthophotos. The Government must assume one method or the other in developing a cost estimate. The difference in cost should be negligible.

Direct labor

CHART 3 ORTHOPHOTO PRODUCTION COSTS						
ELEVATION MODEL (DEM) DEVELOPMENT (ORTHO ONLY) DEVELOPED BY THE STEREO COMPILER						
# STEREO MODELS	HOURS/MODEL			TOTAL DEM TIME STEREO MODELS H HR/MOD		
	2 HR/MODEL					
TASKS BELOW ACCOMPLISHED BY SOFTCOPY TECHNICIAN						
NATURAL COLOR AND COLOR IR				BLACK AND WHITE		
	HRS/IMAGE	No. of Images	Total Hr.	HRS/IMAGE	No. of Images	Total Hr.
IMAGE SCANNING	0.3 HR			0.2 HR		
DEM - SCAN DATA MERGE	0.5 HR			0.5 HR		
RADIOMENTERIC CORRECTION	2.5 HR			2.0 HR		
TILING/SHEETING	0.25 HR					
TOTAL HR						

4-15. Summary of Production Hours

A summary of the production hours itemized above is shown in the following list. Current Unit Costs should be established for each task to be used in a project. The Unit Costs should include necessary equipment as well as labor. These rates may be most accurately estimated by reviewing similar current Government Contracts. <u>Note that in addition to the total labor hours an appropriate overhead should be established and applied to the total cost of labor. Also, an appropriate profit should be established and applied to the total of labor and direct costs.</u> <u>Ground survey requirements established by Government survey staff should be added to the total costs.</u>

CHART 4 **PHOTOGRAMMETRIC MAPPING PROJECT PRODUCTION**			
PRODUCTION LABOR			
	HOURS	UNIT COST	TOTAL COST
AERIAL PHOTOGRAPHY			
AEROTRIANGULATION			
MODEL SETUP			
PLANIMETRY			
TOPOGRAPHY			
ORTHOPHOTOGRAPHY			
TOTAL			
DIRECT COSTS			
	UNITS	UNIT COST	TOTAL COST
FILM			
PRINTS			
DIAPOSITIVES			
HARDCOPY PRINTS			
CD'S, DISKS OR TAPES			
AIRCRAFT W/ CAMERA			
STEREO PLOTTER			
SOFTCOPY WRKSTA.			
EDIT WRKSTA.			
SCANNER			
TOTAL DIRECT COST			

Section III

4-16. Photogrammetric Mapping - Sample Scope of Work and Cost Estimate

This section provides sample scope of work documents along with cost estimates. The samples provided are to be used as a general guide to highlight all items that should be included in a Government estimate. The Government estimate is to be a tool to use in negotiating a fair and reasonable cost for A-E mapping services. The negotiations for a specific project are to use the Government estimate along with technical knowledge of the project to arrive at a FAIR and REASONABLE cost. The unit and total costs along with associated labor and equipment times and efforts may vary for photogrammetric projects depending upon the location, time of year, specific contracting issues, and the contractor's capability and existing work load. However, if the Government includes all items required and a reasonable effort and associated unit cost, a suitable Government estimate should be obtainable from the methods provided in this chapter.

SAMPLE PROJECT #1

1. Description of work:

Mapping of portions of the ALCOA site in East St. Louis, IL, has been requested . The area to be mapped is approximately 800 acres. The final mapping products requested are digital, planimetric, and topographic map files in ARC/INFO format. The map scale will be 1 in. = 50 ft with 1-in. contours. The aerial photography will be flown at a negative scale of 1 in. =330 ft utilizing panchromatic (black and white) film. Minimal ground survey control to perform aerotriangulation (AT), develop digital terrain models (DTM), and produce the digital mapping will also be obtained. All photography will be flown at approximately 1,980 ft Above Mean Terrain (AMT). The final mapping will fully comply with ASPRS Class I Accuracy Standards for mapping at a horizontal scale of 1 in. = 50 ft with a DTM suitable for generation of 1-ft contours. All digital files will be fully compatible with the current ARC/INFO system at the E. St. Louis Business & Economic Development Department.

2. Information supplied by the Government:

a. Map showing project area.

b. Corpsmet 95 - available at:

http://corpsgeol.usace.army.mil

3. Work to be performed by the Contractor: Contractor shall provide equipment, supplies, facilities, and personnel to accomplish the following work:

a. Contractor will establish an aerial photo mission and ground survey control network for the project. The Contractor will fly and photograph the project area at an altitude of approximately 1,980 ft AMT with a negative scale of 1 in. = 330 ft in panchromatic (black and white). Photography will be flown with 60-percent forward lap and approximately 30-percent side lap. GPS data collection and processing will include latitude, longitude, and ellipsoid elevation for each photo center. All ground survey plans including survey network layout, benchmarks to be used, etc. shall be approved by the USACE prior to initiation of project. The plan submitted shall include but not be limited to maps indicating proposed GPS network, benchmarks to be used, flight lines, and project area.

b. Additional ground survey data will be collected to be used in the mapping process and to check the final mapping. The plan for additional ground survey control required for mapping and procedures to accomplish the ground survey control will be submitted to the USACE for approval prior to initiation of the project. In addition, USACE will provide approximate locations for two check profiles to be established and submitted directly to USACE to be used as an additional check of the topographic mapping. The check profiles will be 1,000 ft in length or shorter with an elevation established approximately every 100 ft. All original notes for these surveys shall be submitted and no copies shall be made by the Contractor. All survey data shall be in the Illinois West State Plane Coordinate System, referenced to WGS-84. Vertical datum will be NGVD88 w/ 93 (High Accuracy Reference Network {HARN}) adjustment. All surveys shall be accomplished in accordance with the technical section of Contract DACW43-98-D-0505.

c. Two sets of contact prints will be made in accordance with the technical section of Contract DACW43-98-D-0505. One set of the prints will be used as control photos for mapping. The control prints will have all ground control marked on the back and front of each photo. All photography will include in the border areas the negative scale (as a ratio), the dates of photography, flight line and frame numbers, and the title "E. STL – ALCO."

d. Ground control (panel data and photo identifiable data) will be utilized to perform analytical aerotriangulation to generate sufficient photo control points to meet National Map Accuracy Standards for mapping at a horizontal scale of 1 in. = 50 ft with a DTM suitable for generation of 1-ft contours. The Contractor will produce a written report discussing the aerotriangulation procedures used, number of ground control points used, any problems (and how they were resolved), the final horizontal and vertical RMSE, and how to read the aerotriangulation print out (units, etc.). The written report will be signed and dated by the author.

e. The 1-in. = 330-ft photo diapositives will be utilized, and planimetric feature detail (all that can be seen and plotted from the photography) and digital terrain model (DTM) data will be collected for topographic mapping at a horizontal scale 1 in. = 50 ft with 1-ft contours. DTM production will utilize collection of mass points and breaklines to define abrupt changes in elevation. Data will be delivered in digital ARC/INFO GIS format (.e00)on CD ROM disks.

f. The Contractor will produce the planimetric feature data, DTM, and contour files in ArcInfo (.e00) format on CD-ROM disks. The data structure, symbology, and layers will comply with the Tri-Service SPATIAL DATA Standards. All files will be topologically structured.

g. The Contractor will produce a paper check plot of contours that will cover the areas of the check profiles. The locations will be provided to the Contractor by the Government after DTM and orthophoto files are delivered.

h. The Contractor will provide metadata for the aerial flight, ground control and mapping data sets in accordance with the applicable provisions of the Content Standards for Digital Geospatial Metadata Workbook, Workbook Version 1.0, Federal Geographic Data Committee, March 24, 1995. Metadata associated with all generated coordinated data produced shall be accomplished using CORPSMET95, version 2.0.

4. Delivery items:

a. Copy of computer printout of aerotriangulation solution. Aerotriangulation report, as defined in paragraph 3*c*, and one copy of the written aerotirangulation report.

b. Copy of camera calibration reports.

c. One copy of digital planimetric feature files and topographic data files at a horizontal scale of 1 in. = 50 ft, with 1-ft Contours. One copy of the DTM files suitable for 1-ft contours. The digital files will be in ARC/INFO formation CD-ROM disks.

d. All survey data (including ground surveys), raw GPS files ,any other survey information developed and or collected for the project and all check profile data.

e. Two sets of the panchromatic (black and white) prints, and one set of diapositives.

f. Flight line index for the project on paper maps indicating the flight lines and beginning and ending frames for each flight line along with altitude and negative scale of the photography.

g. Metadata on CD ROM for aerial photography, ground control, and mapping data sets.

h. All manuscript copies, horizontal and vertical control information, aerial photographs, pugged diapositives, and aerial film will be returned to the Government when the project is completed.

5. Schedule and submittal:

a. The Contractor will capture the photography before November 30, 1998. The Contractor will deliver all final products (including CD-ROM digital data files) within 45 calendar days after photography is flown.

b. All material to be furnished by the Contractor shall be delivered at the Contractor's expense to: U.S. ARMY CORPS OF ENGINEERS.

6. Time extensions:

In the event these schedules are exceeded for reasons beyond the control and without fault or negligence of the Contractor, as determined by the Contracting Officer, this task order will be modified in writing and the task order completion date will be extended one (1) calendar day for each calendar day of delay.

<u>PRODUCTION HOURS FOR AERIAL PHOTOGRAPHY</u>
Direct labor

Project Mission:

Flight preparation = 1.5 hr

Takeoff/landing = 0.5 hr

Cross-country flight = miles to site H 2 ways / mph
= 50 H 2 / 150
= 0.5 hr

Photo flight = 0.5 hr

End turns = 5 lines H 0.08 hr = 0.4 hr

Photo Lab:

Develop film = 40 photos H 0.04 = 1.6 hr
Check film = 40 photos H 0.04 = 1.6 hr
Title film = 40 photos / 40 = 1 hr

Contact prints = 80 photos / 45 = 2 hr

Equipment rental

Aircraft = project mission hours = 2 hr

Airborne GPS = project mission hours = ______ hr
(if not included in aircraft rental)

Film processor = develop film hours = 1.6 hr

Film titler = title film hours = 1 hr

Contact printer = contact prints hours = 2 hr
PRODUCTION HOURS FOR AEROTRIANGULATION
Direct labor

Photo scan = ________ photos H 0.3 hr = ______ hr

Aerotriangulation (workstation):

Model orientation = 40 models H 0.2 hr
= 8 hr

Coordinate readings = 40 photos H 0.3 hr
= 12 hr

Computations = 40 models H 0.4 hr = 16 hr

Equipment rental

Scanner = scanning hours = ______ hr

Workstation = aerotriangulation hours = ______ hr

Computer = computations hours = ______ hr

Model Setup:

Model setup includes planning the collection procedures and setting models in the data collection system. Data collection may be accomplished by analytical stereoplotters or softcopy workstations. Analytical stereoplotters will require diapositives, and softcopy workstations will require high-resolution scans. For additional explanation and detail, review portions of Chapters 2 through 10.

Model orientation = 40 models H 0.1 hr = 4 hr

Photo scan = ________ photos H hr = ______ hr
(if not done previously)

PLANIMETRY				APPROX. PLAN. TIME (HOURS)/MODEL			
				FINAL MAP SCALE			
DENSITY TYPE	MODELS PER TYPE	HOURS PER TYPE	TOTAL PLAN HR	1"=40' TO 1"=60'	1"=100' TO 1"=150	1"=200' TO 1"=300'	1"=400' TO 1"=1600'
LIGHT							
1		3.0		3.0	2.5	2.5	2.5
2		4.0		4.0	3.5	3.5	3.5
MEDIUM							
3	4	5.0	20	5.0	4.0	4.0	4.0
4	7	7.0	49	7.0	6.0	6.0	5.0
HEAVY							
5	16	10.0	160	10.0	8.0	7.0	6.0
TOTAL PLANIMETRY HOURS			229				
EDIT TIME: GENERALLY 30% OF TOTAL PLANIMETRIC COMPILATION HOURS			69				

TOPOGRAPHY (TOPO) COLLECTION OF MASS POINTS AND BREAKLINES FOR PRODUCTION OF CONTOURS				APPROX. TOPOGRAPHY TIME(HOURS)/MODEL			
				FINAL MAP CONTOUR INTERVAL SCALE			
TERRAIN CHARACTER (SLOPE)	MODELS /TYPE	HOURS /TYPE	TOTAL TOPO HOURS	1 FT	2 FT	4 FT	5 TO 8 FT
FLAT	4	2.0	8.0	2.0	2.5	2.5	2.0
ROLLING	6	4.0	24.0	4.0	4.0	4.0	3.0
HILLY		6.0		6.0	6.0	5.0	4.0
STEEP		8.0		8.0	8.0	6.0	5.0
DISTURBED	10	10.0	100	10.0	10.0	8.0	7.0
TOTAL TOPO HOURS			132				
EDIT TIME: GENERALLY 30% OF TOTAL TOPO COLLECTION TIME			40				

<u>COST ESTIMATE WORKSHEET</u>
IL EPA ALCOA E. ST. LOUIS, IL
PHOTOGRAMMETRIC MAPPING
CONTRACT NUMBER
TASK ORDER NO.

DISCIPLINE	HOURS	RATE (2^{ND})	EXTENSION
PROJECT MANAGER	24	$30	720.00
CHIEF PHOTOGRAMMETRIST	20	$30	600.00
PHOTOGRAMMETRIST SUPER.	40.	$23	920.00
AERIAL PILOT	3.5	$19	66.50
AERIAL PHOTOGRAPHER	3.5	$16	56.00
COMPUTER OPERATOR	40	$23	920.00
COMPILER	401	$15	6,015.00
DRAFTER/CADD OPERATOR	109	$11	1,199.00
PHOTO LAB TECHNICIAN	8	$9	72.00
TOTAL DIRECT LABOR			10,568.50
COMBINED OVERHEAD ON DIRECT LABOR AND GENERAL AND ADM. OVERHEAD AT 160.5%			16,962.44
TOTAL DIRECT LABOR AND OVERHEAD			$27,530.94

DIRECT COSTS

AIRPLANE W/CAMERA & GPS	2	$700.00 / HOUR	1,400.00
B/W PRINTS	80	$ 0.55 /□EACH□	44.00
B/W DIAPOSITIVES	40	$ 1.65 /□EACH□	66.00
CD-ROM	2	$ 5.00 /□EACH□	10.00
TOTAL DIRECT COSTS			$1,520.00

TOTAL DIRECT LABOR, OVERHEAD & DIRECT COSTS
$29,050.94

PROFIT @ 12%	$3,486.11

SUBCONTRACT
GROUND SURVEYS

18 H/V 3 FIELD DAYS + 1 DAY COMPUTATIONS	<u>$ 6,400.00</u>
TOTAL	$38,937.05

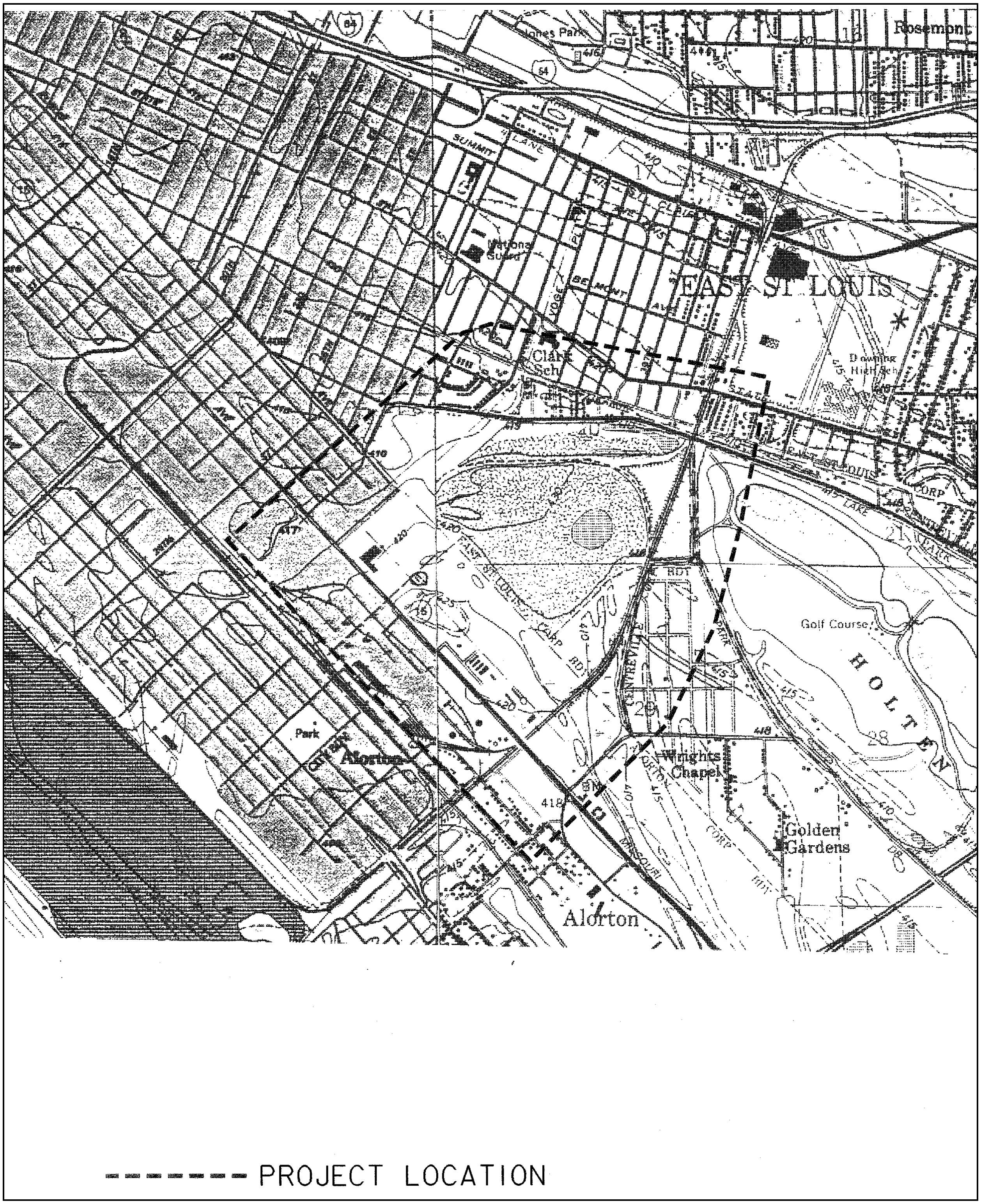


Figure 4-10. Project location

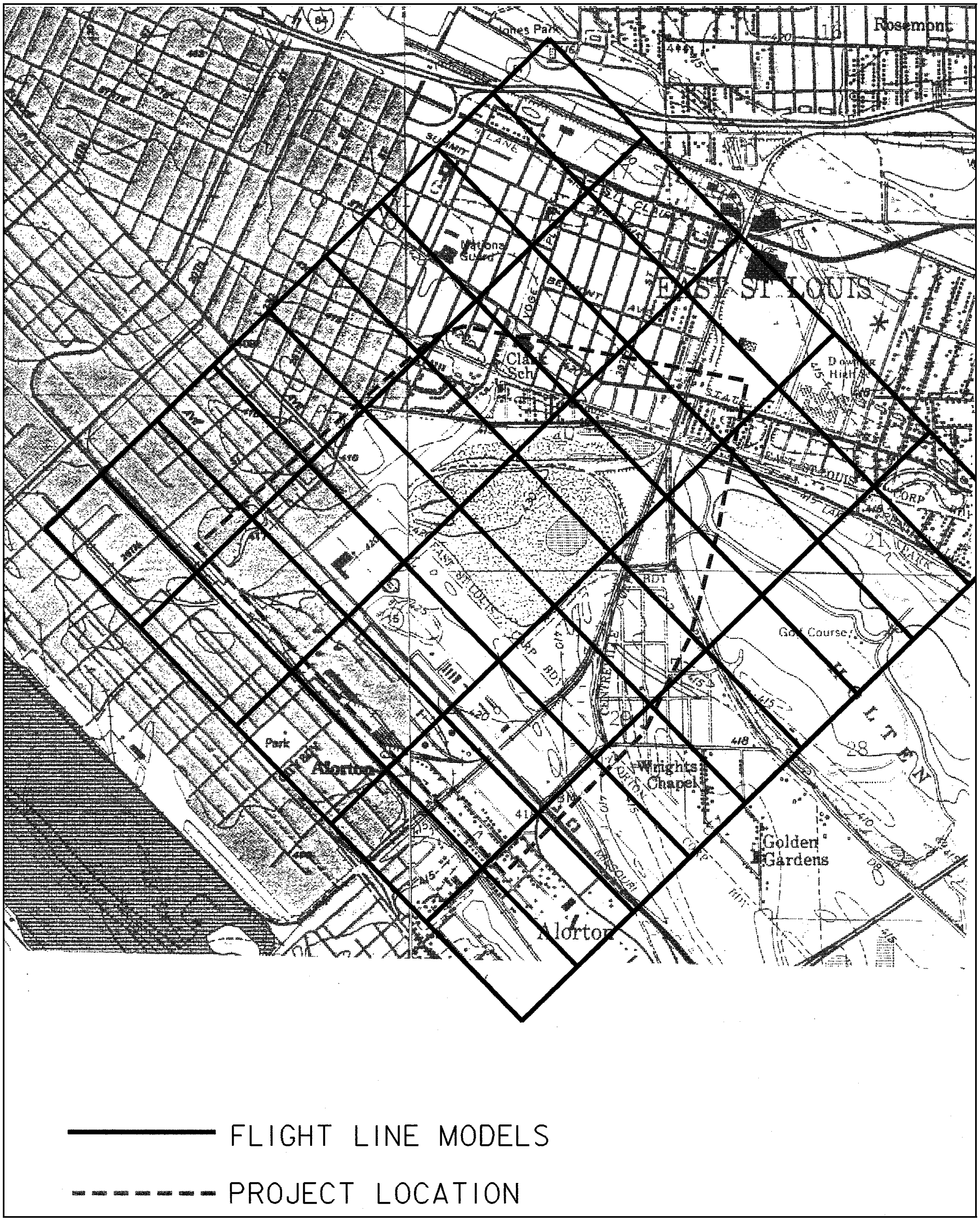


Figure 4-11. Project flight lines and stereo model coverage

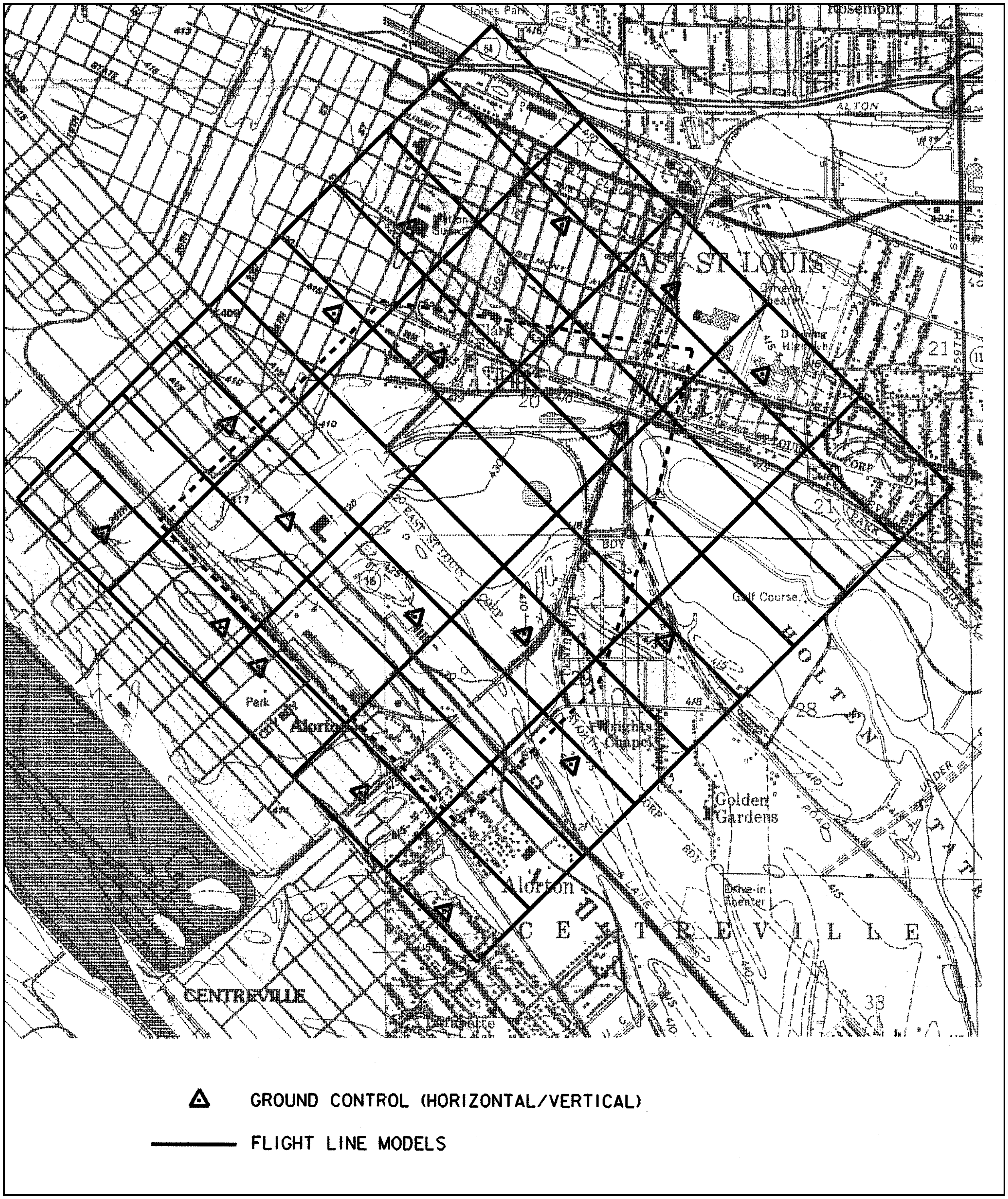


Figure 4-12. Project approximate ground control configuration

Chapter 5
Aerial Photography

5-1. General

This chapter is subdivided into three sections specifying flight, camera, and film requirements for USACE aerial photography. Excepting references to Chapter 2 specifying permissible scale ratios between negative and map scales, this chapter is self-contained and may be directly referenced in aerial photography contracts. Many of the criteria contained in this chapter involve normal Contractor QC functions, which the Government may or may not review as part of its QA effort.

a. Uses of aerial film. Aerial photography can be used in both mapping and photo interpretation for various disciplines. Photogrammetry normally employs panchromatic and, to a limited extent, natural color photography. Image analysis uses all of those discussed above plus, to a lesser degree, some of the more specialized films. Sometimes a single type of film is best for a particular use. For some uses, several types can be used in combination. Color films are more expensive than black and white, especially if reproduction products are required. However, there can be situations where the additional cost may be overshadowed by the amount of extra detail that can be extracted from one film type as opposed to another. Table 5-1 lists some uses of various film types. There are many applications for time-lapse air photo comparison, whereby aerial photos can be exposed over the same features periodically to see changes during the interim period.

Table 5-1
Uses of Film Types

Use	Type
Accident Scenes	Pan, Color
Archeological Features	Pan, IR
Crop Disease Detection	CIR
Earthwork Computations	Pan, Color
Flooding Studies	Pan, IR
Forest Inventory	IR, CIR
Franchise Siting	Pan, Color
Game Habitat	Pan, IR, CIR, Color
Geological Landforms	Pan, Color
Ice Flow	Pan, Color
Jetty Damage	Pan, Color
Land Use	Pan, Color
Land/Water Separation	IR, CIR
Levee Erosion	Pan, Color
Planimetric Mapping	Pan, Color
Quarry Extraction Volumes	Pan, Color
Route Location	Pan, Color
Soil Moisture Location	IR, CIR
Soils Delineation	Pan, IR, CIR, Color
Stockpile Volumes	Pan, Color
Topographic Mapping	Pan, Color
Vegetation Identification	IR, CIR
Vegetation Vigor	IR, CIR
Water Purity (particulate)	CIR
Wetlands	CIR, Color
Wildlife Census	Pan, Color

Note: Pan = panchromatic; IR = infrared; CIR = color infrared.

b. Aerial mosiacs. Since the photographic image will have scale variation caused by the perspective view of the camera, photo tilt, unequal flying heights, and terrain relief, each aerial mosaic product must be evaluated according to how the scale variation problem is treated. Aerial mosaics may be uncontrolled, semiuncontrolled, or controlled. They may be constructed from unrectified, rectified, or differentially rectified photographs. A controlled mosaic is prepared using photographs or scanned digital images that have been rectified to an equal scale, while an uncontrolled mosaic is prepared by a "best fit" match of a series of individual photographs.

c. Photo indexes. A photo index is a rough composite of a number of individual photographs of a flight line or set of flight lines overlaid one on top of the other without trimming the photo prints. These products may be generated digitally using scanned images and softcopy imaging techniques.

d. Photo maps. Photo maps are maps using a photograph (preferably an orthophotograph) as the base to which limited cartographic detail such as names, route numbers, etc. are added. Photo maps (Orthophotographs) can provide accurate digital and hardcopy pictorial views of the earth. Properly designed and constructed orthophotographs can be used as a base for engineering planning and design. Features are usually labeled or "annotated" to facilitate the recognition of critical areas. Photo maps that use orthophoto techniques are georectified and may be an important layer in a geographic information system (GIS). Other appropriate GIS data sets may be overlays to the photo maps for engineering and environmental analysis. Photo maps are particularly useful for land use, land cover delineation, land planning, zoning, tax maps, facility management, and preliminary engineering design.

5-2. Subcontracted Photography

Before commencement of any aerial photography by a Sub-Contractor, the Contractor shall furnish the Government Contracting Officer, in writing, the name of such Sub-Contractor, together with a statement as to the extent and character of the work to be done under the subcontract, including applicable camera certifications.

Section I
Aircraft Flight Specifications

5-3. General

The Contractor shall be responsible for operating and maintaining all aircraft used in conformance with all governing Federal Aviation Administration and Civil Aeronautics Board regulations over such aircraft. Any inspection or maintenance of the aircraft resulting in missing favorable weather will not be considered as an excusable cause for delay.

a. Crew experience. The flight crew and cameraman shall have had a minimum of 400 hr experience in flying precise photogrammetric mapping missions.

b. Acquisition delays. The Contractor shall inspect and constantly monitor the photographic coverage and film quality and shall undertake immediate reflights of areas wherein coverage does not meet specifications. The reason for any photography that does not meet the standard specifications shall be legibly handwritten using a grease pencil on the inspection prints. Rejection of photography by the Contractor or the Contracting Officer shall not in itself be a reason for granting of delay or of another photo season. Failure to undertake reflights or delays in forwarding materials for preliminary inspection (if required) that result in a lost season may be reason to invoke default of contract.

5-4. Operational Procedures

The camera and its mount shall be checked for proper installation prior to each mission. Particular attention shall be given to vacuum supply. Except on short flight lines, a minimum of two runoff or blank exposures is required between usable frames immediately prior to the start of the photography for each flight line or part of a flight line. Any exposures within the project area with a color balance shift compared to the remainder of the roll will result in unacceptable exposures. Some unexposed film must be retained at the beginning or end of each roll for a step wedge, which is required for controlled processing.

a. Aircraft. The aircraft furnished shall be capable of stable performance and shall be equipped with essential navigation and photographic instruments and accessories, all of which shall be maintained in operational condition during the period of the contract. No windows shall be interposed between the camera lens system and the terrain, unless high-altitude photography is involved. Also, the camera lens system shall not be in the direct path of any exhaust gasses or oil from aircraft engines. A typical aerial mapping aircraft is shown in Figure 5-1.

Figure 5-1. Typical aerial mapping aircraft, courtesy of Atlantic technologies

b. Aircraft utilization. Total aircraft utilization to, from, between, and over project sites is based on the provisions contained in the contract. For the purposes of estimating aircraft operational time, any day containing two or more consecutive hours of suitable flying conditions, in any sizable portion of the area not yet photographed, will be considered a suitable day for aerial photography. Additional crew costs will accrue during deployment at or near the project site, where applicable. Aircraft and flight crew standby at the home base shall be considered as an overhead expense.

c. Emergency aircraft standby. Detailed requirements, conditions, notification procedures, and compensation provisions for emergency dedication of an aircraft to a USACE Command shall be specified. Direct and indirect costs shall be clearly identified in establishing the crew-day rate for such an item.

d. Weather conditions (flying conditions). Several conditions should be considered in aerial photo flight planning, since they influence the amount of flying time, project cost, delivery schedule, quality of photography, or accuracy of the mapping data. Photographing shall not be attempted when the ground is obscured by haze, smoke, or dust or when the clouds or cloud shadows will appear on more than 5 percent of the area of any one photograph without permission of the Contracting Officer.

(1) Time of day. Normally flights are limited to the time period that falls between 3 hr after sunrise to 3 hr before sunset. This causes the number of daily available photography hours to fluctuate by both latitude and season. In the middle latitudes of the United States, this may equate to 3 hr or so in December and perhaps up to almost triple that in June.

(2) Sun angle. The sun angle lessens during the winter to the point where it not only shortens the flying day but it also creates long, dense shadows, especially on wooded north-facing slopes. When the sun angle drops below 30 deg to the horizon, flying should be terminated. This condition should be a problem for only a few days in the southern two-thirds of the country. In the northern one-third, this condition could be more restrictive. Of course, during that timeframe these latitudes could also be snow covered, which may also a deterrent for photography. Photographing shall be undertaken when the sun angle is 30 deg or greater above the horizon. Special care must be taken to minimize shadows in mountainous and canyon areas since shadows on color infrared positive film are black and contain little or no detail. Exceptions to the stated sun angle requirement may be made if additional shadow detail will enhance ground images or if reflections or hot spots will mar the imagery on the aerial film.

(3) Cloud cover. Photographs shall not be obtained during poor weather conditions. Excessive wind conditions that will not permit maintaining the allowable flight line tolerances shall be avoided. Photographs that contain clouds, haze, or smoke so that critical ground areas are obscured shall be rejected. Most contracts call for images that are essentially free of clouds and cloud shadows. In warm weather, even if early morning is clear, clouds usually begin building up before the flying day ends. When a cold front moves through, a period (from a few hours to a few days) of good flying weather tends to follow. In winter, there are cold days when the sky is clear and sharp, sometimes lasting from one to several days. In certain situations, when it is advantageous to have a minimum of shadows, photos may be exposed under an overcast. However, in order to enhance the photography, the overcast must be solid, high, thin, and bright. The negative aspect of this situation is that image viewers rely on shadows to locate and identify certain image features.

(4) Season. In areas of deciduous vegetation, flights which involve topographic mapping are normally made in the leaf-free season (late November through early April). In evergreen vegetation areas, the leaves are retained year-round and the ground is obscured on the photos during all seasons. This limits mapping to nonvegetated areas. During summertime photography, there is a greater reflectance variance than in other seasons. This tends to range from almost white (fields, paved surfaces) to almost black (vegetation, shadows), which may result in unacceptable contrasting imagery.

(5) Site restrictions. Airports and military reservations may have restrictions on overflights. These could be total exclusions or restrictions limited only to certain time slots.

(6) Film limits. Normally, color film requires more favorable weather conditions than black and white. On the other hand, infrared has better haze-penetrating capability than panchromatic.

(7) Height restrictions. In order to ensure the safety of both the flight crew and general public, Federal flight regulations decree that an aircraft must not fly lower than that altitude from which the plane can, if it were to lose its power source, glide far enough to clear populated areas. This generally equates to a minimum altitude of 1,000 ft above the ground. Also, at altitudes in excess of 18,000 ft, the flight crew is infringing upon the airspace of commercial airways. The pilot must then file a flight plan prior to commencing a mission, which may place scheduling restrictions on the photo mission.

(8) Turbulence. Wind and thermal currents, assuming otherwise favorable conditions, can create sufficient adverse conditions to prohibit a photo flight. This situation may cause excess tilt, crab, or drift in the photography. Although turbulence can be a problem at any flight height, it is especially troublesome at low altitudes.

(9) Haze. There is usually some haze present near urban areas that can diminish image definition. This urban haze spreads a considerable distance from the source. The degree of haze tends to rise along with temperature.

(10) Snow cover. Some snow might be tolerated on aerial photos, especially thin, spotty patches. Snow cover can have several adverse effects on aerial photography: surface of the snow causes a high light reflection, creating high-density light flares on the image; little surface contrast on a high-reflective material, which tends to flatten the terrain image; depending upon the snow depth, a certain amount of ground cover is obliterated on the image; snow has a depth that affects the measurement of terrain contours.

(11) Ground conditions. The season and any special requirements concerning foliage, snow, or other conditions will be specified in the contract. Conditions that might obscure ground detail shall be the responsibility of the Contractor. However, if questions or concerns about conditions exist, consultation with the Contracting Officer or the Contracting Officer's Representative (COR) before undertaking or continuing the work is advisable. Photographic operations shall be limited to the season specified in the contract unless otherwise authorized by the Contracting Officer.

e. Allowable flight line tolerances. The centers of the first two and last two exposures of each flight line shall fall beyond the project boundaries.

(1) Flight lines. The minimum area(s) to be photographed will be indicated on maps provided for each photographic assignment. **The Contractor shall design the flight lines (with approval by the Government)** to obtain proper side lap to ensure full stereoscopic photographic coverage. Generally, the flight lines shall be parallel to each other and to the longest boundary lines of the area to be photographed. For single strip photography, the actual flight line shall not vary from the line plotted on the flight map by more than the scale of the photography expressed in feet. For example, the allowable tolerance for photography flown at a scale of 1 in. equals 1,000 ft is more or less 1,000 ft. Any proposed variation in either the camera focal length or negative scale constitutes a major change in scope and therefore must be effected by formal contract modification.

(2) Flight height. Departures from specified flight height shall not exceed 2 percent low or 5 percent high for all flight heights up to 12,000 ft above ground elevation. Above 12,000 ft, departures from specified flight height shall not exceed 2 percent low or 600 ft high. During inspection for acceptance, the flight height will be verified by multiplying the focal length of the camera (in feet) by the denominator of the calculated scale of the aerial film. The photography scale is calculated by dividing the distance between two identifiable points as measured on one of the photographs (as near as possible at the mean ground elevation) by the actual ground distance as measured from the best available map.

(3) Stereoscopic coverage. Stereoscopic coverage shall be treated as follows:

(a) Full project coverage. The entire area of the project shall be stereoscopically covered by successive and adjacent overlaps of photographs within the usable portion of the field of the lens. This is an essential requirement for photomapping work.

(b) Reflights. Lack of acceptable stereoscopic coverage caused by the Contractor's failure to adhere to the specified flight design shall be corrected by reflights at the Contractor's own expense.

(c) Reimbursable reflights. Lack of acceptable stereoscopic coverage caused by conditions that could not be avoided by the exercise of reasonable diligence and care on the part of the Contractor will be corrected by reflights at the Government's expense, when authorized by the Contracting Officer.

5-5. Flight Line Maps

Flight line maps should be prepared by the Contractor. Mapping Contractors have available to them software which --once the appropriate photo scale, project dimensions, and USGS Digital Raster Graphics (DRG) file are selected--automatically produce a flight line map and model coverage imprinted on a rendition of a USGS quadrangle. Manually produced flight maps will be acceptable so long as they are neat and decipherable. The Contractor should produce a flight line map and deliver it to the Contracting Officer prior to the photographic mission for verification of proper project coverage.

a. Substitute photography. In flight lines rephotographed to obtain substitute photography for rejected photography, all negatives shall be exposed to comply with flight specifications, including scale and overlap requirements. The joining end negatives in the replacement strip shall result in complete stereoscopic coverage of the contiguous area on the portion or portions not rejected.

b. Flight log. For each flight day, the pilot or cameraman shall prepare a flight log containing the date, project name, aircraft used, and names of crew members. In addition, the following shall be prepared for each flightline: altitude, camera, magazine serial number, f-stop, shutter speed, beginning and ending exposure numbers and times, and any other comments relative to the flight conditions. The flight logs shall be delivered to the Contracting Officer as specified in the work order.

c. Scale of photography. The flight height above the average elevation of the ground shall be such that the negatives have an average scale suitable for attaining required photogrammetric measurement, map scale, CI, and accuracy. Negatives having a departure from the specified scale of more than 5 percent because of tilt or any changes in the flying height may be rejected.

d. Overlap. Unless otherwise directed by the Contracting Officer, the overlap shall be sufficient to provide full stereoscopic coverage of the area to photographed, as follows:

(1) Project boundaries. All of the area appearing on the first and last negative in each flight line that crosses a project boundary shall be outside the boundary. Each strip of photographs along a project boundary shall extend over the boundary not less than 15 percent or more than 55 percent of the width of the strip.

(2) Strip overlap. Where the ends of strips of photography join the ends of other strips, or blocks flow in the same general direction, there shall be a sufficient overlap of stereoscopic models. If the scales of photography are different, they shall be at the smaller photo scale. In flight lines rephotographed to obtain substitute photography for rejected photography, all negatives shall be exposed to comply with original flight specifications, including scale and overlap requirements. The joining end negatives in the replacement strip shall have complete stereoscopic coverage of the contiguous area on the portion or portions not rejected.

(3) Shoreline coverage. Strips running parallel to a shoreline may be repositioned to reduce the proportion of water covered provided the coverage extends beyond the limit of any land feature by at least 10 percent of the strip width.

(4) End lap. Unless otherwise specified in the contract, the end lap shall average 60 percent but not less than 57 percent nor more than 62 percent. End lap of less than 55 percent or more than 68 percent in one or more negatives may be cause for rejection of the negative or negatives in which such deficiency or excess of end lap occurs. In some situations involving orthophotos, aerotriangulation, and/or airborne GPS, the mapper may recommend a greater end lap to enhance accuracy or image definition.

(5) Side lap. Unless otherwise specified in the contract, the side lap shall average 30 percent. Any negative having side lap less than 15 percent or more than 50 percent may be rejected. The foregoing requirement

can be modified, subject to the Contracting Officer's approval, in cases where the strip area to be mapped is slightly wider than the area that can be covered by one strip of photographs; where increase in side lap is required for control densification; or where increase or decrease in side lap is required to reach established ground control. In some situations involving orthophotos, aerotriangulation, and/or airborne GPS, the mapper may recommend a greater sidelap to enhance accuracy or image definition.

(6) Terrain elevation variances. When ground heights within the area of overlap vary by more than 10 percent of the flying height, a reasonable variation in the stated overlaps shall be permitted provided that the fore and aft overlap does not fall below 55 percent and the lateral side lap does not fall below 10 percent or exceed 40 percent. In extreme terrain relief where the foregoing overlap conditions are impossible to maintain in straight and parallel flight lines, the gaps created by excessive relief shall be filled by short strips flown between the main flight lines and parallel to them.

e. ABGPS Flights. Photo projects employing airborne GPS procedures may require greater than average end lap and/or side lap plus cross strips based on the project parameters and the Contractor experience.

f. Crab. Any series of two or more consecutive photographs crabbed in excess of 10 deg as measured from the mean flight path of the airplane, as indicated by the principal points of the consecutive photographs, may be considered cause for rejection of the photographs. Average crab for any flight line shall not exceed 5 deg. Relative crab in excess of 10 deg between two successive exposures shall be rejected. For aerotriangulation, no photograph shall be crabbed in excess of 5 deg as measured from the line of flight.

g. Tilt. Negatives exposed with the optical axis of the aerial camera in a vertical position are desired. Tilt (angular departure of the aerial camera axis from a vertical line at the instant of exposure) in any negative of more than 3 deg, an average tilt of more than 1 deg for the entire project, an average of more than 2 deg for any 10 consecutive frames, or relative tilt between any two successive negatives exceeding 5 deg shall be cause for rejection.

Section II
Aerial Cameras

5-6. General

The photographs to be used in precise photogrammetric work must be obtained using a fully calibrated precision camera with a single high-resolution low-distortion lens. Cameras used for photogrammetric mapping must meet the requirements outlined in the following text. The cost for calibration and other compliance will be borne by the Contractor. The aerial camera used shall be of quality sufficient to produce photography, which will meet accuracy and resolution requirements. A shutter speed shall be chosen that meets the combined requirements of minimal image movement and optimum lens aperture for the prevailing illumination conditions. Many Contractors employ aerial cameras equivalent to the RC-30. This camera or equivalent should meet or exceed most project requirements. However, older camera systems may be sufficient for specific projects and should not necessarily be rejected. Camera system selection should be based solely on capability to generate suitable imagery for the project and cost to use the system. Figure 5-2 shows a typical camera system mounted in an aircraft.

Figure 5-2. Typical camera system mounted in an aircraft (Courtesy of Dave Kreighbaum and Earthdata Corporation)

5-7. Types of Aerial Cameras

There are three types of aerial cameras:

a. Analog. The analog camera captures the photographic image on a strip of film which is coated with a varnish of silver salts.

b. Digital frame. The digital camera captures the image on a charge coupled device which generates a file of radiometric pixels. Used primarily for surveillance photography or in multispectral data collection.

c. Video cameras. The aerial video camera is a low-resolution videography system which records a continuous swath of raster data. These are similar to those used by amateur photographers in the home. Video cameras are sometimes employed in conjunction with analog cameras and the collection of multispectral data.

Currently the analog camera is by far more extensively used in the mapping field. At the time of publication of this manual, digital frame and video cameras are not suitable for most USACE large-scale mapping projects. Hence, this section will confine the discussion to analog aerial cameras. Recent advancements in these systems indicate that they will become major image collection systems in the near future. The cost, data storage, and accuracy of systems is prohibitive for most large-scale mapping. Selection of a system and Contractor for digital frame and video surveillance and multispectral data capture should be based on demonstrated experience specific to the USACE project requirements.

5-8. Analog Aerial Cameras

Analog aerial camera systems are very expensive because of precision construction and meticulous lens polishing. These cameras are finely adjusted and must be periodically subjected to a calibration test to ensure their continued accuracy.

a. A vacuum is applied to the film at the instant of exposure so that the film is held flat. Otherwise, there could be air bubbles beneath the film, causing uncontrollable distortions on the photographic image.

b. The camera lens system is compound, meaning that there are several elements of polished glass.

c. Focal length of a given camera is the distance from the rear nodal point of the lens system to the focal plane. There are several focal lengths available: narrow angle (12 in.), normal angle (8.25 in.), wide angle (6 in.), and superwide angle (3.5 in.). Image analysis projects may use all of these various focal lengths, whereas photogrammetric line mapping projects use the 6-in. focal length predominantly.

Several compensatory devices used to adjust for flight irregularities are integrated into the camera system: forward image motion compensation, gyroscopic stabilization, and electronic navigation and airborne GPS for navigation and/or photo control.

5-9. Camera Filters

Aerial photography is usually exposed through a glass or gelatin filter attached beneath the lens. There are a variety of filters depending upon the type of film used and the purpose of the imagery. Most common filters are as follows:

a. Minus blue filter. This so-called haze filter is a yellow-colored filter that passes some of the blue rays and all of the red and green while absorbing much of the haze-scattered visible blue light. This filter is used with panchromatic (black-and-white) photography.

b. Antivignette filter. This clear filter absorbs various gradations of light in different areas of the lens so that the total image has a more even tonal grade. This filter is used with color film.

c. Deep red filter. This dark red filter, absorbing all but the longer wavelengths, can be used with infrared film to enhance the image.

5-10. Camera Classifications

There are two classes of analog cameras. The first is the precision mapping camera that shall have been calibrated by USGS. The second is the substitute camera. A precision mapping camera shall be used for all photogrammetric mapping projects. If a substitute camera is required for taking special-purpose photographs, prior approval must be obtained from the Contracting Officer.

5-11. Camera Mounting Requirements

The camera mount shall be regularly serviced and maintained and shall be insulated against aircraft vibration.

a. Camera opening. The camera opening in the aircraft shall provide an unobstructed field of view when a camera is mounted with all its parts above the outer structure. The field of view shall, so far as practicable, be shielded from air turbulence and any effluence such as gasses and oil. The camera port glass (if required) shall be free of scratches and shall not degrade the resolution or the accuracy of the camera.

b. Exposure control. An automatic exposure control device is permitted and recommended for all photography, but a manual override capability is required for some types of terrain to achieve proper exposure.

5-12. Camera Criteria/Reporting

The camera shall meet the following criteria:

a. Type of camera. A single-lens precise aerial mapping camera equipped with a high-resolution, distortion-free lens shall be used on all assignments. The camera shall function properly at the necessary altitude and under expected climatic conditions and shall expose a 9-in.-square negative. The lens cone shall be so constructed that the lens focal plane at calibrated focal length, fiducial markers, and marginal data markers comprise an integral unit, or are otherwise fixed in rigid orientation with one another. Variations of temperature or other conditions shall not cause deviation from the calibrated focal length in excess of 0.05 mm or preclude determination of the principal point location to within 0.003 mm.

b. Calibration. The aerial camera(s) furnished by the Contractor shall have been calibrated by the USGS within 3 years of award of a contract. The calibration report shall be presented to the Contracting Officer prior to use of the camera. Certification shall also be provided indicating that preventive maintenance has been performed within the last 2 years. Camera features and acceptable tolerances are as follows:

(1) Focal length. The calibrated focal length of the lens shall be 153 mm, 3 mm, and measured to the nearest 0.001 mm.

(2) Platen. The focal plane surface of the platen shall be flat to within 0.013 mm and shall be truly normal to the optical axis of the lens. The camera shall be equipped with means of holding the film motionless and flat against the platen at the instant of exposure.

(3) Fiducial marks. The camera shall be equipped with a minimum of eight fiducial marks for accurately locating the principal point of the photograph. The lines joining opposite pairs of fiducial marks shall intersect at an angle within 1 min of 90 deg.

(4) Lens distortion. The absolute value of radial distortion measured at maximum aperture, as stated in the calibration report, shall not exceed 0.01 mm.

(5) Lens resolving power. With appropriate filter mounted in place, the Area Weighted Average Resolution (AWAR) of state-of-the-art are in the range of 100+ lines/millimeter when measured on type V-F spectroscopic plates at maximum aperture stated on calibration report. The lens shall be fully corrected for color photography.

(6) Filter. An appropriate light filter with an antivignetting metallic coating shall be used. The two surfaces of the filter shall be parallel to within 10 sec of arc. The optical characteristics of the filter shall be such that its addition and use shall cause no undesirable reduction in image resolution and shall not harmfully alter the optical characteristics of the camera lens.

(7) Shutter. The camera shall be equipped with a between-the-lens shutter of the variable speed type, whose efficiency shall be at least 70 percent at the fastest rated speed.

(8) Stereomodel flatness. The deviation from flatness of the average data from two models (elevation discrepancy at photography scale) at measured points may not exceed 1/8,000 of the focal length of a nominal 6-in. (153-mm) focal length camera. If elevation discrepancies exceed this value, the camera will not be acceptable.

(9) Substitute cameras. Substitute cameras may be used for taking photography only if prior approval is obtained from the Contracting Officer or is provided for in the contract. Substitute cameras shall meet the minimum requirements for resolution as specified for precision mapping cameras.

Section III
Photographic Film

5-13. General

Only unexpired film of the type specified in a contract or task order shall be used. The Contractor shall purchase all film, unless specifically stated otherwise. All aerial film shall be of archival quality. The film exposed and processed shall not be spliced. The processed negatives shall be free of stains, discoloration, or brittleness that can be attributed to aging. Black-and-white panchromatic, black-and-white infrared, color, and color infrared are the allowable film emulsion types. Each specific mapping requirement will dictate which emulsion type to be used. Table 5-2 provides guidance on the type of emulsion to use for particular applications.

5-14. Radiant Energy and the Electromagnetic Spectrum

All forms of radiant energy composing the electromagnetic spectrum travel in waves. The human eye sees only that portion of the electromagnetic spectrum denoted as visible light. Aerial photographic films only span the limited amount of the electromagnetic spectrum. Collection of data outside of these wavelengths must be done with sensors other than an analog camera.

Table 5-2
Applicable Aerial Film Emulsions For Applications And Techniques

Application	Technique	Emulsion Types: Black and White	Natural Color	Color Infra-Red
Photogrammetric Mapping	Stereo Map Feature Compilation – Analytical or Softcopy	Yes	Yes	Yes
Route Corridor Studies; Area Wide Planning Studies	Orthophotography Analysis and Interpretation	Yes	Yes	Yes
Vegetation Alnalisis and Classification; Landuse Classifiction	Monoscopic Visual Inspection of Aerial Photos or Film Transparancies	Yes	Yes	Yes
Photo Interpretation	Monoscopic or Stereo Pair Inspection – Visual or Stereo Plotter	Yes	Yes	No

Note:
Yes = Applicable
No = Not Applicable

The portions of the electromagnetic spectrum that interest the aerial mapper and photo analyst are visible light and infrared light.

(1) *Visible light.* The sun emits solar energy, which beats down upon the earth. Objects on the earth's surface absorb and/or reflect varying amounts of this radiation. A white light source, such as the sun, includes the primary visible colors of blue, green, and red. The visible spectrum spans the 0.4- to 0.7-micron range. Various colors of the rainbow are blends of the primary physical colors of red, green, and blue. Equal parts of blue, green, and red appear as white light. Absence of all three, results in black. A radiant wave will be deflected by colliding with any foreign particle of matter larger than that wavelength. The shorter the wavelength, the more it is scattered by particulate matter in the air. Blue wavelengths are shortest and they ricochet off the most minute particles (gases, dust, and vapor) causing them to skitter all over the sky, while the longer green and red wavelengths plow on through. This prolific scattering of the shorter waves dominates the sense of vision and compels humans to see blue. But, as the size of the particulate matter increases (caused by smoke, moisture, or dust storms) the longer waves then are deflected. Thus, more of the greens and reds fill the sky.

(2) *Infrared*. Infrared implies heat radiation.

(a) There are two types of heat that will be detectable by specific sensors: thermal and reflected.

(b) Thermal. Longer infrared wavelengths are actual temperature radiations emitted from an object. Emitted heat images must be sensed with a thermal scanner, which breaks this information into variable intensity light pulses used to create the photographic image. Since midinfrared and thermal infrared are not captured by film, these will not be further discussed.

(c) Near-Infrared. Reflected heat refers to the shorter wavelengths and indicates the relative amounts of solar heat that reflect off the molecular composition of the surface of an object. It does not indicate the actual temperature of the mass.

(d) Healthy vegetation (whether leaves on trees or bushes, blades of grass, stalks of corn, foliage of soybeans) produces sugar through the photosynthetic process. When this chemical function breaks down, and photosynthesis decreases or stops, the leaf surface takes on a different molecular structure. The amount of infrared reflection differs at these various stages and is seen as different hues, especially with color infrared imagery where healthy vegetation is red and various stages of less vigor result in more subdued pinks.

(e) Clean water absorbs infrared waves; therefore, this feature tends to be very dark on infrared images. As the amount of suspended particles increases, the infrared waves hit this foreign material and are reflected, resulting in a lighter image tone.

(f) A portion of the near-infrared images (0.7 to 1.0 micron) can be exposed directly on aerial film and produce an image just as with visible light photography.

(g) Essentially, the photogrammetrist is concerned only with aerial photography covering 0.4 to 0.7 micron, whereas the image analyst must be familiar with a wider portion of the spectrum both shorter (ultraviolet) and longer (infrared) than visible radiation.

5-15. Film Characteristics

a. Panchromatic film. Radiometric sensitivity of the silver halide crystals in the panchromatic film emulsion encompasses the visible portion, blue through the red (0.4 to 0.7 micron), of the spectrum. It is usually desirable to use a minus blue (yellow) or bright red filter to reduce the effects of haze and smog. There is greater latitude in exposure and processing of black-and-white panchromatic films than there is with color films, which assures a greater chance of success in every photo mission.

b. Color. Color aerial photography entails the taking of photographs in natural color by means of a three-layer emulsion sensitive to blue, green, and red visible colors. Both color negative and color positive film types are available. Color photography requires above-average weather conditions, meticulous care in exposure and processing, and color-corrected lenses. For these reasons, color photography and color prints are more expensive than panchromatic.

c. Infrared. Infrared emulsions have greater sensitivity to red and the near-infrared. They record the longer red light waves, which penetrate haze and smoke. Thus, infrared film can be used on days that would be unsuitable for ordinary panchromatic films. It is also useful for the delineation of water and wet areas, and for certain types of vegetation, environmental and landuse studies. Its chief disadvantage is a greatly increased contrast, which may tend to cause a loss of image information.

d. Color infrared. Color infrared has many of the same uses as black-and-white infrared, in addition the nuances of color help in photo interpretation. Because healthy vegetation (normally green) are recorded as reds on this emulsion, it is often termed "false color film." It is used in the detection of diseased plants and trees, identification and differentiation of a variety of fresh and salt water growths for wetland studies, and many water pollution and environmental impact studies. A color-corrected camera lens is required. The cost of obtaining infrared color is greater than that for black and white. Because of the cost of making infrared color prints, color transparencies may be used and viewed on a light table.

5-16. Type of Diapositives

All black-and-white and color diapositive transparencies used for photogrammetric measurements, including map compilation, shall be capable of maintaining accuracy and resolution of delivery products.

5-17. Film Processing and Handling Specifications and Criteria

All aerial film shall be processed under controlled conditions in automatic, continuous film processors. The film shall be processed in accordance with the manufacturer's instruction. The processing, including development and fixation and washing and drying of all exposed photographic film, shall result in negatives free from chemical or other stains, containing normal and uniform density and fine-grain quality. Before, during, and after processing, the film shall not be rolled tightly on drums or in any way stretched, distorted, scratched, or marked and shall be free from finger marks, dirt, or blemishes of any kind.

a. Storage and handling. Storage and handling of all photographic material shall be in accordance with the manufacturer's recommendation. Adverse storage conditions affect the color-emulsion layers, and subsequently, the color balance of the film, and possibly overall film speed and contrast.

b. Image quality. The imagery on the aerial film shall be clear and sharp and evenly exposed across the format. The film shall be free from clouds and cloud shadows, smoke, haze, light streaks, snow, flooding, excessive soil moisture, static marks, shadows, tears, crimps, scratches, and any other blemishes that interfere with the intended purpose of the photography. If, in the opinion of the Contracting Officer, the Contractor has adhered to the specifications and has exercised reasonable care to meet density requirements, allowance will be made for unavoidable shadows, permanent snow fields, or reflectance from water bodies. It must be possible to produce black-and-white internegatives and duplicate positives from original color infrared films and duplicate negatives from original black-and-white films with no significant loss of image detail.

c. Image resolution. When there is doubt concerning the resolution of images obtained, a comparison will be made of well-defined edges of man-made structures and other features in the film with previous imagery of acceptable quality, similar scale, and contrast. If the imagery is obviously degraded when compared to previously accepted like images, the film shall be rejected for poor image quality. The film will be evaluated by the following criteria:

(1) *Characteristic curve and color balance.* A 21-step gray sensitometric wedge (0.15 density increments) shall be exposed on one end of each roll of film before processing. The Contractor shall make appropriate density measurements on the step wedge and plot the characteristic curves and determine color balance for each roll of color infrared film and gamma for each roll of black-and-white film. The plotting shall be on Kodak curve-plotting graph paper E-64 or equivalent. The plot shall be delivered with each roll of film.

(2) *Density measurements.* The density units defined herein are for those measured on a transmission densitometer with a scale range of at least 0.0 to 3.0 and a 1-mm aperture probe. Readings shall not be made closer than 25 mm (1 in.) to an exposure edge nor closer than 40 mm (1.5 in.) to an exposure corner. Specular reflectors (such as water surfaces) or small, isolated density anomalies within a scene shall not be used for determining the maximum or minimum densities or density range of a roll of film. The maximum density in useful areas of the negative shall not exceed D 1.5 above base, other than in areas of high reflectance where a maximum density of D 2.0 shall be permissible.

f. Dimensional stability of film. Equipment used for processing shall be either rewind spool-tank or continuous processing machine and must be capable of achieving consistent negative quality without causing distortion of the film. The film shall be dried without affecting its dimensional stability.

g. Film roll specifications. A roll of aerial film shall consist only of exposures made with the same camera system (lens, cone, and magazine). No more than one project may be placed on a roll. All film on any one roll shall have the same roll number.

h. Leader and trailer. A minimum of 3 ft of blank or unused film shall be left beyond the first and last used exposure on each roll to serve as a leader and trailer. If 3 ft of blank or unused film is not left on the original film roll, 3 ft of leader or trailer must be spliced onto the roll. There shall be no splices within the 3 ft of leader or trailer.

5-18. Camera Panel

The camera panel of instruments should be clearly legible on all processed negatives. Failure of instrument illumination during a sortie may be cause for rejection of the photography. All fiducial marks shall be clearly visible on every negative.

5-19. Film Report

A report shall be included with each project giving the following information:

a. Film number.

b. Camera type and number, lens number, and filter type and number.

c. Magazine number or cassette and cassette holder unit numbers.

d. Film type and manufacturer's emulsion number.

e. Lens aperture and shutter speed.

f. Date of photography.

g. Start and end time for each run in local time.

h. Negative numbers of all offered photography.

i. Indicated flying height.

j. Scale of photography.

k. Contract number and/or delivery order designation, as applicable.

l. The calibrated focal length of the lens unit.

m. Contractor's name.

5-20. Negative Annotation

Each negative shall be labeled clearly with the identification symbol and numbering convention furnished herein. Each negative shall be provided with the following annotation, which shall also appear on the prints:

a. Year, month, and day of flight.

b. USACE project identification.

c. Photo scale (ratio).

d. Film roll number.

e. Negative number.

f. Spatial coordinates of camera station (if ABGPS).

5-21. Container Labels

The Contractor-furnished container and spool for each roll of film shall become the property of the Government. Container labels shall be typed or neatly lettered by the Contractor with the required data and securely affixed to each container. All rolls of aerial film shall be shipped in sturdy, cylindrical, plastic containers with each container labeled. Minimum suggested labeling shall be as follows:

a. Name and address of the contracting agency.

b. Name of the project.

c. Designated roll number.

d. Numbers of the first and last numbered negatives of each strip.

e. Date of each strip.

g. Approximate negative scale (expressed as a ratio).

h. Focal length of lens in millimeters.

i. Name and address of Contractor who performed the photography.

j. Contract number.

5-22. Photo Index Map Requirements

Negatives and prints of an assembly of aerial photographs that form an index of a project's aerial photography may be prepared if called for in the specifications.

a. Assembly. A photo index map may be produced digitally or manually. A manual photo index shall include photographic prints made from all negatives of the photography taken and accepted for the project. The prints shall be trimmed to a neat and uniform edge along the photographic image without removing the fiducial marks. The photographs shall be overlap-matched by conjugate images on the flight line with each photograph identification number clearly shown. The photographs for each adjacent flight line strip shall overlap in the same direction. Airbase lengths shall be averaged in the image matching of successive pairs of photographs on flight lines, and adjoining flight line assemblies shall be adjusted in length by incremental movement along the flight line as necessary. In most cases today, a digital photo index map will be generated. A digital photo index map is generated with the utilization of scanners and softcopy workstations. Low resolution scans of the images are created and ported to a softcopy workstation. The softcopy workstation is used to create a mosaic of the images similar to that generated in a manual photo index. Hardcopies can be generated via plotters at minimal expense. High-quality prints may be generated via production of a negative through a film writing process and generation of Mylar or photographic paper prints from the negative in a photography enlargement lab.

b. Labeling and titling. For geographic orientation, appropriate notations shall appear on the index, naming or otherwise identifying important and prominent geographic and land-use features. All overlay lettering and numbering shall be of drafting quality. In addition, a north arrow, sheet index, if applicable, and a title block shall appear on each index. The title block shall contain project name, Contractor's name, contract agency name, date of photography, and average scale of photography.

c. Scale and size. The stapled or taped assembly of photography shall be photo-reduced to a scale of about one-third of the original negative scale. A larger photo index scale can be used if all exposures for one project fit the required format on a single sheet.

5-23. Contact Prints

All contact prints shall be made on medium-weight, semimatte paper stock approved and by the Contracting Officer. Contact prints shall be delivered flat and trimmed and contain all highlight and shadow detail. Prints may be labeled on the back or on the packaging. Labeling requirements shall be specified in each contract or task order. The following is suggested labeling:

Project_________________________________
USACE Contract No. DAXXXX __________
Date of Photography ____________________
Calibration of Camera Date_______________
Contractor______________________________
Address_________________________________
Telephone_______________________________

a. Photographic print quality. The processing shall result in dodged photographic prints having fine-grain quality, normal uniform density, and such color tone and degree of contrast that all photographic details of the negative from which they are printed show clearly in the dark-tone areas and highlight areas as well as in the halftones between the dark and the highlight. Excessive variance in color tone or contrast between individual prints will be cause for their rejection. All prints shall be clear and free of stains, blemishes, uneven spots, air bells, light fog or streaks, creases, scratches, and other defects that would interfere with their use or in any way decrease their usefulness.

b. Print condition. All prints shall be delivered to the Government Contracting Officer in a smooth, flat, usable condition.

5-24. Contract Deliverables

a. All the required film and contact print materials shipped shall conform to the requirements stated in the contract or task order specifications and shall become the property of the Government. Deliverables should be limited to those required for the project. Unnecessary deliverables increase the cost of the project without benefit. Suggested minimum requirements for contract deliverables are specified below:

(1) All film exposed on the project.

(2) One set of positive black-and-white prints (from black-and-white film) or one set of negative black-and-white prints (from color-infrared film) of all photography.

(3) The flight log.

(4) One photo index including photographic prints made from all negatives of the photography for the project.

(5) Camera Calibration Report.

b. The following additional items shall also be delivered if specified in the contract or task order:

(1) One set of clear film positives of the flight maps used by the Contractor. These positives, in flight line strips, shall be the same scale as the inspection prints submitted.

(2) The photography supplement report, which identifies all photography flown as part of the contract.

(3) Color-infrared color balance test strips and graphs.

(4) Black-and-white processing test exposures and graphs.

(5) Weekly progress reports.

(6) Monthly progress reports.

(7) Camera log.

(8) Film edit log.

Chapter 6
Ground Control Requirements for Photogrammetric Mapping

6-1. General

This chapter covers ground control requirements for photogrammetric mapping projects. Control surveys associated with photogrammetric mapping projects shall be in compliance with the July 1, 1998, "Public Review Draft FGDC Geospatial Positioning Accuracy Standards, Part 4: Standards for Architecture, Engineering, Construction (A/E/C) and Facility Management." The fundamental requirements for control network configuration, point location, and image characteristics are discussed in this text. However, the overview presented is not intended to be used for field survey design or survey procedural instruction. The USACE specification writer or photogrammetric engineer should refer to appropriate survey standards and specifications for guidance in designing the project control surveys. Current standards should be employed. Outdated unrevised standards can provide outdated technology and procedure guidance and cost the Government unnecessary time and money. Listed below are some of the current (at the time of the publication of this Engineer Manual) publications that may be used.

July 1, 1998, Public Review Draft, "FGDC, Geospatial Positioning Accuracy Standard, Part 4"

EM 1110-1-1002, "Survey Markers and Monumentation"

EM 1110-1-1003, "Navstar Global Positioning System Surveying"

6-2. Coordinate Reference Systems

The coordinate reference system is the backbone of a mapping project. It provides the framework to tie together all field survey and map data. The coordinate reference system must be specified for the final map product. Typically, the State Plane Coordinate zone or the Universal Transverse Mercator (UTM) zone in which the project is located is used to define a mapping coordinate system. The North American Datum of 1983 (NAD 83 HPGN) and the North American Vertical Datum of 1988 are the most current horizontal and vertical datums as of this publication. NAD83 and NAVD88 should be used for most USACE projects within the continental United States unless unique circumstances make the use of these datums unreasonable. NAD27 and National Geodetic Vertical Datum of 1929 (NGVD29) are horizontal and vertical datums that have been used for USACE projects for many years. USACE Commands may choose to continue the use of these datums for specific projects. The photogrammetric engineer must be familiar with the reference datum, the coordinate system definition, and the methods required to transform all data into the final map coordinate system. Reference datums and coordinate systems used shall be clearly identified as part of the ground control META data and in specifications for surveying contractors performing photogrammetric ground control data collection. Chapter 3 reviews the definitions of the datums and coordinate systems typically encountered in mapping. Several sources in Appendix A provide detailed information on datums, coordinate systems, and map projections.

6-3. Ground Control Requirements for Photogrammetric Mapping

Field surveying for photogrammetric control is generally a two-step process. The first step consists of establishing a network of *basic control* in the project area. This basic control consists of horizontal control monuments and benchmarks of vertical control that will serve as a reference framework for subsequent surveys. The second step involves establishing *photo control* by means of surveys originating from the basic control network. Photo control points are the actual points appearing in the photos (photo identifiable points or panel points) that are used to control photogrammetric operations. The accuracy of basic control surveys is generally of higher order than subsequent photo control surveys. According to FGDC Standards, Part 4 (FGDC 1998), control surveys accuracies may be specified in either positional tolerance accuracy or relative closure ratio accuracy. Control survey accuracies are usually measured in relative closure ratios rather than positional tolerance. The horizontal and vertical control survey types recommended in Table 2-1 coupled with the FGDC Horizontal and Vertical Accuracy Standards stated in Tables 5-1 and 5-2 shall be used to establish survey control accuracies for USACE photogrammetric mapping projects. It is imperative that a geodesist with photogrammetric control experience in the geographic area of the project be an integral part of the ground control planning team. The geodesist should specifically be considered in the final placement of not only basic control but also photo control to ensure required accuracies are met and time and costs are kept to a minimum. GPS technology is now an integral part of almost any field survey project to include photogrammetric control surveys. Increased satellite availability, improved receiver processing and software along with more accurate geoid models have enhanced the reliability and accuracy of GPS measurements. GPS is one of several tools that may be used in establishing photogrammetric ground control. GPS technology does have limitations that must be understood and dealt with when planning and executing a ground control project. Proper employment of GPS in obtaining photogrammetric survey control can contribute to decrease cost and time in the field. Further information regarding GPS technology, theory, and planning can be obtained from several sources to include EM 1110-1-1003, “Navstar Global Positioning System Surveying.”

a. Basic control. A basic control survey provides a fundamental framework of control for all project-related surveys, such as property surveys, photo control surveys, location and design surveys, and construction layout. The accuracy, location, and density of the basic control must be designed to satisfy all the project tasks that will be referenced to the control. The National Geodetic Referenced System (NGRS) has been established and is maintained by the Federal Government through the National Geodetic Survey (NGS). The NGRS consists of more than 270,000 horizontal control monuments and more than 600,000 benchmarks throughout the United States. The NGS continues to establish, upgrade, maintain, and disseminate geodetic control information. Relative accuracies within the current NGRS vary. GPS technology appears to provide reference points with more consistent and more accurate locations than those established by more conventional methods. The NGS along with many states have created High Precision Geodetic Networks, (HPGNs). The HPGNs-fit GPS derived reference point locations to less accurate state networks. Established HGPNs should be considered in the planning and establishment of control when possible for USACE photogrammetric projects. Procedures for GPS ground control establishment should follow guidance provided in EM 1110-1-1003, “NAVSTAR Global Positioning System Surveying.”

(1) Horizontal basic control points should be angle points in traverses or vertices of network triangles. Vertical basic control points should be turning points in level routes. Vertical control obtained by GPS should be checked by conventional level loops for selected points to check accuracy of the geoid model in the project area. Conventional survey side shots or open traverses should not be used to locate basic control. Second or Third-Order plane surveys will generally be of sufficient accuracy to establish basic control for most, if not all, USACE photogrammetric mapping projects. See also the guidance in Table 2-1.

(2) In planning the basic control survey, maximum advantage should be taken of existing, or project, control established in the area by the USACE Command. Basic control may also be established with HPGN, NGRS, or USGS reference points. In many locations, local control points exist such as those established for State agency and urban area networks. Care should be exercised before using any control points to verify that they are adequately interconnected or are adequately connected to the national network (i.e., NGRS).

b. Photo control. Photo control points are photo identifiable or panel points that can be measured on the photograph and stereomodel. Photo control points are connected to the basic control framework by short spur traverses, intersections, and short level loops. Lengthy side shots and open traverses should be avoided.

Photo control surveys are local surveys of limited extent. Photo control points are surveyed to the accuracy required to control the photogrammetric solution. The accuracy requirement for photo control points should generally be Third Order and, in some instances, Second Order as established in Table 2-1.

(1) Characteristics. Photo control points should be designed by considering the following characteristics: location of the control point on the photograph; positive identification of the image point; and measurement characteristics of the image point. GPS derived photo control points require special consideration. The locations of GPS points must be in a location that will allow for the required GPS horizon parameters to be met.

(a) Location. Of the characteristics listed in (1) above, location is always the overriding factor. Photo control points must be in the proper geometric location to accurately reference the photogrammetric solution to the ground coordinate system. Horizontal photo control points should define a long line across the photographic coverage. The horizontal control accurately fixes the scale and azimuth of the solution. Vertical photo control should define a geometrically strong horizontal triangle spanning the photographic coverage. The vertical control accurately fixes the elevation datum of the solution. The location should be established in accordance with current photogrammetric practice considering the project area and the map accuracy requirements.

(b) Identification. The identification of the photo control points on the aerial photographs is critical. Extreme care should be exercised to make this identification accurate. The surveyor should examine the photo control point in the field using a small pocket stereoscope with the aerial photographs. Once a photo control point is identified, its position on the photograph should be pricked using a sharp needle. A brief description and sketch of each point should be made on the reverse side of the photograph. Each photo control point should be given a unique name or number.

(c) Measurement. Subject to the constraints imposed by location considerations, photo control points should be designed to provide accurate pointing characteristics during photogrammetric measurements. Furthermore, control points should not be located at the edge of the image format, since image resolution and distortion are both degraded at the edge of the format. Photo control points falling in the outside 10 to 15 percent of the image format should be rejected.

(2) Horizontal photo control. Images for horizontal control have slightly different requirements from images for vertical control. Because their horizontal positions on the photographs must be precisely measured, images of horizontal control points must be very sharp and well-defined horizontally. Care should be exercised to ensure that control points do not fall in shadowed areas.

(3) Vertical photo control. Images for vertical control need not be so sharp and well-defined horizontally. Points selected should, however, be well-defined vertically. Since measurements are typically made stereoscopically, good vertical control points should have characteristics that make it easy for the operator to accurately put the floating mark at the correct elevation. Vertical control points are best located in small, flat, or slightly crowned areas with some natural features nearby that assist with stereoscopic depth perception.

(4) When GPS methods are employed, photo control images should be discrete, since these procedures create a precise spatial coordinate (X,Y,Z).

c. Control point distribution. If photo control is being established for the purpose of orienting stereomodels in a mapping instrument for planimetric and / or topographic map compilation, the control point distribution depends upon the mapping procedures that are employed to adjust the imagery to the earth. The exact location of specific control is site dependent. The survey crew should be provided with current photography of the project area to assist in establishing the location of control points. Additional information regarding ground control point distribution can be found in Chapters 7 and 8. Figure 6-1 is a typical ground

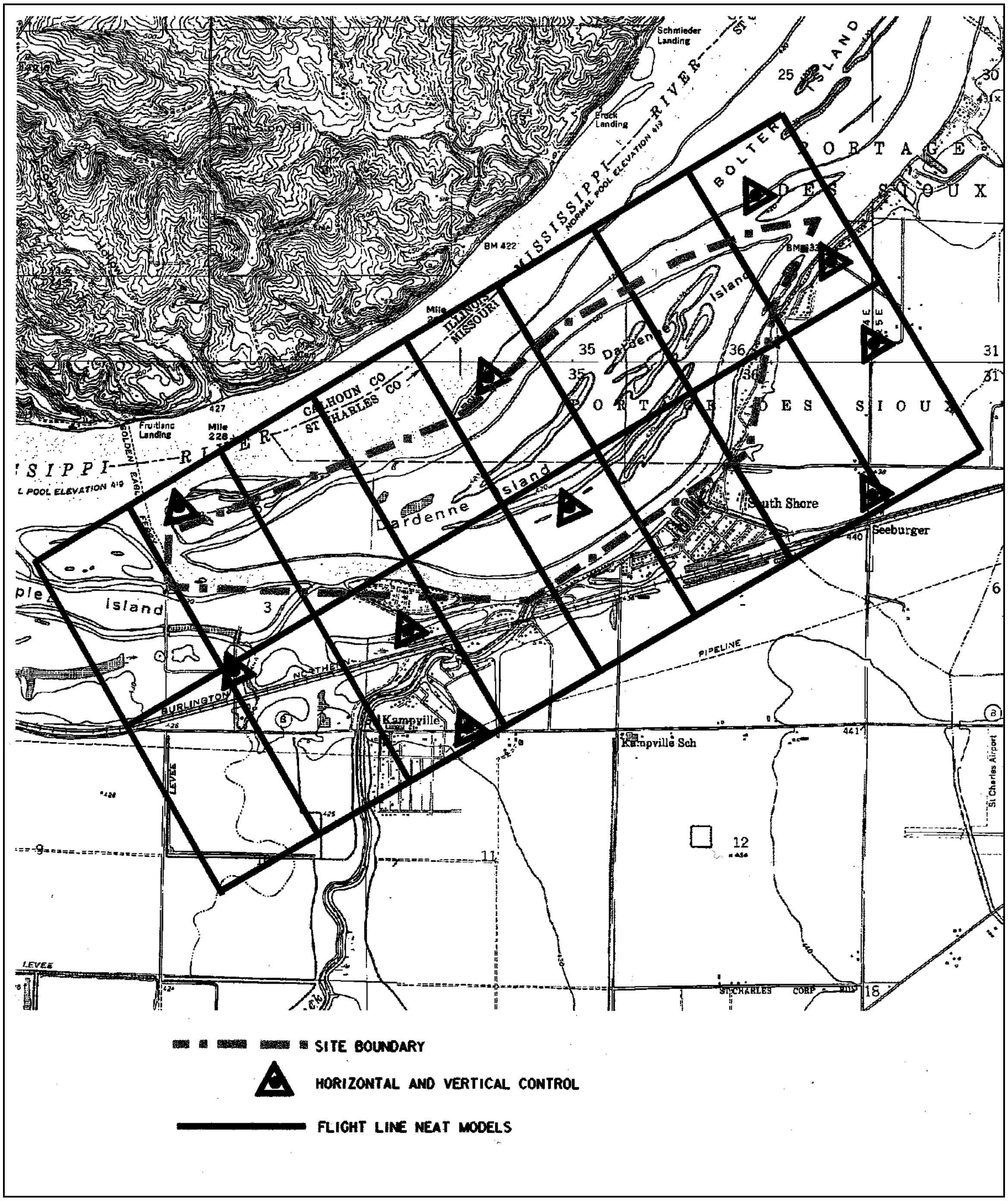


Figure 6-1. Typical ground control plan

control plan for aerotriangulation, showing the approximate neat models for each photograph required to cover the project boundary and the approximate locations of ground control.

(1) The absolute geometric minimum amount of photo control needed in each stereomodel is four points. In small projects requiring just a few models this control can be established on the ground by conventional field surveys. Figure 6-2 is a diagram of the ground control point distribution, assuming all of the survey points were to be located by ground survey methods.

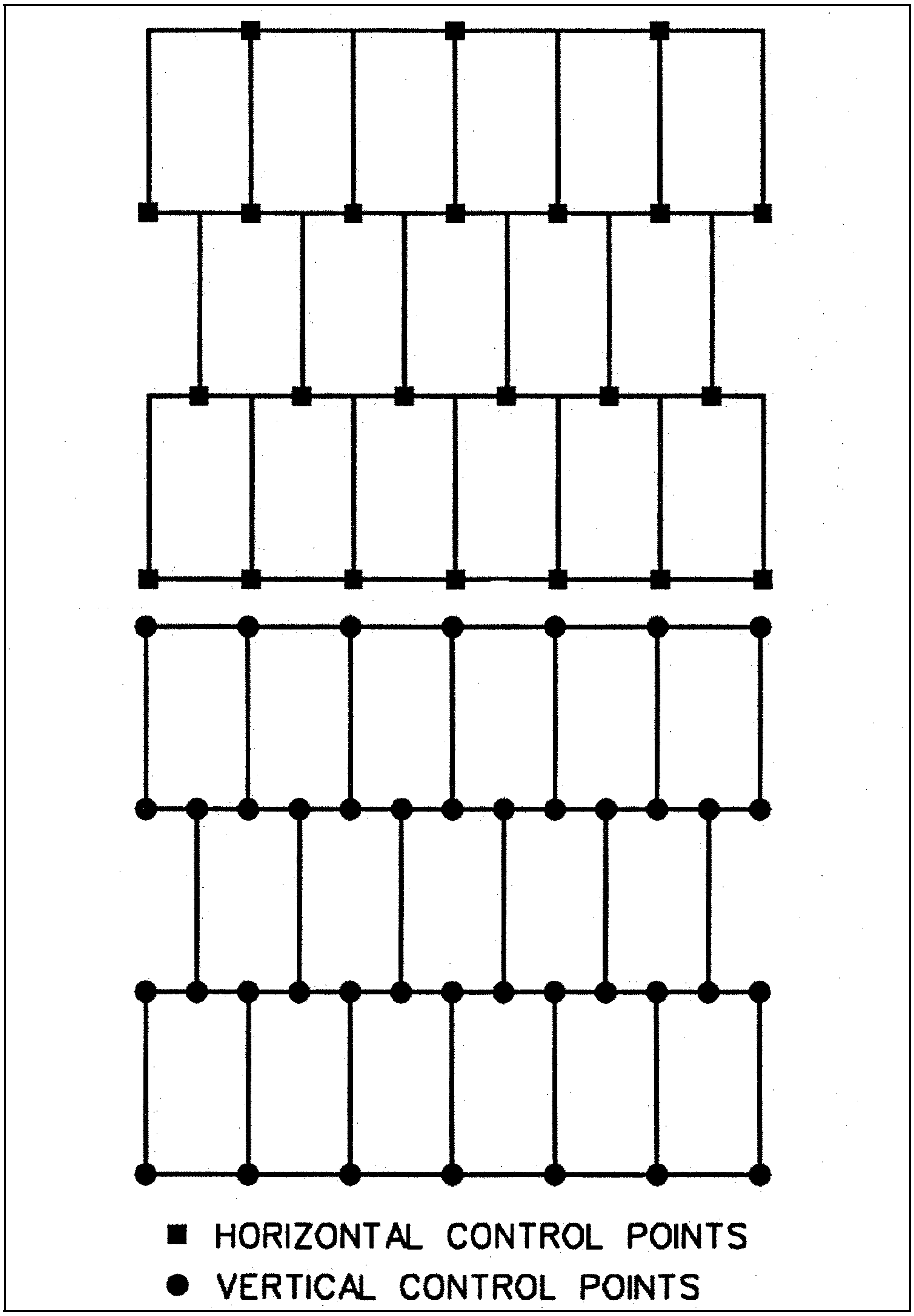


Figure 6-2. Conventional photo control point configuration

(2) On most projects requiring more than a few stereomodels, a skeletal pattern of strategic field control points is established. A network of six or more supplemental photo control points per photograph are generated by aerotriangulation (airtrig, AT) procedures. In this process (discussed in Chapter 8), the amount of ground control required can be significantly reduced. Generally, aerotriangulation procedures make it is necessary to provide field control points only in every third model in a flight strip. Some project sites may allow for even fewer (dependent on the map scale, final products and specific site). Figure 6-3 is a diagram of the ground control point distribution if aerotriangulation procedures supplement ground survey control.

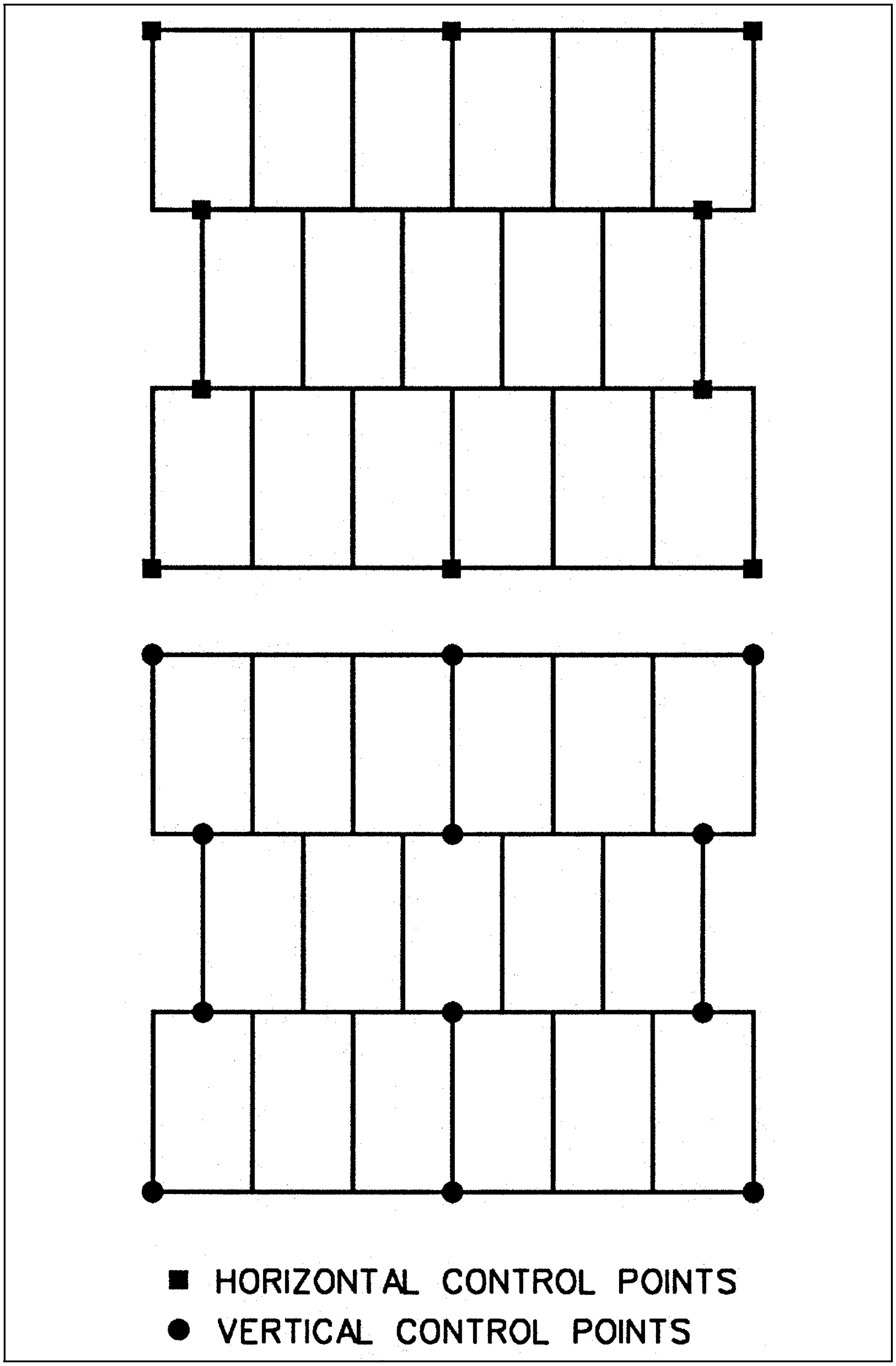


Figure 6-3. Photo control point configuration for aerotriangulation

(3) If airborne GPS procedures are integrated into the photographic flight the amount of primary ground control points required may be further reduced. Airborne GPS projects generally require a block of imagery that includes the mapping area. Photo control point configuration for an airborne GPS project should include horizontal and vertical points at defining corners of the block plus selected skeletal horizontal/vertical points selection throughout the block. The amount of additional skeletal primary ground control is based on

considerations such as map accuracy, terrain, geoid model in the project area, equipment, and available network control. A Contractor with proven experience should be used for airborne GPS projects. The amount and location of ground control necessary is site and equipment dependent. The primary ground control points and airborne GPS points (at photo centers) can be used in the aerotringulation solution.

(4) The information that is gathered at field control stations may be derived in either of two ways:

(a) Conventional field survey procedures utilizing traversing for horizontal coordinated and spirit leveling for vertical elevations. This is common practice for small projects numbering a few stereomodels.

(b) GPS procedures may also be employed for establishing ground control. GPS may be used in conjunction with conventional leveling and in some instances may be the sole tool used. In many projects GPS may be used for both horizontal and vertical control. The decision to use GPS for either horizontal or vertical control shall be based on accuracies required for the mapping project and the accuracies attainable from the GPS procedures employed by the survey crew. GPS technology involves the ranging signal data captured from navigational satellites by ground receivers. The time and location data captured is processed into spatial (X,Y,Z) coordinates at ground location to be established. Several accepted GPS procedures are available to include static and kinematic methods. The methods to be employed depend upon equipment available, site conditions and accuracies required. For more information regarding GPS and GPS procedures refer to EM 1110-1-1003, "Navstar Global Positioning System Surveying." At this time it is common practice to consider utilizing GPS technology for establishing ground control for map scales of 1 in. = 50 ft or smaller, as well as contour intervals of 2 ft or greater.

6-4. Marking Photo Control

Photo identifiable control points can be established by marking points with targets before the flight or by selecting identifiable image points after the flight.

a. Premarking. Premarking photo control points is recommended. Marking control points with targets before the flight is the most reliable and accurate way to establish photo control points. Survey points in the basic control network can also be targeted to make them photo identifiable. When the terrain is relatively featureless, targeting will always produce a well-defined image in the proper location. However, premarking is also a significant expense in the project because target materials must be purchased, and targets must be placed in the field and maintained until flying is completed. The target itself should be designed to produce the best possible photo control image point. The main elements in target design are good color contrast, a symmetrical target that can be centered over the control point, and a target size that yields a satisfactory image on the resulting photographs.

(1) Location. Target location should be designed according to the characteristics for photo control points discussed in paragraph 6-3b. The optimum location for photo control points is in the triple overlap area; however, when control is premarked, it is difficult to ensure that the target will fall in the center of the triple overlap area when the photography is flown. Care should be taken that targets are not located too near the edge of the strip coverage so that the target does not fall outside of the neat model.

(2) Material. Targets may be made of cloth or plastic or may be painted on plywood, fiberboard, or similar sheet material or on pavement or flat rock outcrops. Flexible targets may be made by assembling pieces of the material to form the pattern or by printing the pattern on sheet material. Cloth, paint, and other material used for targets should have a nonglossy matte surface. Targets should be held in place by spikes, stakes, small sandbags, chicken wire, or any other means necessary to keep them in position and maintain flatness.

(3) Shape. Targets should be symmetrical in design to aid the operator in pointing on the control point. A typical cross design suggested by Wolf (1983) is illustrated in Figure 6-4. Similar leg and center panel designs can be developed in Y, T, and V shapes if field conditions require alternate shapes as illustrated in Figure 6-5. The center panel should be centered over the control point, since this is the image point at which measurements will be taken. The legs help in identifying the targets on the photos and also in determining the exact center of the target should the image of the center panel be unclear.

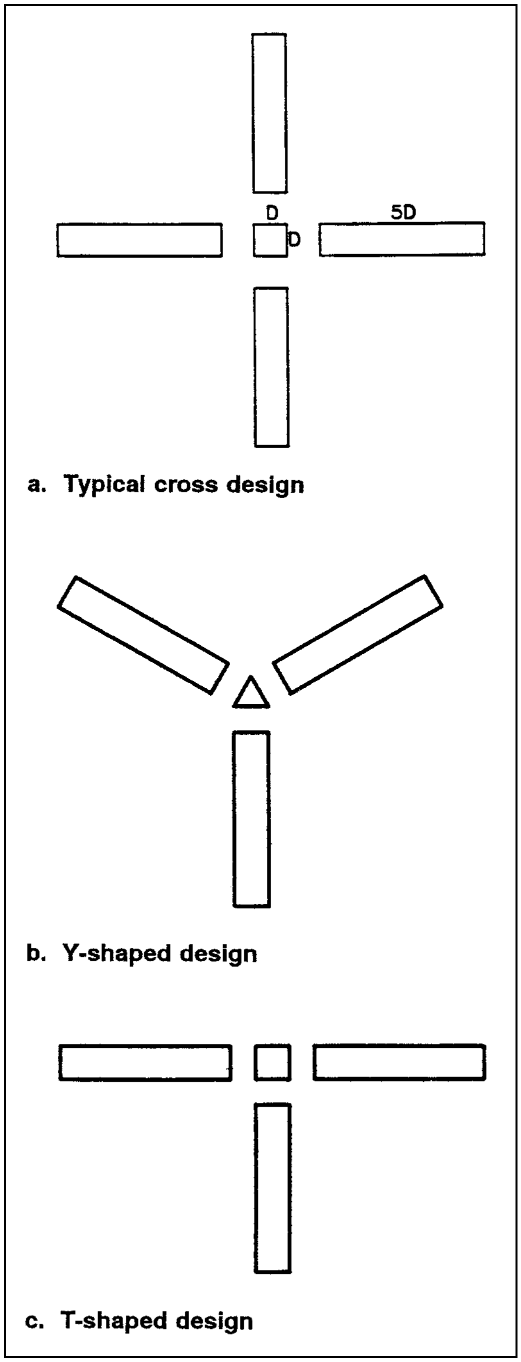


Figure 6-4. Typical cross design for ground panel

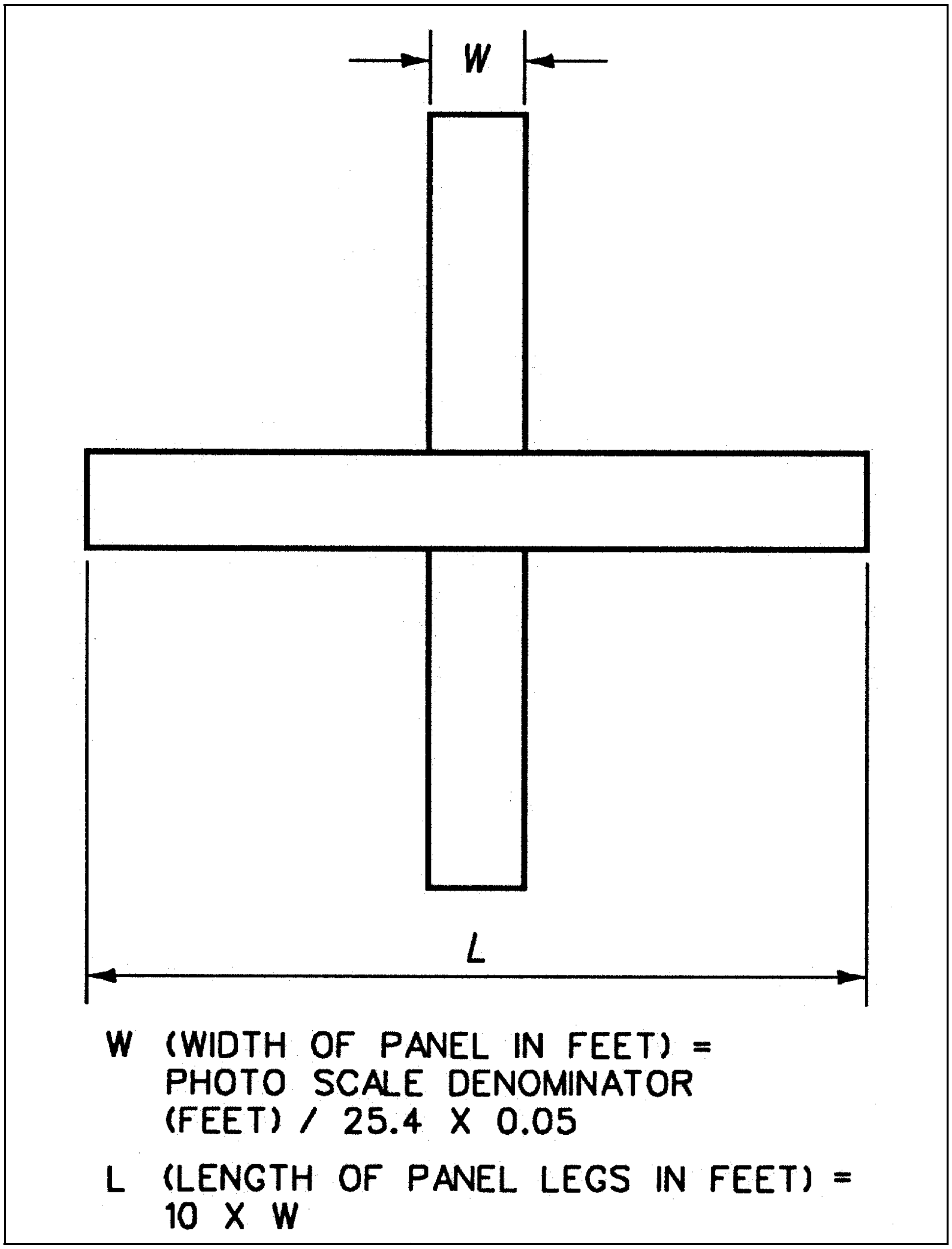


Figure 6-5. Typical ground control panel designs

(4) Size. Target sizes should be designed on the basis of intended photo scale so that the target images are the optimum size for pointing on the photos. Target size is related to the size of the measuring mark in the comparator and stereoplotter instruments used. An image size of about 0.050 mm square for the central panel is a typical design value. As shown in Figure 6-5, if the ground dimension of the central panel of the target is *D*, then the leg width should also be *D*, leg length should be 5*D*, and the open space between the central panel and the leg should be *D*. Target sizes are readily calculated once photo scale and optimum target image size are selected. If, for example, a central panel size of 0.050 mm is desired and photography at a scale of 1:12,000 is planned, then *D* should be 2.0 ft.

(5) Maintenance. All targets should be maintained in place and protected from or restored after damage by man, animals, or weather until photography has been taken. As soon as feasible after photography has

been taken, each target should be inspected. If the inspection reveals that the target has been moved from its proper position or otherwise disturbed in any way, this fact should be reported in the photo control survey report. Damaged or lost targets will require that the photography on which the targets should appear be replaced with a new flight if the lost targets will jeopardize meeting the accuracy requirement for the photogrammetric product. As an alternative to replacing or relocating lost targets and replacing the deficient photography, unless the photography will be used for Class 1 mapping aerotriangulation, it may be permissible to substitute natural images for the lost targets when acceptable natural images are present and suitably located to replace all lost targets.

b. Postmarking photo identifiable control. Postmarking photo control after the photography is flown is a method that may be used to save time during the aerial flight phase for selected projects and for Class 3 mapping. In some instances, this method can save time during the aerial flight phase of a project and reduce ground control costs by having a current image of the site from which the ground survey crew can plan the ground survey mission. The postmarking method consists of examining the photography after it is flown and choosing natural image features that most closely meet the characteristics for horizontal or vertical photo control points. The selected features are then located in the field and surveyed from the basic control monuments. One advantage of postmarking photo control points is that the control point can be chosen in the optimum location (the corners of neat models and in the triple overlap area). The principal disadvantage of postmarking is that the natural feature is not as well defined as a targeted survey monument either in the field or on the image.

c. Airborne Global Positioning System (ABGPS) Control. ABGPS technology may also be employed for photo control. This procedure involves establishing the horizontal and vertical location of the principal point of every photo at the instant of exposure. The principal point of each image must be transposed to its corresponding earth location. The location data are processed with a selected geoid model and ellipsoid to establish the principal point location on the earth. The data produced from the flight also include flight aberrations and positional parameters at each exposure. Ground control requirements, when utilizing ABGPS, can be significantly reduced. GPS theory indicates that, if all conditions are ideal (i.e., satellite configuration and signal, geoid model consistency), no additional ground control should be required. In practice, this is not an acceptable risk considering the cost of deploying equipment and personnel to revisit the project site if problems surface after the flight. Therefore, minimal ground control should be planned. The amount of ground control required depends upon such factors as:

(1) Size of project area.

(2) Regularity of project shape.

(3) Constancy of geoid model throughout the project area.

(4) Accuracy, integrity and location of the existing monument control used to verify the geoid model prior to the flight.

(5) Reliability of the aerotriangulation system (including hardware and software).

(6) ASPRS Map Class

(7) Photo Negative Scale

ABGPS flights are usually flown in blocks to obtain sufficient photo control for aerotriangulation procedures. In order to increase the amount of control available for aerotriangulation procedures and map accuracy some ABGPS projects may require increased forward, sidelap and/or cross flight strips at various locations.

ABGPS flight planning should involve personnel with significant expertise in ABGPS aerotriangulation procedures and subsequent photo control requirements. A regular shaped ABGPS flight block of reasonable size should require the following minimum field control:

(a) A spatial (X,Y,Z) point in each of the four corners of the project. It would be even more judicious to place point pairs at these locations to provide redundancy.

(b) Six or more points (depending upon flight block size) scattered throughout the interior of the project. These points could be withheld from the aerotriangulation procedure so that their coordinates may be compared with the coordinates assigned by the aerotriangulation results.

(c) At least one static ground GPS receiver working in conjunction with the aircraft receiver. Two ground receivers are often employed. This arrangement allows the crew to compare results and check of the solutions and to highlight any malfunction of equipment.

Irregular shaped projects may require additional control and perhaps additional flight and ground data collection (i.e., cross flights). Large area projects may require additional receivers. Additional vertical control may be required along the boundaries of the mapping project to maintain level stereomodels on the exterior flight lines. However, if the project is planned with the first and last flight line photo centers outside the mapping boundary, this additional control may not be necessary. As ABGPS technology improves it is becoming the predominate tool used to establish photo control for large and small projects alike. Increased Contractors' experience coupled with reduction in the cost of equipment are driving the cost of this technology to be as competitive as conventional traverse and leveling procedures. However, experience of the Contractor is vital in realizing a successful ABGPS controlled project. Planning ABGPS projects that encompass large areas should include breaking the large areas into smaller segments. This will facilitate ground control logistics, and allow for additional checks of geoid undulations over the entire project. Ground control for ABGPS requires timing and logistical planning between the ground and aircraft crews. Breaking projects into reasonable data collection time frames will allow the field crew to review data sets in reasonable blocks and catch any blunders before they affect large portions of the total project.

6-5. Survey Accuracy Standards

Ground control should be established in accordance with the current FGDC Geospatial Positioning Accuracy Standards. Basic and photo control shall be to a level of accuracy commensurate with that specified for the final map product as established in Table 2-1). Careful planning and analysis of the basic control and photo control ground surveys should be agreed upon by the Government and the Contractor. The plan should ensure that sufficient accuracy will be obtained throughout the project area to meet aerotriangulation and map compilation criteria. FGDC relative accuracy standards for horizontal and vertical control are shown in Tables 6-1 and 6-2. All basic and photo control data will include FGDC compliant META data. The FGDC META data standards will be those in force at the time of issuance of the contract.

Table 6-1
FGDC Horizontal Distance Accuracy Standards

Survey Classification	Minimum Distance Accuracy, Ratio
First Order	1:100,000
Second Order, Class I	1:50,000
Second Order, Class II	1:20,000
Third Order, Class I	1,10,000
Third Order, Class II	1:5,000

Table 6-2
FGDC Elevation Accuracy Standards

Survey Classification	Maximum Elevation Difference Accuracy, mm/km
First Order,Class I	0.5
First Order, Class II	0.7
Second Order, Class I	1.0
Second Order, Class II	1.3
Third Order	2.0

The distance accuracy $1{:}a$ is defined in Equation 6-1.

$$a = \frac{d}{s} \qquad (6\text{-}1)$$

where

a = distance accuracy denominator

d = distance between survey points

s = propagated standard deviation of distance between survey points obtained from a weighted and minimally constrained least squares adjustment

$$b = \frac{s}{\sqrt{d}} \qquad (6\text{-}2)$$

The elevation difference accuracy b is a ratio defined in Equation 6-2

where

b = elevation difference accuracy ratio

s = propagated standard deviation of elevation difference in millimeters between survey points obtained from a weighted and minimally constrained least squares adjustment

d = distance between control points in kilometers measured along the level route

6-6. Deliverables

Unless otherwise modified by the contract specifications, the following materials will be delivered to the Government upon completion of the control surveys:

a. General report describing the project and survey procedures used including description of the project area, location, and existing control found; description of the basic and photo control survey network geometry; description of the survey instruments and field methods used; description of the survey adjustment method and results such as closures and precision of adjusted positions; justification for any survey points omitted from the final adjusted network and any problems incurred and how they were resolved.

b. Additional information required when GPS is a part of the project should include the following:

(1) Descriptions of all initial field control plan including all points to be occupied and referenced

(2) Geodetic Datum and Geoid Model used.

(3) Brand of receivers.

(4) Processing software.

(5) Raw data files in XXXXX format.

(6) Post processes data.

c. One set of paper prints showing all control points. The points should be symbolized and named on the image side, and the exact point location should be pinpricked through the print. ABGPS exposure control points are considered to be at the center of each exposure. The latitude, longitude, and ellipsoid elevation shall be in the border information for each exposure.

d. A list of the adjusted coordinates of all horizontal and vertical basic and photo control points.

e. Metadata fully compliant with the current FGDC Metadata Standards.

Chapter 7
Airborne Global Positioning System Techniques

7-1. ABGPS

Airborne Global Positioning System (ABGPS) technology may be employed to supplement and minimize ground survey control points required for aerotriangulation and rectification of aerial photography. ABGPS employs on-the-fly (OTF) survey techniques for initialization of a receiver while it is in motion. Additional information regarding GPS theory, OTF, and mission planning is addressed in EM 1110-1-1003, "NAVSTAR Global Positioning System Surveying." Similar to ground GPS data collection, ABGPS receivers lock on to a minimum number of navigation satellites to ensure maximum attainable accuracy of photo center locations. The photo center locations (X, Y, and Z) are then used to supplement minimal ground control data in aerotriangulation procedures. Figure 7-1 is a flowchart depicting a general airborne GPS task flow for aerotriangulation data collection.

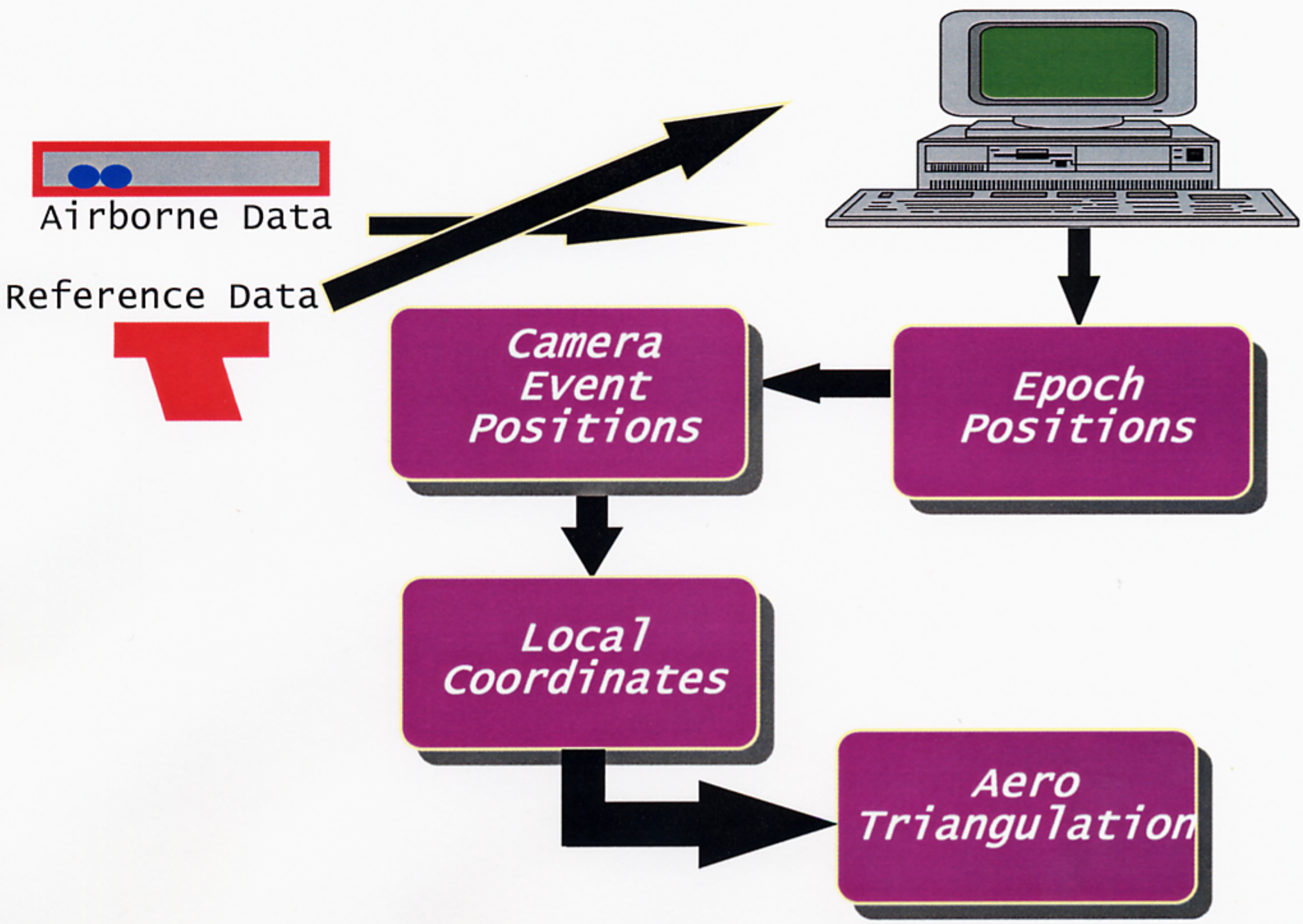


Figure 7-1. ABGPS data collection flowchart

7-2. Project Planning

Planning photography control for a mapping project with the ABGPS requires specialized experience. ABGPS technology is one of the tools to be considered for collection of necessary reference control for a photogrammetric mapping and is used in conjunction with other traditional ground survey methods. ABGPS contractors should be selected on their specific ABGPS experience. Planning an ABGPS controlled project should include the following considerations.

a. Basic Photogrammetric Mapping Requirements. Photo and mapping scale requirements.

b. Aerotriangulation Requirements. Aerotriangulation accuracy requirements for ABGPS photo center control and any ground control.

c. Satellite Availability. Satellite lock must be maintained throughout the flight operation.

d. Location. Placement and number of ground GPS receivers required for the project and the required data collection rate for the receivers.

e. Selection of reference ground control (Base Stations). Coordinate integrity of base stations and ground control must be validated.

f. Aircraft and ground crew logistics. Base ground stations and aircraft receivers must be using the same satellite configuration and limitations. Accuracy of the antenna camera offset must be validated. Detailed and accurate flight logs must be developed and maintained. Crew experienced in ABGPS data collection is imperative (i.e., Making sharp turns may cause loss of satellite lock).

g. Site Access. Site access for ground survey and ground receiver operation during the flight.

h. Flight Time. Flight time required for additional sidelap and cross flights which may be required for aerotriangulation.

i. Experience. Experience of personnel in planning and implementing an ABGPS project to include aerotriangulation and ABGPS data.

j. Aircraft Cost. Additional cost of aircraft use equipped with ABGPS.

k. Postprocessing. Experience and cost of personnel in post processing ABGPS data (including RINEX data) for use in aerotriangulation.

7-3. Other Considerations

Issues to be considered include:

a. Overlap. The amount of forward overlap (endlap) and sidelap required and how it affects the amount of control for aerotriangulation.

b. Ground Control. The number and placement of ground GPS receivers affects the amount of additional ground surveys.

c. Communications. The communications link between the ground crews and the flight crew.

Additional information regarding planning may be obtained from the FGDC 1996 Geospatial Positioning Accuracy Standards and EM 1110-1-1003, “NAVSTAR Global Positioning System Surveying.”

7-4. Ground Receiver

In order to achieve maximum accuracy, receivers must be capable of tracking both coarse acquisition (C/A) and pseudorange (P-code). They must provide dual frequency (L1 and L2), and multichannel capability. The receivers should be capable of recording carrier phase data during the flight. The distance between the ground receiver and the airborne receiver depends upon the type of receiver but generally can be within 20 to 50 km if the geoid model is known throughout the project area. These data captured at the established ground station provide correctional information to maximize the accuracy of the airborne position. See Figure 7-2 for typical ground receiver data collection.

Figure 7-2. Typical ground receiver data collection

7-5. Airborne Receiver

ABGPS receiver software must be capable of OTF ambiguity resolution. The receiver must be a dual frequency receiver capable of tracking both the C/A and P-Code satellite signal data. Figure 7-3 is a schematic illustration of an ABGPS configuration. The basic components of a an airborne GPS system are:

a. GPS antenna. This unit intercepts the ranging signals from at least four satellites.

b. GPS receiver. This unit houses the GPS receiver which logs the raw data. The receiver is interfaced with a computer which is the heart of the flight management system, providing navigation information and real-time position stationing.

c. Operator terminal. This is the interface between the camera operator and all of the integrated sensors allowing supervision of the survey flight. The computer can control the camera operation automatically.

d. Aerial camera. The camera may have several flight controlling features which lessen stress for both pilot and photographer while producing precise high-definition photos:

(1) Gyro-stabilizing mount eliminates pitch, roll, and yaw to assure vertical photography.

(2) Internal drift reference allows external drift control.

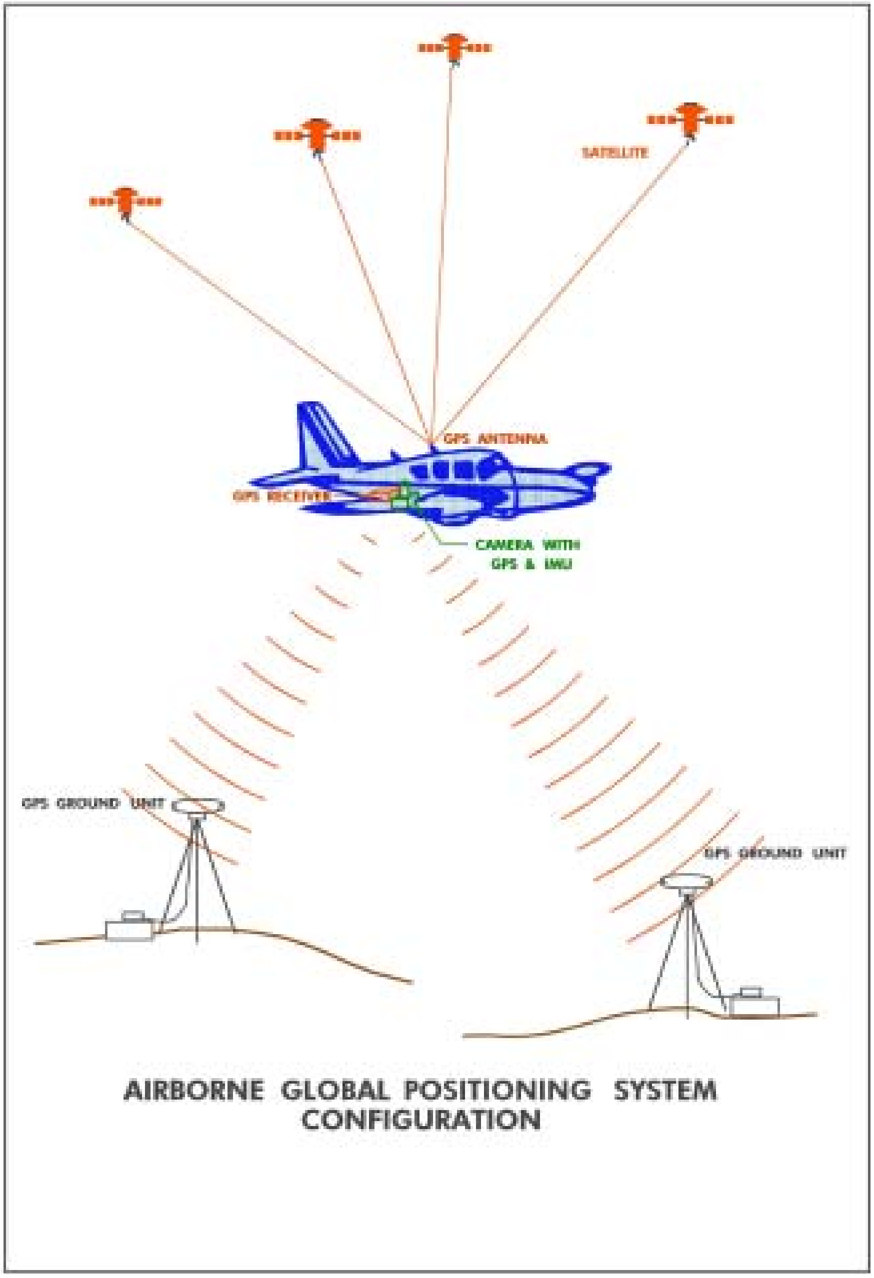


Figure 7-3. ABGPS configuration

(3) Precision lens system provides faithful color rendition and false color differentiation.

(4) Forward motion compensation (FMC) to compensate for the forward motion of the aircraft during the exposure cycle.

(5) Automatic exposure meter.

e. Pilot display. This unit provides the pilot with continuous graphic guidance information.

7-6. ABGPS Project Configuration

ABGPS is not necessarily less expensive than obtaining conventional ground control. ABGPS does not eliminate the need for ground control but it can reduce the requirement significantly for many projects. As stated above, the decision to use ABGPS should consider the required scale and accuracy specifications of mapping. At the time of writing this document, it is generally accepted that mapping projects requiring mapping scale specifications of 1 in. =100 ft mapping with 2-ft contours or smaller can realize significant savings in time with the use of ABGPS. ABGPS technology usually provides maximum benefit for projects that can be accomplished in blocks of photography with more than a single flight strip. A large block of photography can generate additional time and cost for aerial photography and aerotriangulation but should reduce time and cost of obtaining ground control. This is not necessarily true when projects consist of single flight lines or irregular blocks. Figure 7-4 depicts a flight and ground control plan of a mapping project flown in an ABGPS block configuration. ABGPS technology is dynamic, constantly improving, and becoming more available and more cost effective. Improved receivers and software, coupled with more accurate geoid models and global datums, are allowing ABGPS control to reduce to a minimum the amount of ground control required for even large-scale projects. When planning a photogrammetric project, ABGPS should be considered along with other options, being careful neither to eliminate its feasibility nor force the limitation of this technology to fit the specific project specifications. Conditions, which might make utilization of ABGPS worthwhile, include:

a. Access. Difficulty in obtaining access to ground control locations (i.e., military exclusions, hazardous sites, uncooperative land owners, remote terrain).

b. Area. Projects with large areas to be controlled for mapping.

c. Schedule. Reduced ground survey time can allow a more flexible production schedule.

7-7. Quality Control

It must be understood by the user that the control philosophy of the photogrammetric mapping contractor substantially influences the accuracy of the final mapping product. ABGPS is simply one of the tools that the Contractor may choose to use to collect necessary ground control data for adjustment of aerial photography to the earth for mapping. This suggests that the user's representative should be knowledgeable about planning photogrammetric mapping projects that include the use of ABGPS. Quality Control (QC) for ABGPS projects should be similar to QC for any ground control collected for a mapping project. Table 7-1 may be used as a guide for an Airborne GPS Quality Control Plan. Experienced Contractors should use and provide a similar plan for each project.

Additional information regarding QC may be found in EM 1110-1-1003, “NAVSTAR Global Positioning System Surveying.” QC procedures for ABGPS projects should be part of the selection procedures for highly qualified contractors. Prior to mission implementation, the Contracting Officer (or his technical representative) should be assured that the Contractor’s QC procedures and ground control plan will provide the required accuracies for the photogrammetric mapping. Quality assurance (QA) testing of the ABGPS results may be required for some projects. QA testing may include third-party independent ground surveys reestablishing selected reference points and known hard points visible in the final mapping. These points may be withheld from the primary survey contractor and the mapping contractor until the project is completed and used as an initial check of the mapping accuracy. QA testing procedures will follow ASPRS guidelines.

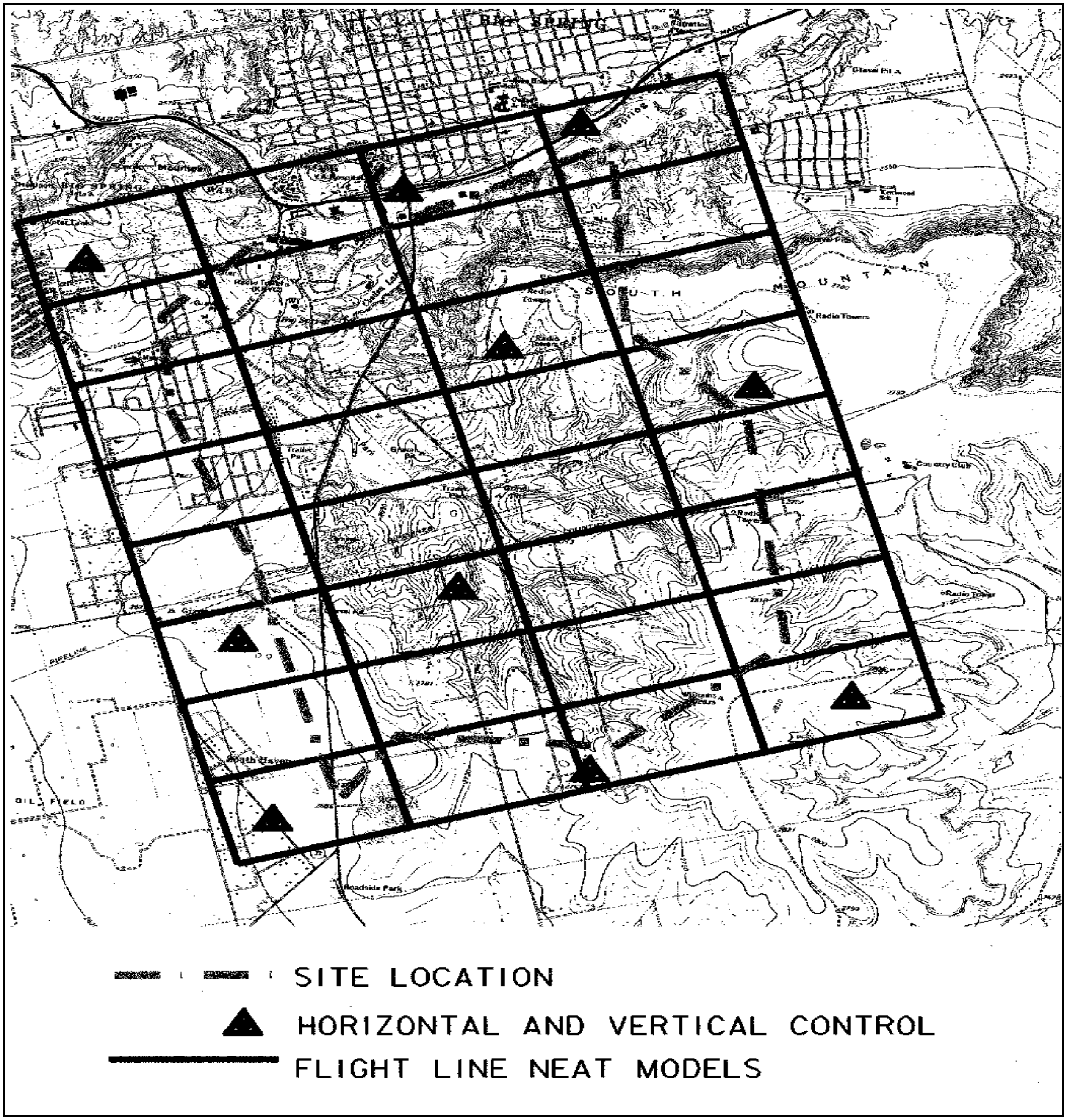


Figure 7-4. ABGPS flight and ground control plan

Table 7-1
Airborne GPS Quality Control Plan

Project Planning

Review project specifications

1. Location and size of area
2. Map & photo scale, contour interval
3. Review survey data (i.e., vertical and horizontal datums, accuracy of ground control)
4. Review and confirm GPS planning (i.e., base station requirements).

Aircraft and Camera Operation

1. Verify the camera antenna offset.
2. Perform check of all equipment to include GPS units in aircraft and the camera operation.

Airborne GPS Data Acquisition

1. Ensure comunication between air and ground crew.
2. Ensure all equipment (air and ground) are in good working condition.
3. Ensure proper preflight system check (antenna height).
4. Ensure that data are properly downloaded and stored.

Airborne GPS Data Processing

1. Review raw data.
2. Process and evaluate base station and aircraft data.
3. Review flight lines and GPS event numbers. Correlate aerial film event numbers to the flight and exposure number.
4. Correlate GPS event numbers to the lettered flight line and exposure number.
5. Create final control file, i.e., photo number, easting, northing, elevation.
6. Data backup of all data sets.

Chapter 8
Analytical Aerotriangulation

8-1. General

Since ground control is a significant expense in any mapping project, aerotriangulation bridging or control extension methods are often used to reduce the amount of field surveying required by extending control to each stereomodel photogrammetrically. The number of control points required to scale and level each stereomodel does not change on small projects of a few stereomodels. Ground control requirements for projects with only a few stereo pairs are minimal, and conventional photo control as indicated in Figure 6-2, Chapter 6, may be suitable and time and cost efficient. However, as the arial extent of a project increases, and thereby the number of stereomodels, aerotriangulation becomes an efficient method of extending a sparse field survey control network. This chapter emphasizes fully analytical aerotriangulation methods since these methods are most appropriate for modern instruments and large-scale mapping requirements.

8-2. Aerotriangulation Principles

a. Definition. Aerotriangulation is the simultaneous space resection and space intersection of image rays recorded by an aerial mapping camera. Conjugate image rays projected from two or more overlapping photographs intersect at the common ground points to define the three-dimensional space (3-D) coordinates of each point. The entire assembly of image rays is fit to known ground control points in an adjustment process. Thus, when the adjustment is complete, ground coordinates of unknown ground points are determined by the intersection of adjusted image rays.

b. Purpose. The purpose of aerotriangulation is to extend horizontal and vertical control from relatively few ground survey control points to each unknown ground point included in the solution. The supplemental control points are called pass points, and they are used to control subsequent photogrammetric mapping. Each stereomodel is scaled and leveled using the adjusted coordinate values of the pass points located in the stereomodel.

c. Relationship to ground control. Aerotriangulation is essentially an interpolation tool, capable of extending control points to areas between ground survey control points using several contiguous uncontrolled stereomodels. An aerotriangulation solution should never be extended or cantilevered beyond the ground control. Ground control should be located at the ends of single strips and along the perimeter of block configurations. Within a strip or block, ground control is added at intervals of several stereomodels to limit error propagation in the adjusted pass point coordinates. Extending control by aerotriangulation methods is often referred to as *bridging* since the spatial image ray triangulation spans the gap between ground control.

8-3. Softcopy Methods

a. Definition. Aerotriangulation procedures that involve softcopy workstations must necessarily include fully analytical aerotriangulation software and high-resolution scanners. Diapositives are not required and all interior, exterior, and control point mensuration are read from the scanned images. The elimination of diapositives removes the process of identifying and drill marking the points for mensuration. **For the purpose of this manual, the processes and standards for softcopy aerotriangulation will be assumed identical to analytical stereo plotter methods once the orientation process begins.**

b. Softcopy Process. Accurate softcopy aerotriangulation requires equipment and materials not necessarily required for analytical stereoplotter aerotriangulation procedures. Softcopy aerotriangulation must follow procedures and utilize equipment that will allow the operator the ability to ascertain feature resolution at a level that will achieve the aerotriangulation accuracy required. A major advantage to softcopy aerotriangulation is that the software is generally interactive and thus provides excellent quality control. The results of point selection, measurements, and weighting are shown to the operator immediately. Successful softcopy aerotriangulation planning must begin at the image acquisition phase. Issues for consideration are listed below.

(1) High-resolution film must be used.

(2) Extreme care must be taken in the processing of the film to ensure maximum **clarity**.

(3) Processed film must be handled in a manner to minimize dust and scratches prior to scanning.

(4) Scanning must be accomplished with a scanner capable of scanning between 7 and 25 microns.

(5) Color scanning may be accomplished by a single-pass or three-pass scanning system.

(6) Software and hardware must be capable of model orientation in both stereo and monoscpoic modes, capable of interior, relative, and absolute orientation, as well as single photo resection.

Once acceptable scanned images are created, the aerotriangulation process is similar to the process followed using an analytical stereoplotter. Latitude should be used in allowing contractors to use specific expertise in softcopy aerotriangulation as it relates to the number of artificially marked pass points. Softcopy processes make the identification of these points relatively easy and some contractor experience indicates that more artificially marked pass points can improve the solution in some cases. The minimum number of artificially marked pass points stated in this manual for analytical stereoplotter processes should be the minimum used for softcopy processes.

8-4. Pass Points

Pass point requirements are related to type of point used, location, and point transfer and marking requirements. **Softcopy aerotriangulation processes do not require diapositives, nor the identification or drill marking of pass points.**

a. Type of points. Pass points may be artificially marked points, targeted points, or natural images. However, since pass points must lie at or very near the center line of the triple overlap area, artificially marked points designed from the photography taken should be used. Premarked targets are too expensive and too difficult to align with the triple overlap areas. Natural images are not always suitable for precise pointing.

b. Marking artificial points. Artificially marked pass points must be well-defined symmetrical patterns drilled, punched, or otherwise marked in the emulsion using a suitable marking instrument such as a Wild PUG or equivalent. Only the aerotriangulation/compilation positives should be marked. The original negatives should not be marked.

c. Location. A minimum of three pass points must be marked along the center line of each triple overlap area. One pass point must lie near the photo principal point, and two as wing points in the sidelap with adjacent flight lines. To better control error skew, the wing points could be in pairs. Pass point locations are to be selected by examining the photographic prints with a stereoscope. Pass points must be located on unobscured level ground in accordance with the characteristics for vertical photo control. All pass point locations must be symbolized and labeled on the control photographs.

d. Point transfer for monoscopic measurements. Artificial pass points are typically marked in stereoscopic correspondence on all photographs showing the site of the point, using a stereoscopic transfer and point marking device such as a Wild PUG or equivalent. For the minimum of three pass points in each triple overlap area, this operation will result in a minimum of nine pass points on each photo. This method is required when photo coordinates are to be measured on a monocomparator. This method may be used when pass points are to be measured stereoscopically, either as photo coordinates on a stereocomparator or analytical stereo plotter or as model coordinates on any stereoplotter. Stereoscopic point transfer and marking should be done by a highly experienced operator using utmost care in choosing the site and in the marking of each pass point.

e. Point transfer for stereoscopic measurements. When pass points are to be measured stereoscopically, either as photo coordinates on a stereocomparator, softcopy workstation, analytical stereoplotter, or as model coordinates on any stereoplotter, artificial pass points need be marked on the center photograph only using a suitable point marking device. Viewing the marked point stereoscopically with adjacent photographs will accomplish the point transfer of the pass point location to the overlapping photo as part of the measurement process. When parallel flight lines of photography are used, tie points should be transferred from one flight line to each adjacent flight line using a stereoscopic transfer and point marking device such as a Wild PUG or equivalent. Artificial points are typically not superimposed on images of targets.

f. Softcopy pass points. Aerotriangulation with softcopy simplifies the procedure of pass points processing. After the photos are scanned, two successive photo images are displayed on the monitor screen. The operator then selects arbitrary pass points on one image, then the computer automatically assigns appropriate photo coordinates of that point on each photo. Images of adjacent flight line photos can then be displayed and the position of pass points in the sidelap area are stored in the computer's database. This operation eliminates the necessity of manual pugging, plate reading, and transferring as discussed above. Refer to Figure 8-1 for a schematic of this concept.

8-5. Ground Control Points

Ground control requirements are related to targeting, control location, and survey accuracy requirements.

a. Targeting. Whenever feasible, ground control points for Classes 1 through 3 aerotriangulation and subsequent mapping should be ground panels placed at the appropriate locations prior to the flight. Targeting should be in accordance with paragraph 6-4. It is understood that for many projects and many reasons it is necessary to establish photo identifiable features to be used ground control targets. All ground control photo identifiable and panel points should be approved by the Government prior to use in a project.

b. Control location. Final control location and bridging distances used should be the decision of the Contractor, but the following guidelines should be applied:

(1) Single strips.

(a) Along a single flight line of photography (Figure 8-1), horizontal control points should be in pairs at the strip ends within the terminal stereomodel, one on each side of the flight line approximately opposite each other. For each single flight line, additional horizontal control points should be located at intervals along the strip that do not exceed the maximum allowable bridging distance. Horizontal basic control points should be no more than one-third of the width of coverage of a photograph from the flight line.

(b) Along a single flight line of photography, vertical control points should be in pairs, one on each side of the flight line approximately opposite each other and at a distance from the flight line of between one-fourth and one-third of the width of coverage of a photograph. For each single flight line, the pairs of vertical control points should be located at the strip ends within the terminal stereomodel and at intervals along the strip that do not exceed the allowable bridging distance for the class of mapping.

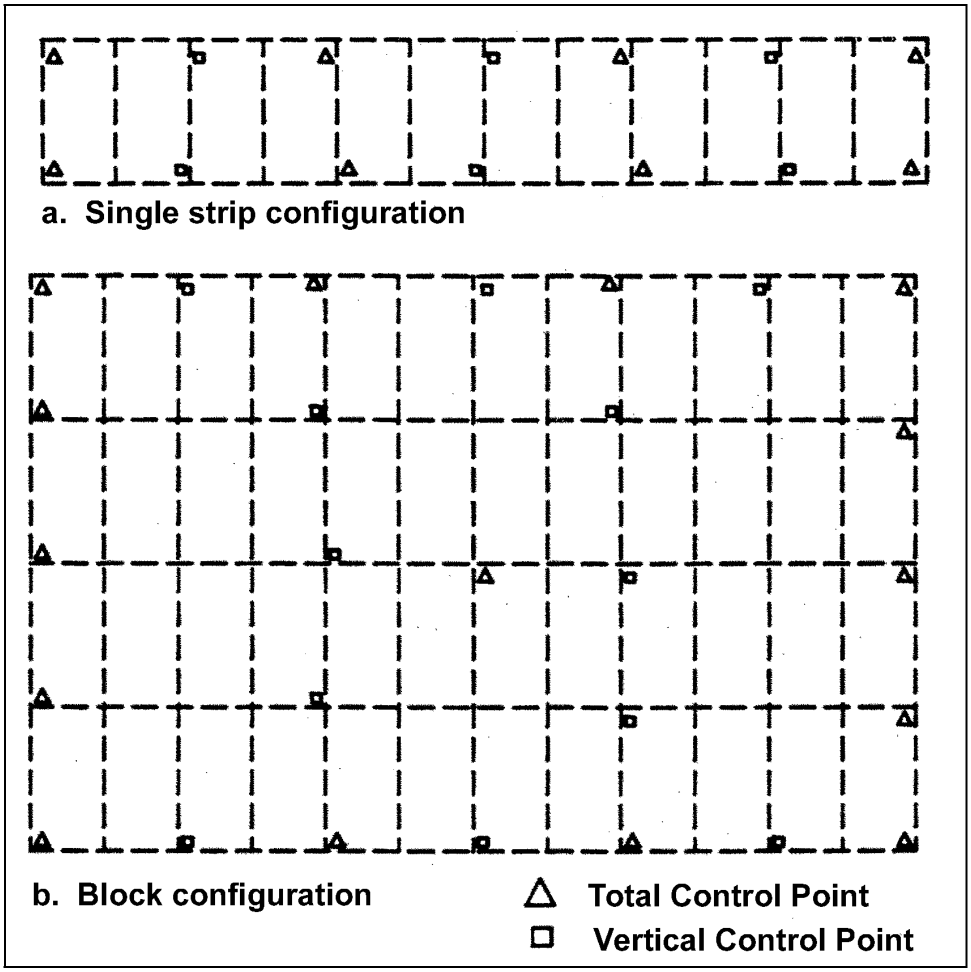


Figure 8-1. Typical strip and block control configurations

(2) Blocks. A block of photography, consisting of two or more flight lines of photography (Figure 8-1), should have control points spaced approximately equally around the periphery following the same spacing and location guidelines as for strips in paragraph 8-4*b*. There should be at least one horizontal control point and two vertical control points near the center of any block.

(a) Additional horizontal control should be located in the center of the block such that horizontal control falls in alternating strips at an interval not to exceed two times the allowable horizontal bridging distance. There should be at least one horizontal control point and two vertical control points near the center of any block.

(b) Additional vertical control should be located in the center of the block such that vertical control falls in each strip at an interval not to exceed two times the allowable vertical bridging distance.

c. Bridging distance. Table 8-1 lists typical allowable bridging distances that may be used as a guide in estimating control requirements for a project. **These guidelines apply to softcopy methods.** These are minimum guidelines, and many contractors will design a more dense control pattern. For example, a horizontal control points every five stereomodels regardless of block size. When ground control is attained with GPS procedures, an XYZ coordinate is derived. Hence, the lesser of the horizontal/vertical stipulations in Table 8-1 should be used.

Table 8-1
Allowable Bridging Distances

	Allowable Bridging Distance (Stereomodel Basis)	
Map Class (ASPRS)	Maximum Horizontal Control Spacing	Maximum Vertical Control Spacing
1	4	3
2	5	4
3	6	5

d. Ground control accuracy. Ground control accuracy for aerotriangulation should be more stringent than for a project fully controlled by field survey points.

The aerotriangulation solution will contribute to the propagated error in the pass point ground control values. Since the pass point coordinates should meet the accuracy required for photo control, the photo identifiable ground control points used to control the aerotriangulation should be more typical of the accuracy of the basic control survey.

e. GPS control. The GPS is an effective method of establishing basic project control and photo control. GPS is an especially effective way to connect the project area surveys to existing national network stations outside the project region. Kinematic GPS methods are also being used to position the camera at the time of exposure. The use of kinematic GPS methods should be evaluated carefully. Unless the terrain is inaccessible for ground targeting, terrestrial GPS surveys to establish control points and normal flying procedures may be more cost-effective and accurate for large-scale mapping.

8-6. Other Points

Coordinates can be established by aerotriangulation for additional points located on the photography by targets or artificially marked as pass points. For example, these points may be aerotriangulation checkpoints, stereo-plotter test points, or cadastral points to be located on the map. The Government should specify all points required to be included in the aerotriangulation in addition to the control points and standard pass point pattern. If a supplemental pass point is required for checking stereomodel flatness at compilation time, it should be located near the center of the stereomodel within a circle whose diameter is the central third of the airbase.

8-7. Instrumentation

Precise photo coordinate measurements are required for fully analytical aerotriangulation. A softcopy workstation or analytical stereoplotter are usually utilized by contemporary photogrammetric mapping companies.

8-8. Accuracy and Quality Control Criteria

The contractor is responsible for designing the aerotriangulation scheme that will meet the requirements of the photogrammetric product. Table 8-2 summarizes the guidelines for evaluating aerotriangulation methods. However, since meeting required pass point accuracies is dependent on the photogrammetric system, the contractor should be allowed some latitude in meeting criteria for these intermediate results.

a. Photo coordinate measurements. Photo coordinate measurement is the most critical factor contributing to the accuracy of aerotriangulation results. The contractor should be especially careful to control the quality of point transfer, point marking, and point measurement. The measurement stage(s) of the softcopy workstation, stereo plotter or the monocomparator should have a least count of 0.001 mm or less. The viewing, pointing, and digitizing components of these instruments should enable the operator to group multiple readings

Table 8-2
Guidelines for Evaluating Analytical Aerotriangulation

Analytical Aerotriangulation Procedures	Criteria
Photo Coordinate Measurements: Softcopy System or Analytical Stereoplotter	
Least Count of Stage Coordinate	0.001 mm
Interior Orientation: Transformation to Fiducial Coordinates	
Minimum (Recommended)	**4 (8)**
Maximum Residual (after Affine Transformation)	0.020 mm
Preliminary Sequential Strip Formation and Adjustment	
Stereomodel Relative Orientation	
Minimum Number of Points, Y-Parallax Residuals	6
RMSE	0.005 mm
Maximum	0.015 mm
Stereomodel Joins	
Minimum Number of Points	3
X,Y Pass Point Coordinate Discrepancy	
RMSE	H/12,000 ft
Maximum	H/6,000 ft
Z Pass Point Coordinate Discrepancy	
RMSE	H/10,000 ft
Maximum	H/5,000 ft
Polynomial Strip Adjustment	
X,Y Control Point Coordinate Residual	
RMSE	H/10,000 ft
Maximum	H/6,000 ft
Z Control Point Coordinate Residual	
RMSE	H/7,000 ft
Maximum	H/6,000 ft
Simultaneous Bundle Adjustment	
Rmse of Photo Coordinate Residual	0.004 mm
Maximum Variance Factor Ratio	1.5
(See Also Table 8-3)	

on any well-defined target or marked pass point within a maximum spread of 0.004 mm. Multiple readings are of more value if they are not consecutive; however, this reading scheme is often not practical. If multiple readings are made consecutively, the operator must move off the image and repoint between each reading. The instrument used should be capable of measuring a photo coordinate with an RMSE not greater than 0.003 mm. It is mandatory to end the measuring of a photograph with a reading on the first point measured (usually a fiducial mark) to assure that the instrument encoders have not drifted or skipped counts.

b. Interior orientation. Interior orientation refers to the geometric relationship between the image plane and the perspective center of the lens.

(1) The initial step is to transform the measured stage coordinates into the photo coordinate system defined by the calibrated fiducial coordinates. An affine transformation, which accounts for differential image scale and shear, is typically used to establish the photo coordinate system. The transformation parameters are determined by a least squares adjustment using at least four fiducials (**eight is recommended**).

(2) After the photo coordinate system is established, the image measurements must be corrected for systematic errors. This procedure is called photo coordinate refinement. Corrections are applied for principal point offset, radial lens distortion, tangential lens distortion, and atmospheric refraction.. Photo coordinate refinement may be performed by the analytical stereo plotter software or the aerotriangulation software. Typically, the interior orientation and refinement parameters are considered known based on the calibration report. Then the photo coordinate refinement is performed before the photo coordinates are used for the

aerotriangulation adjustment. If self-calibration aerotriangulation software is used, the camera interior orientation parameters are considered to be approximations, and they are adjusted as a parameter in the aerotriangulation solution.

c. Preliminary sequential aerotriangulation. This process (Table 8-2) refers to the sequential assembly of independent stereomodels to form a strip unit and the polynomial strip adjustment into the ground coordinate system. The sequential procedure is a preliminary adjustment that develops initial approximations for the final simultaneous bundle adjustment. The sequential procedure also serves as a quality control check of the photo and ground coordinate data. The guidelines listed in Table 8-2 are not rigorously enforced, but they are used to evaluate the building blocks of a larger strip or block configuration.

(1) Relative orientation of each stereo pair is performed by a least squares adjustment using the collinearity equations. The stereomodel is created in an arbitrary coordinate system, and the adjustment is unconstrained by ground coordinate values. Therefore, the photo coordinate residuals should be representative of the point transfer and measuring precision. The photo coordinate residuals should be examined to detect misidentified or poorly measured points. The minimum number of points that will uniquely determine a relative orientation is six. The six-point minimum recommended in Table 8-2 results if the standard nine pass points per photo configuration is used. Typically, more than the minimum six pass points are available (field survey points and pass points from adjacent flight lines). The RMSE and maximum residual values listed will more likely be reached when larger numbers of pass points are used.

(2) When stereomodels are joined to form a strip, the pass points shared between models will have two coordinate values, one value in the strip coordinate system and one value in the transformed model coordinate system. The coordinate differences or discrepancies between the two values can be examined to evaluate how well the models fit to one another. Horizontal coordinate discrepancies will typically be smaller than vertical discrepancies since the image ray intersection geometry is weaker in the vertical direction. As the stereomodels are transformed into the strip, one after the other, the pass point coordinate discrepancies should be uniform and no outliers should be observed. The coordinate discrepancy criterion is expressed as a fraction of the flying height above terrain because the magnitude of the discrepancy in ground units is dependent on the photo scale.

(3) Polynomial strip adjustment is a preliminary adjustment that produces initial ground coordinate values for all the pass points in a strip. Pass point coordinate values will be adjusted again by the final bundle adjustment. Polynomial correction curve is fit to the coordinate errors at the control point locations using a least squares adjustment. Residuals of the least squares curve fit can be examined to evaluate the adequacy of the polynomial adjustment. The residual criterion is expressed as a fraction of the flying height above terrain because the magnitude of the discrepancy in ground units is dependent on the photo scale. Evaluation of the polynomial residuals is the least critical check in the aerotriangulation process, and a great deal of latitude can be allowed in meeting these criteria. From project to project, large variations in the residuals may occur because of the number of stereomodels in the strip, the polynomial function used, and the distribution of the control points. It is more important to check the X, Y, and Z error curves after the linear transformation of the strip into the ground coordinate system and before the polynomial correction. These error curves should be smooth Second- or Third-Order curves. Outliers from a smooth continuous curve are an indication of a blunder in the photogrammetric value or the ground survey value at a control point.

d. Simultaneous bundle adjustment. Fully analytical aerotriangulation must be adjusted by a weighted least squares adjustment method. Adjustment software must form the collinearity condition equations for all the photo coordinate observations in the block and solve for all photo orientation and ground point coordinates in each iteration until the solution converges.

(1) The exterior coordinate system used for the adjustment should be a local rectangular coordinate system as defined in Chapter 3. This coordinate system contains no earth curvature or map projection distor-

tions. These effects may be judged to be negligible for small project areas and low flying heights, but they are significant factors for large project areas and high flying heights.

(2) Least squares adjustment results should be examined to check the consistency of the photo coordinate measurements and the ground control fit. Residuals on the photo coordinates should be examined to see that they are representative of the random error expected from the instrument used to measure them. Residuals should be randomly plus or minus and have a uniform magnitude. Residuals should be checked carefully for outliers and systematic trends. Standard deviation of unit weight computed from the weighted adjusted residuals should not be more than 1.5 times the reference standard deviation used to compute the weights for the adjustment. A large computed reference variance indicates inflated residuals and possible systematic errors affecting the adjustment. For example, if photo coordinates were judged to have an overall measurement standard deviation of 0.005 mm and this value was used to compute observation weights, the standard deviation of unit weight computed by the adjustment should not exceed 0.0075 mm.

(3) Accuracy of aerial analytical triangulation should be measured by the RMSE and the maximum error in each coordinate (X, Y, and Z) direction for the combined checkpoints. The maximum allowable error should be checked at the midpoint of the bridging distance between ground control points using checkpoints or test drop points surveyed for this purpose. Table 8-3 lists the accuracy criteria suggested for each class of mapping. These criteria are the final and most important check of the aerotriangulation results.

Table 8-3
Aerotriangulation Accuracy Criteria (for 6-in. Focal Length Photography)

		Allowable RMSE at Test Points[1]	
Map Class	**Aerotriangulation Method**	**Horizontal[2]**	**Vertical[2]**
1	Fully Analytical	H/10,000	H/9,000
2	Fully Analytical	H/8,000	H/6,000
3	Fully Analytical or Semianalytical	H/6,000	H/4,500

Notes:
[1] The maximum allowable error is 3 RMSE.
[2] One-sigma level.

8-9. Stereoplotter Settings

Fully analytical aerotriangulation determines the six camera exterior orientation parameters for each photograph, camera position (X_L, Y_L, and Z_L), and angular orientation. By relating these parameters to the flight line between each two successive camera stations and scaling to the stereomodel, data are obtained for setting up the stereoscopic model in the stereoplotter.

8-10. Deliverables

Unless otherwise modified by the contract specifications, the following materials will be delivered to the Government upon completion of the aerotriangulation:

a. General report about the project and procedures used including description of the project area, location, and extent; description of the instrumentation used for pass point transfer and marking, and photo coordinate measurement; and description of the aerotriangulation methods and software used including version numbers.

b. One set of paper prints showing all control points and pass points used. The points should be symbolized and named on the image side, and the exact point location should be pinpricked through the print.

c. A list of the computed coordinates of all points specified by the Government.

d. A report of the accuracies attained and listing discrepancies in each coordinate direction at control points and checkpoints separately, a justification for any control points or pass points omitted from the final adjustment, and the RMSE and maximum error (in relation to ground surveyed coordinates) in each coordinate direction (X, Y, and Z) for the control points and checkpoints as a group.

e. Complete copies of all computer printouts.

f. A list of stereoplotter orientation settings, if specified.

Chapter 9
Stereocompilation Procedures

9-1. General

This chapter reviews stereoplotter and softcopy workstation map compilation procedures and discusses the instruments and procedures employed in compiling line and digital map products. The primary focus is on modern analytical plotters and softcopy workstations that can directly translate photographic images to digital files for use in CADD, GIS, LIS, and AM/FM databases.

9-2. Preparation

Preparation for stereo map compilation begins with gathering the materials required to perform the compilation and then georeferencing the stereomodel in the stereoplotter or softcopy workstation.

a. Materials required. Materials required to begin stereoplotter setup and compilation include the following:

(1) Positive transparencies. Positive transparencies for the stereoplotter must be radiometrically dodged from the original negatives. Positives are made by contact printing from the original film negative of a standard 9- by 9-in. format camera and must be printed on a dimensionally stable film base (termed film positives). Positive transparencies may not be required for softcopy workstations depending upon the project requirements, exposed film conditions, equipment, and expertise of the contractor.

(2) Camera calibration parameters. Camera calibration parameters define the interior orientation of the imaged bundle of rays. The camera calibration parameters may be stored in the analytical stereoplotter's computer data files. The camera calibration report should be current (within the last 3 years). The Contractor should provide proof that the camera system is in proper working condition as it was originally intended. This information is not included in the camera calibration report.

(3) Ground control data. A file of ground coordinate values for all the photo control points surveyed on the ground and the pass points located by aerotriangulation is required to perform absolute orientation of each stereomodel. The coordinate file must be accompanied by a set of photo prints showing all photo control and pass points clearly symbolized on the image and identified on the back of the print.

(4) Photographic prints. A set of photographic prints should be available to the stereoplotter operator. These prints are used with a stereoscope to familiarize the operator with the terrain prior to compilation of a stereomodel. The prints can also be used by the operator during compilation for notations concerning interpretation of features and difficult areas to contour. Sometimes mapworthy detail is interpreted from observations in the field in advance of stereo compilation. This information should be annotated on the contact prints given to the operator for incorporation into the map.

b. Stereomodel setup. Stereomodel setup proceeds through the three orientation steps: interior, relative, and absolute. The stereoplotter operator must use care in performing each orientation step and check each completed stereomodel for accuracy. Model setups should be checked for systematic model deformations by examining control coordinate discrepancies and image residuals. Stereomodels can be uniformly tilted in any direction, twisted (opposite diagonals systematically high or low), bowed (center systematically high or low), or incorrectly scaled. Proper placement of photo control points will alleviate these conditions.

9-3. Stereoplotters

A general overview of existing stereoplotter designs and general operating procedures is presented in this chapter. For the purposes of this chapter, only instruments that perform a complete restitution of the interior and exterior orientation of the photography taken will be considered. Since the inception of commercially viable photogrammetry in the 1930s, several generations of steromapping systems have become obsolete. Only those which are capable of generating digital geospatial data will be discussed in this text.

9-4. Types of Stereoplotters

The three main component systems in all stereoplotters are the projection, viewing, measuring, and tracing systems. Stereoplotters are most often grouped according to the type of projection system used in the instrument.

a. Analytical stereoplotters. Analytical stereoplotters use a mathematical image ray projection based on the collinearity equation model. The mechanical component of the instrument consists of a precise computer-controlled stereocomparator. Since the photo stages must move only in the x and y image directions, the measurement system can be built to produce a highly accurate and precise image measurement. The x and y photo coordinates are encoded, and all interior and exterior orientation parameters are included in the mathematical projection model. Except for the positive format size that will fit on the photo stage, the analytical stereoplotter has no physical constraints on the camera focal length or model scale that can be accommodated. See Figure 9-1, Typical analytical stereoplotter.

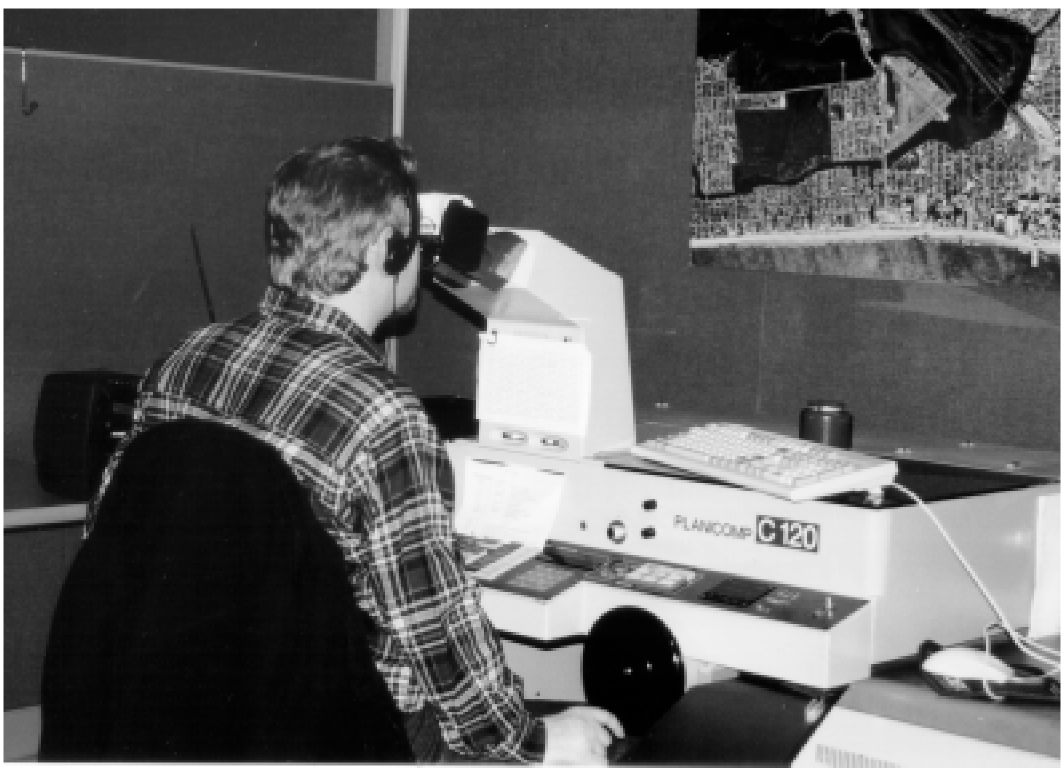


Figure 9-1. Typical analytical stereoplotter (courtesy of Surdex Corporation)

(1) The viewing system is an optical train system typically equipped with zoom optics. The measuring mark included in the viewing system may be changeable in style, size, and color. The illumination system should have an adjustable intensity for each eye.

(2) The measuring system consists of an input device for the operator to move the model point in three dimensions. The input device is encoded, and the digital measure of the model point movement is sent to the computer. The software then drives the stages to the proper location accounting for interior and exterior orientation parameters. These operations occur in real time so that the operator, looking in the eyepieces, sees the fused image of the floating mark moving in three dimensions relative to the stereomodel surface. The operator's input device for model position may be a hand-driven free-moving digitizer cursor on instruments designed primarily for compilation, or it may be a hand wheel/foot disk control or similar device on instruments supporting fine pointing for aerotriangulation.

(3) Analytical stereoplotters are accurate because the interior orientation parameters of the camera are included in the projection software. Therefore, any systematic error in the photography can be corrected in the photo coordinates before the photogrammetric projection is performed. Correcting for differential film deformations, lens distortions, and atmospheric refraction justifies measuring the photo coordinates to accuracies of 0.003 mm and smaller in analytical stereoplotters. To achieve this accuracy, the analytical stereoplotter must have the capability to perform a stage calibration using measurements of reference grid lines etched on the photo stage.

d. Digital stereoplotters. The latest generation of stereoplotters is the digital (or softcopy) stereoplotter. These instruments will display a digital image on a workstation screen in place of a film or glass diapositive. The instrument operate as an analytical stereoplotter except that the digital image will be viewed and measured. The accuracy of digital stereoplotters is governed by the pixel size of the digital image. The pixel size directly influences the resolution of the photo coordinate measurement. A digital stereoplotter can be classified according to the photo coordinate observation error at image scale. Then it should be comparable to an analytical stereoplotter having the same observation error, and the standards and guidelines in this manual should be equally as applicable. At the time of writing this document, the generally accepted guidance is that softcopy and analytical stereoplotters can achieve the same resulting map accuracies for most projects. Some projects may require that the aerial photography be captured at a lower altitude to achieve required accuracies. The Contractors opinion regarding softcopy data (flight heights, image scanning specifications) requirements should be considered. See Chapter 2, Tables 1 through 8, for expected map accuracy requirements utilizing softcopy stereoplotters. See Figure 9-2, Typical Softcopy Workstation.

9-5. Stereoplotter Operations

Models in stereoplotters must be georeferenced to the ground for measuring or mapping in three consecutive steps: interior, relative, and absolute orientation.

a. Interior orientation. Interior orientation involves placing the photographs in proper relation to the perspective center of the stereoplotter by matching the fiducial marks to corresponding marks on the photography holders and by setting the principal distances of the stereoplotter to correspond to the focal length of the camera (adjusted for overall film shrinkage).

b. Relative orientation. Relative orientation involves reproducing in the stereoplotter the relative angular relationship that existed between the camera orientations in space when the photographs were taken. This is an iterative process and should result in a stereoscopic model easily viewed, in every part, without “y parallax” the separation of the two images so they do not fuse into a stereoscopic model. When this step is complete, there exists in the stereoplotter a stereoscopic model for which 3-D coordinates may be measured at any point; but it may not be exactly the desired scale, it may not be level, and water surfaces may be tipped.

Figure 9-2. Typical softcopy workstation (courtesy of Dave Kreighbaum & Earthdata Corporation)

c. Absolute orientation. Absolute orientation uses the known ground coordinates of points identifiable in the stereoscopic model to scale and to level the model. When this step is completed, the X, Y, and Z ground coordinates of any point on the stereoscopic model may be measured and/or mapped.

9-6. Stereoplotter Output Devices

Stereoplotters may be connected to a variety of devices for hardcopy plotting or storing of digital data. Modern stereoplotters are quite often interfaced to a graphical or digital output device. Examples of these output devices include hard disk storage devices and pen or inkjet plotter.

a. Stereoplotters are computer assisted. The movement of the measuring mark of these stereoplotters is digitally encoded. The digital signal is sent directly to a computer-controlled coordinatograph. The operator can include feature codes in the digital signal that the computer can interpret to connect points with the proper line weight and type, plot symbols at point locations, label features with text, etc. The final map product can be produced at the manuscript stage by an experienced operator.

b. A digitally encoded stereoplotter is interfaced to a digital compilation software system in which the compiled line work and annotations appear on a workstation screen. Similar to the computer-assisted stereo-plotter and coordinatograph, the compilation on the workstation screen can be displayed with proper line weights (or colors and layers), line types, symbols, and feature labels. In addition, since the map exists in a digital computer file, basic map editing can be done as the manuscript progresses. Typically, the digital compilation file is converted (or translated) to a full CADD design file where it can be merged with adjacent compiled stereomodels and final map editing performed. The deliverable product from these systems is often in digital form on computer tape or disk.

9-7. Softcopy Workstation

Softcopy Workstations can be employed as mapping instrumentation. Softcopy workstations are generally composed of an image high-resolution scanner (Figure 9-3), high-speed computer processor, large high-resolution monitor coupled with appropriate software for viewing scanned images in 3-D, drawing and editing planimetric and topographic information, and translating data sets to various formats for the end user.

a. Image scan. Where stereoplotters utilize a photographic image, softcopy workstations require the photo to be scanned to create a digital image file. Scan resolution can vary depending upon the accuracy requirements of the mapping. Generally, an image scan file with a pixel resolution between 11 and 15 microns provides the most efficient image file for planimetric and topographic map compilation. However, for some special cases (very large-scale mapping projects) it may be necessary to maintain pixel size at the 7- to 8-micron level. Depending upon the production system of the contractor, either the negatives may be scanned directly or film transparencies must be produced and scanned. When possible, is it preferable to scan directly from the photo negative.

b. Model orientation. Once the scanned model files are created, the operator can select a stereopair and register the two working images on the monitor screen. Using a cursor, the operator points to the photo control stations on the images. The computer then georeferences the two images to one another and then produces an absolute orientation. Typically, projects will utilize aerotriangulation methods to extend the field surveyed horizontal and vertical control to a network sufficient to set up each stereomodel within the project area. This process will produce the interior, relative, and absolute parameters that are used by softcopy workstations to perform the model orientations. When choosing the model to be set up, the operator loads the orientation parameters enabling the workstation to display the stereomodel in its correctly georeferenced state.

c. Stereomapping. Through the medium of spectacles (using light polarization principles), the operator observes a single 3-D model on the monitor screen. Guiding the reference mark over the surface of the stereomodel with a cursor, the operator may draw planimetric features, lines of equal elevation (contours), and/or digital elevation model data (mass points and breaklines).

d. P*roduction.* Softcopy is a versatile concept. With this instrumentation the operator can provide aerotriangulation, create orthophoto image, and/or produce mapping. Mapping products can include digital elevation data, planimetric features (vectors), and raster images all in various formats. Generally, data sets provided to the end user are very large and are often provided on CD ROM disks.

9-8. Softcopy Workstations Output Devices

Softcopy workstations generally are connected to the same types of output devices as stereoplotters (i.e., pen plotters, film writers, and high-resolution laser plotters). All data utilized, collected, and processed is digital.

9-9. Stereoplotter Accuracies

Stereoplotter accuracies are best expressed in terms of observation error at diapositive scale. In this way, instruments can be compared based on the fundamental measurement of image position on the positive. Measurement error on the positive can be projected to the model space so that expected horizontal and vertical error in the map compilation can be estimated. Stereoplotter accuracy affects the maximum allowable enlargement from photo scale to map scale and the minimum CI that can be plotted from given photo scale.

Figure 9-3. Typical high-resolution scanner (courtesy of Walker Associates)

a. Enlargement from photograph to target map scale. The enlargement ratio from photograph to the target map scale refers primarily to the projection system of the stereoplotter. A contact positive of the original negative and a compilation of the stereomodel at final map scale are assumed. Criteria for maximum enlargement from photograph to map scale are guidelines for determining the smallest photographic scale that should be used to compile a given map scale on a given stereoplotter. If the focal length of the camera is specified (e.g., 6 in.), then the maximum flying height can be determined. Specific USACE criteria for maximum photo enlargement and flight altitude are provided in the tables in Chapter 2.

b. C-Factor. The C-Factor is a traditional expression of vertical compilation accuracy. It is defined as the ratio of the flying height above terrain to the minimum CI that should be compiled on the stereoplotter. The C-Factor is an empirical rating scale that depends not only on the stereoplotter instrument but also on the camera, film, photographic processing, ground survey control, aerotirangulation, and skill of the operator. An exact C-Factor is not to be specified for a specific instrument. It is a “calibration” factor of the entire photogrammetric system, and each production unit should be aware of its own limitations. When a photogrammetric project is planned, the C-Factor is an assumption and may be used as a rule of thumb to evaluate the relationship between photo scale and CI. If a ratio is indicated that is far outside the typical range, it may serve as a warning to evaluate the project plan more carefully. Few instrument manufacturers of photo mapping firms can quantify a specific C-Factor, and may be over optimistic in their ratings. The C-Factor is used to derive the negative scale and flight altitude to achieve the vertical accuracy based on the specified CI. Assuming too optimistic (high) a C-Factor will adversely affect the resultant accuracy of the map product. By the same token, an over-cautious approach may unnecessarily increase project cost. The maximum C-Factor ranges given in Chapter 2 are based on practical experience and are recommended for USACE engineering and design mapping work. They should not be exceeded regardless of manufacturer/contractor claims that they are too conservative.

9-10. Line Map Compilation Procedures

All planimetric features and contours are delineated by following the feature with the floating mark, adjusting the elevation so that the floating mark is always in contact with the apparent model surface as the compilation proceeds. The particular map details to be compiled depend on the type of map being prepared and the land use characteristics of the project area (Appendix D).

a. Compilation of planimetry. As a general rule, those features whose accurate positioning or alignment is most important should be compiled first. The relationship of the model to the datum should be checked at frequent intervals during the compilation process. It is preferable to compile all the features of a kind at one time; in this way, the chances of overlooking and omitting any detail are minimized. Some stereoplotters are equipped with superimposition of graphic data over the photo image, which makes keeping track of completed detail very obvious.

(1) Care should be taken when plotting objects having height, such as buildings and trees, to avoid tracing their shadows instead of their true positions. Buildings may have to be plotted by their roof lines, as the photograph perspective may cause their bases to be partially obscured.

(2) Planimetry should not be compiled beyond the limits of the neat model.

b. Planimetric features. All planimetric features identifiable on or interpretable from the aerial photographs should be shown on the final maps. The following feature lists may be modified by the Government in the contract scope of work to add or delete features in accordance with the purpose of the map (CADD, GIS, LIS, AM/FM, etc.) and the site-specific characteristics of the area to be compiled:

(1) Land-use features. Land-use features include parks, golf courses, and other recreational areas; historic areas; archeological sites; buildings; fences and walls; canals; ditches; reservoirs; trails; streets; roads; railroads; quarries, borrow pits; cemeteries; orchards; boundaries of logged-off areas and wooded areas; individual lone large trees; the trace of cross-country telephone, telegraph, and electric power transmission lines and their poles and towers; fence lines; billboards; rock and other walls; and similar details.

(2) Structural features. Structural features include bridges; trestles; tunnels; piers; retaining walls; dams; power plants; transformer and other substations; transportation terminals and airfields; oil, water, and other storage tanks; and similar detail. Structural features shall be plotted to scale at all map scales. Minor irregularities in outlines not representable by the limiting RMSE of the map standard may be ignored. Features smaller than 1/20 in. at map scale should be symbolized at 1/20-in. size.

(3) Hydrographic features. Hydrographic features include rivers, streams, lakes, ponds, marshes, springs, falls and rapids, glaciers, water wells, and similar detail. Wherever they exist, such features as the drainageways of draws, creeks, and tributary streams longer than 1 in. at map scale should be delineated on the maps.

(4) Scale-dependent features. On maps at scales of 50 ft to the inch or larger, there should be shown, in addition to the other required land-use features, curbs, sidewalks, parking stripes, driveways, hydrants, manholes, lampposts, and similar features dependent on the functional application.

(5) Ground completion surveys. Areas that are obscured on the photography by buildings, shadows, or vegetation should be completed by ground survey methods that meet the accuracy class of the mapping. Ground surveys are also used to map features that cannot be seen on the photography such as underground utilities, easements and property boundaries, and political boundaries. A stereoplotter operator cannot be expected to pick up all objects on a given site even if visible in the photography. (**This is no different from**

conventional plane table surveying. A certain percentage of omissions is probable.) Requirements for surface and subsurface utilities or other critical features must be specifically and explicitly outlined in the contract scope, including requirements for ground verification, editing, etc. The Contractor cannot be held liable for normal or expected omissions if the Government fails to detail critical portions of the work, and program contract funds therefor. Failure by either the Government or the mapping contractor to adequately depict critical feature requirements is usually caught during construction, and the cost of construction change orders for "differing site conditions" resulting from these deficiencies will usually far exceed the original field mapping effort.

(6) Sample planimetric feature data. Figures 9-4 depicts portions of planimetric and topographic layers developed for engineering design (1 in. = 50 ft).

Figure 9-4. Typical planimetric data set with contours (courtesy of Barton Aerial Technology)

9-11. Compilation of Topography

Photogrammetric mapping generally considers topography compilation to include contours (lines of equal elevation), high and low points, and lines defining abrupt changes in elevation (breaklines). Topographic data are usually created through a process of generating mass points and breaklines (X,Y,Z) that may be processed through software to generate contour lines if desired. The process chosen for topography compilation should be based on available compilation equipment, contour interval required, character of the area that is being mapped, available time and funding budget. Generally, terrain model development and processing are used for contour generation. The Government will specify the media on which the terrain data shall be recorded and its arrangement and format, unless the data will be used exclusively by the contractor's organization in his design operations. The media may be magnetic tape, magnetic disc, or CD-ROM.

a. Types of terrain models. The terrain model may be grid, cross section, remeasurement, critical point type, or as specified by the contract. Terrain model development is a numerical representation of the ground surface that may be used as a substitute for a contour line map. A terrain model is easily stored and manipulated by a computer and may be used to generate a number of useful products. A terrain model may be used to interpolate and plot a topographic contour map, to determine earthwork quantities, or to produce an orthophotograph. It is normally translated into a three-dimensional CADD design file for these subsequent applications.

(1) Breaklines and mass points. The three coordinates (X,Y,Z) of critical points define the topography of an area similar to sideshots in a stadia field survey. Critical points recorded along terrain breaklines can be combined with grid type data to form a very accurate terrain.

(2) Grid, Digital Elevation Model (DEM). DEMs consist of elevations taken at regularly spaced intervals in two horizontal coordinate directions. These two horizontal directions may coincide with the northing and easting of the authorized project coordinate system or they may be skewed to it. DEM=s along with breaklines may be used for contour generation, for small-scale mapping.

(2) Digital Terrain Models (DTM). DTM=s consist of mass points and breaklines. See Figure 9-5, Typical Digital Terrain Model (DTM). The breaklines are collected at points of abrupt elevation change. Mass points are collected in areas and to a density sufficient to define the character of the topography. DTM generation is the preferred method for defining topography for large-scale mapping utilizing current technology and equipment. This method of terrain model generation generally provides accuracy and efficiency when collected by an experienced photogrammetrist.

(3) Triangulated Irregular Network (TIN) models. DEM and DTM data sets can be processed through software packages to develop a triangulated irregular network of data points to create a file of interpolated points at specific contour intervals (TIN models). The TIN models are then processed through software that connects points of equal elevation (contours). See Figure 9-6, Typical TIN File.

(4) Cross sections. Cross sections require that readings be captured at points of significant terrain change along profile lines stretching across a stereomodel.

(5) Remeasurement. Remeasurement defines the terrain after earthwork is completed. Original measurement may have been in grid or cross-sectional pattern; remeasurement extends only as far as construction operations changed the terrain, and it includes measurement of the same grid points or along the same cross-sectional lines, plus significant breaks in the surface as altered by construction.

b. Spot elevations. Spot elevations are elevations of certain topographic and cultural features that are required to furnish the map users with more specific elevations of these features than may be interpolated from the contours. Spot elevations should be recorded by the stereocompiler whenever needed to supplement spot elevations that may have been obtained in the course of field surveys. Spot elevations are typically shown in their proper position at the water level of lakes, reservoirs, and ponds; on hilltops; in saddles; at the bottom of depressions; at the intersection of well-traveled roads, principal streets in cities, railroads, and highways; and similar locations.

(1) Drainage lines, large and small, center lines, road edges, and any abrupt change in elevation should be compiled as breaklines (lines with abrupt elevation change) prior to compiling the contours. Drainage is of great importance in obtaining the proper contour expression of landforms since most landforms have developed to some extent through the effects of erosion.

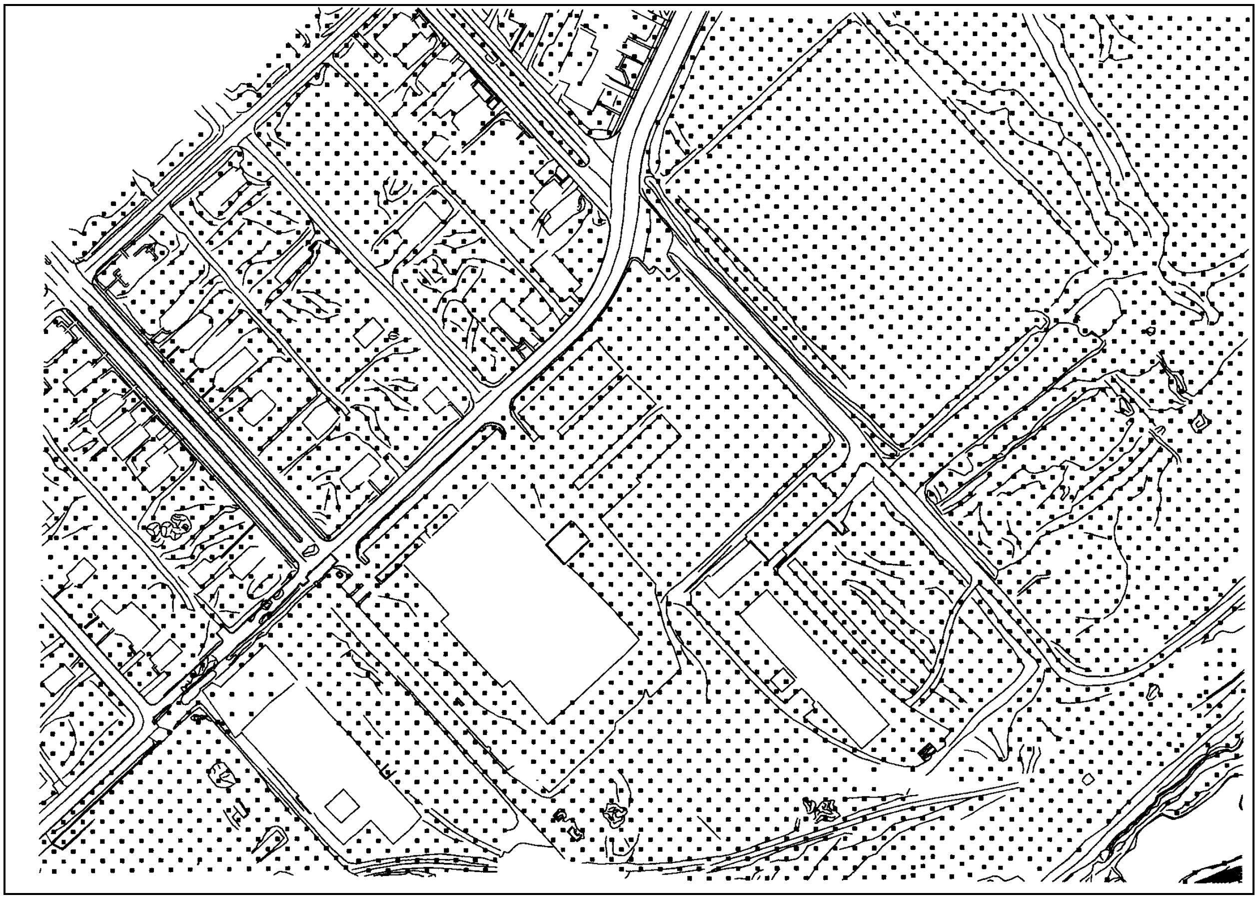


Figure 9-5. Typical digital terrain model (DTM) (courtesy of Barton Aerial Technology)

(2) Spot readings of terrain elevation may be needed in areas where it is difficult to follow the terrain by direct tracing of the contours. Such areas include very flat terrain, large monotone areas such as fields of grass, areas in shadow, and areas covered by trees. If a sufficient number and distribution of accurate spot readings can be made, then the contours can be interpolated from the spot readings. If there is doubt that the interpolated contours will meet the accuracy class of the mapping, then the contours should be shown by dashed lines and the area marked for possible field completion. Where the terrain surface is completely obscured by vegetation, the contours should be omitted and the area marked for field survey completion if the terrain in this area is critical to subsequent design and construction. Contours should not be estimated by tracing the tops of the vegetation and making a height adjustment.

c. Contract requirements. USACE commands will provide in each contract statement of work at least the following:

(1) Area. For design applications, USACE will provide a map of the area to be included in the terrain model, by outlining it. Written description may further define the area. For DEM, DTM, TIN, cross section, or remeasurement terrain models, USACE will also provide the topographic engineer a scaled map of the area required for the terrain model product.

(2) Stereomodel setup data. If the original data were compiled by another contractor, USACE will furnish the contractor the Ground Control Survey Report and the Aerotriangulation Report, which includes the X, Y, and Z ground coordinates of points for orienting the stereoplotter, and the stereoplotter orientation

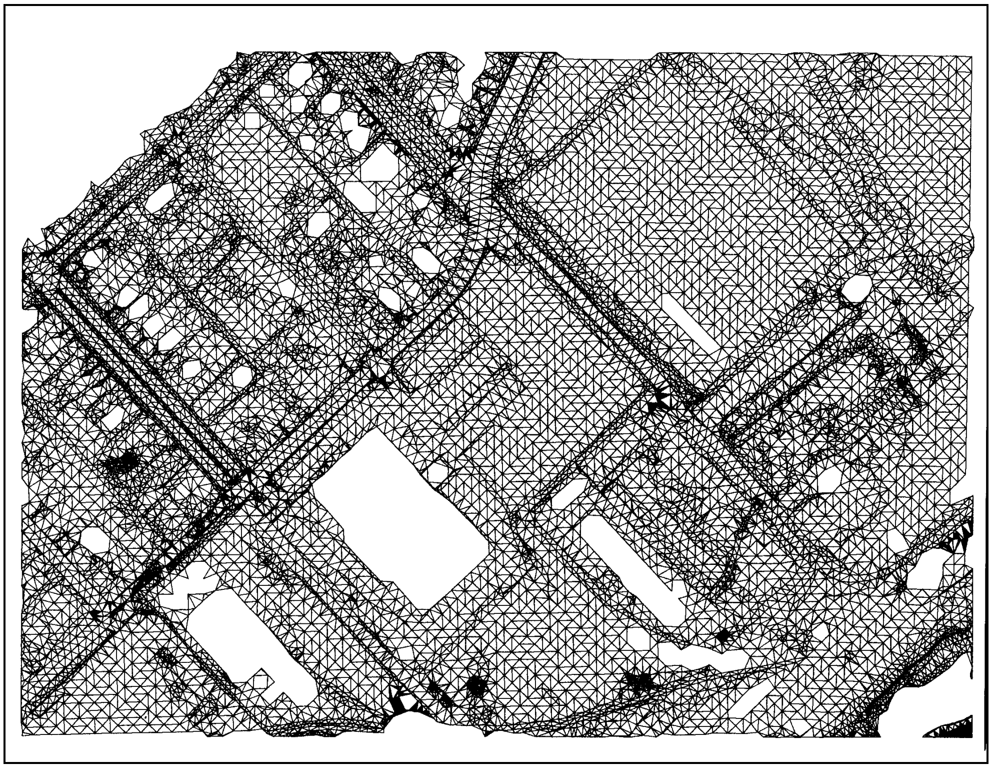


Figure 9-6. Typical TIN file (courtesy of Barton Aerial Technology)

settings if available from the aerotriangulation report. For remeasurement, it shall be the map used for the original measurements.

(3) Point location and spacing.

(a) For DEMs, USACE will specify the spacing of points and outline on the map the area or areas of the elevation model.

(b) For cross sections, USACE will specify the maximum spacing of points and the maximum spacing of sections.

(c) For critical mass points, USACE will specify that the points be collected in patterns and density that will accurately depict the features and terrain specified.

9-12. Map Manuscript

State-of-the-art photogrammetric mapping firms have direct CADD-compatible softcopy or stereoplotter output to video monitors, so the traditional paper or mylar "manuscript" is becoming obsolete. Hardcopy map manuscripts shall be drawn on dimensionally stable, matte-surface, polyester-type plastic drafting film at least 4 mils thick or bond paper.

a. All map detail plotted on the manuscripts shall be to the clarity and accuracy that will result in finished maps fulfilling the map class accuracy standard.

b. Each map manuscript shall be compiled at a scale equal to the target scale specified for the finished map.

c. The map shall be compiled directly into its final form on the graphic display and stored in a digital data base. Preliminary digital map plots or map manuscripts may be plotted on bond paper. The digital data base shall include the horizontal coordinate grid and the ground control points.

d. Map manuscripts shall show in the sheet margin the identification of map area, map scale expressed as both a representative fraction and a graphical bar scale, and flight number and photo numbers of the stereo-models contained in the map. Match notes of adjacent maps shall be shown on all sides of the plot. The original map manuscripts are a deliverable item and shall be maintained in a reasonably clean and legible condition. Lines must be of a clarity and density to provide clear, sharp, and legible paper prints from any standard reproduction equipment. Lettering on the manuscript shall be neat and legible.

9-13. Map Edit

Map manuscripts must be edited carefully before or immediately after the stereomodel compilation phase of the project is completed. The map editor should be someone other than the stereoplotter operator who compiled the original map manuscript.

a. Each map must be checked for:

(1) Compliance with the required map accuracy standards.

(2) Completeness of planimetric and topographic detail, as called for in the contract specifications.

(3) Correctness of symbolization and naming of features.

(4) Agreement of edge-matched planimetric and topographic line work with adjacent maps.

b. Preliminary digital maps may be plotted on bond paper for subsequent editing. Stereoplotters equipped with graphic superimposition in the viewing system can be used to assist the editor in checking the digital data. A typical independent CADD editing workstation is shown in Figure 9-7.

Final map sheets can be prepared by computer driven plotters from a graphic database file. Final sheets should be on dimensionally stable, matte-surface, polyester-type plastic film at least 4 mils thick and of American National Standards Institute (ANSI) (1980) F-Size, unless otherwise specified. Final map sheets should be produced utilizing plotter equipment that will meet the map class standard of accuracy required for the project. Digital data files shall meet the requirements for layers, symbols, line weights, attribution, etc. as specified for the project in the Scope of Work. The current Tri-Service Spatial Data Standards (TSSDS) shall be used unless otherwise specified. Upon completion, each map sheet should be reviewed and edited to ensure completeness and uniformity of the maps.

c. Layout. USACE will specify the final map sheet size, borderline dimensions, and map neat line dimensions and placement. A map sheet layout plan should be prepared for advance approval by USACE. Sheets should be laid out to cover the project area in an orderly, uniform, and logical fashion. The size and location of the stereomodels are dictated by the aerial photographs. The stereomodels may or may not coincide with the size, format, and positioning of the final map sheets.

Figure 9-7. Typical edit workstation (courtesy of Dave Kreighbaum & Earthdata Corporation)

d. Content

(1) Legend and drawing notes. The final drawings should show, at minimum, the following information:

(a) Project title.

(b) Scale and scale bar.

(c) North arrow and magnetic North.

(d) Legend of symbols used (if different from standards).

(e) Credit/Certification/Logo of the mapper.

(f) Adjoining sheet numbers or a sheet layout plan for large projects (i.e., index map).

(g) Grid projection or geographic coordinate datum.

(h) Date of photography.

(i) Date of mapping.

(j) Map Accuracy Statement

The drawing layout and content may be specified by the USACE, or it may be proposed by the Contractor for approval by USACE.

(2) Coordinate grid. The horizontal datum coordinate grid shall be shown on the map manuscript and on the final map. Spacing between grid intersections shall be 5 in. for English unit projects or 10 cm for metric projects at finished map scale. Each coordinate grid line shall be numerically labeled at its ending on the edges of each map sheet.

(3) Ground control. Monumented horizontal control shall be shown by the appropriate symbol on the final map. The location of the control point is the center of the plotted symbol. Monumented vertical control shall be shown by the appropriate symbol on the final map.

(4) Map detail. All planimetric, topographic, and spot elevation map detail shall be plotted directly from a digital data base by high-resolution, high-accuracy, computer-driven plotters. Each line shall be uniform in width for its entire length. Symbols, letters, and numbers shall be clear and legible. All names and numbers shall be legible and clear in meaning and shall not interfere with map features.

9-14. Reproduction

The final map shall be ready for reproduction by any of the standard printing processes so that all lines, images, and other map detail as well as descriptive material will be clear, sharp, and legible.

a. The final map shall be plotted at the target scale specified for the mapping project.

b. When a photographic reproduction is used, a master sheet format showing all standard margin information can be prepared and registered with each drafted or scribed sheet during the photographic reproduction of the final positive map sheets. This is accomplished by contact printing in a vacuum frame.

9-15. Deliverables

The following materials will be delivered to the Government upon completion of the project:

a. Stereomodel computer printouts of stereomodel setup.

b. Aerotriangulation Report.

c. Reproducible positives of each final map.

d. Paper prints of each final map.

e. Computer digital database files. The Government shall specify the media, either magnetic disk or magnetic tape. Files may include DEM=s, DTM=s, TIN=s, Contours, Planimetric detail, Orthophoto Images, and GIS maps as requested in a Scope of Work.

f. Digital files. The Government shall specify the media, magnetic disk, magnetic tape or CD-ROM.

Chapter 10
Orthophotographs

10-1. Orthophotographs

Orthophotographs are photographic images constructed from vertical or near-vertical aerial photographs, such that the effects of central perspective, relief displacement, and tilt are (practically) removed. See Figure 10-1.

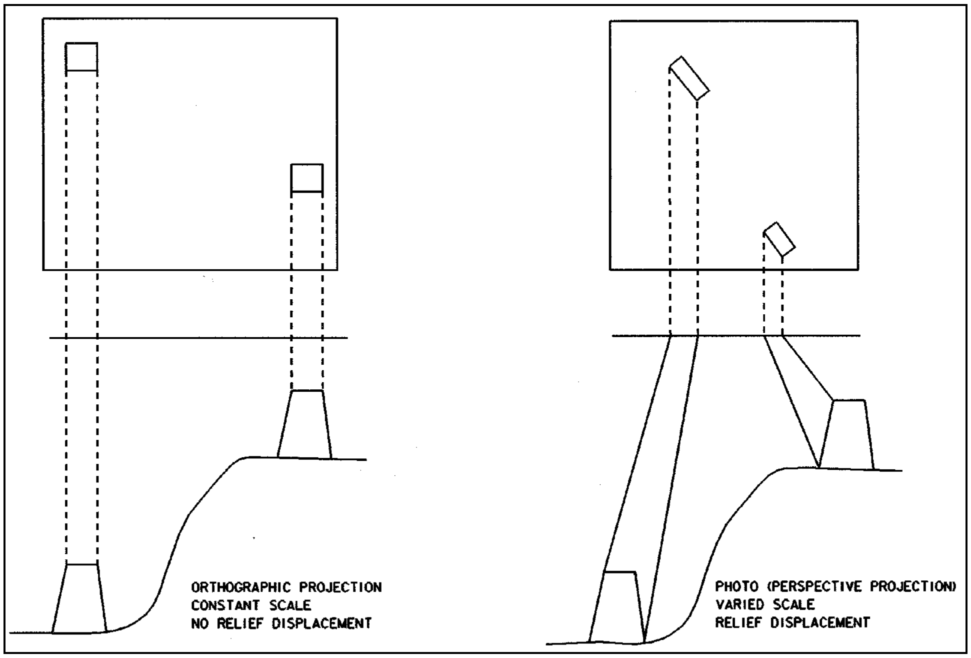


Figure 10-1. Orthographic and perspective images

A **digital orthphoto image** is rectified to thousands of geospatial (XYZ) points, and the image features are aligned orthogonally. The resulting orthophotograph is an orthographic product. **Orthophoto maps** are orthophotographs with overlaid line map data. The common line data overlays include grids, property lines, political boundaries, geographic names, planimetric features, and other selected cultural features as well as contour lines. See Figure 10-2.

10-2. Background

The concept of orthophotography dates back to the 1960s. Original procedures were labor intensive, therefore time-consuming. The first orthophotographs were cumbersome affairs. Elevation slices were taken from a contour map. Using masks, a series of photographic exposures were made from the negative onto a positive base. Each exposure segment covered only the area of a specific elevation range. Thus, the image was a composite of several exposures. They were used mostly by agencies of the Government for experimental projects. In the following 2 decades, analog stereoplotters were adapted to improve and simplify production procedures. The photo image was generated by running the instrument platen along a series of parallel continuous strips. While the film was being exposed, the operator moved the platen up and down, keeping the exposure slit in contact with the apparent ground level. During this period, the mapping industry expected that orthophotography was the answer to a lot of problems. Even though many orthogonal images were produced, acceptance of this product was not nearly as phenomenal as early anticipation.

Figure 10-2. Orthophoto map (courtesy of BAE systems ADR)

10-3. Current Status

The 1990s realized a wide acceptance of orthophoto images. The demand for geographic information is shared by many disciplines (scientists, engineers, economists, geographers, etc.) and the demand is growing dramatically. The demand also drives the technology to create and process geographic data.

a. Geographical Information Systems (GIS) and Land Information Systems (LIS) projects demand pictorial mapping layers to enhance presentation of solutions.

b. Increased demand and use of remotely sensed multispectral imagery and high-resolution elevation data. Orbiting and air breathing sensor platforms are now capable of collecting high-resolution elevation data that can be used for orthophoto processing. Multispectral sensors are being economically brought down to air breathing platforms.

c. Ground control can be a significant time and cost factor in orthophoto development. Global Positioning System (GPS) technology has allowed for a decrease in the time and cost for the capture of ground control data required for orthophoto production. Airborne GPS technology can provide further decreases in time and cost of photo control required for orthophoto creation.

d. Computer processor development has increased the data storage, processing speed and capability of image workstations and software with continued decrease in unit cost. High-resolution metric scanners allow for accurate image creation. Image workstations capable of viewing and analyzing orthophoto data are now on many more desktops than ever before.

e. Digital Photogrammetry Systems (workstations, softcopy, digital stereoplotters) allow users to extract reliable planimetric and topographic data from orthophoto images to create precision thematic maps.

10-4. Map Substitute

Generally orthophotos may not be considered as a substitute for a precise line map since cultural features with a vertical elevation are not as accurate or discernable on an orthophotograph as a planimetric map produced in a stereoplotter. Orthophotographs can be used with caution as a substitute for a planimetric line map for certain smaller scale, nondesign applications. If terrain relief is slight, simple rectification of an aerial photograph might be sufficient. It is possible that ortho rectified images may not be specified when removal of relief distortion is not critical to the accuracy of the functional application. Nonorthorectified image products include photo enlargements and rectified photo enlargements. These products should not be misconstrued as being comparable to orthophotographs.

a. Photo enlargement. This is a photo image sheet enlarged from an aerial photograph to a factor governed by a distance between two points, most often measured from planimetric features on a small-scale map sheet.

b. Rectified photo enlargement. This is a photo image sheet enlarged from an aerial photograph to a best- fit solution to more than two coordinated (XY) points, often extracted from a small-scale map sheet. This procedure is also known as *rubber sheeting*.

In neither of these procedures is the normal image displacement, caused by terrain relief, eliminated. Therefore, image features are not in their true orthogonal location. These products usually involve faster delivery and are significantly less expensive than are orthophotographs; thus, it may be a temptation to use them as a substitute. Improper use of these products may lead to serious problems.

10-5. Image Quality

Throughout the orthophotographic process a wide range of factors can affect the integrity of a digital ortho. Some compound others.

a. Aerial photography. Such items as mechanical and optical integrity of the camera, weather conditions, and photographic lab processing initially influence the sharpness and radiometric density range of the transparency. See Chapter 5 for additional information regarding aerial photography.

b. Pixel scanner. Such items as optical integrity, radiometric sensitivity, dynamic range, and sampling rate influence radiometric quality. If the image collector is a remote sensing device or a digital camera, the capturing and scanning of digital data are a simultaneous operation. In these devices, the pixel resolution is fixed by the mechanical structure of the sensor. The scale of the final ortho image will be limited by the resolution of the system.

c. Magnification. Magnification factor is the relationship of photo scale to final orthophoto scale.

d. Scan resolution. Resolution is the length of one side of a pixel. Hence, a resolution of 20 microns means that the pixel measures 20 microns on each side. Once the final scale is determined, the photo scale and magnification can be calculated. Then the pixel resolution can be computed with the formula

r = 105/mf (10-1)

where

r = resolution (microns)

mf = magnification factor

Assume a hypothetical situation requiring an ortho image scale of 1 in. = 200 ft (1:2400 metric) to the accuracy required by Class 1, ASPRS Accuracy Standards for Large-Scale Maps (Chapter 2). Assume that the project conditions indicate a four-time negative enlargement for maintaining Class 1 accuracy. This is the magnification factor. Hence, the scale of the aerial photos will be

(1"=200') X 4 = 1"=800' (1:9600)

and, using the above formula, the recommended pixel resolution is no larger than

105/4 = 26 microns

e. DPI. Resolution can also be described as the number of dots per inch (dpi) along a single scan path. The same parameters as described in the above item parameters are applicable. Since the magnification in this example has already been declared as 4,

dpi = mf x 240, or dpi = 4 x 240 = 960 (10-2)

f. Ground distance. Resolution can be thought of in terms of actual ground measurements. The size of identifiable ground features in pixels can be determined by either of two formulae, one metric and the other English. Inserting the final scale (fs) parameter in the above situation, the ground feature size would be

Metric: fs/8,000 = (1:2,400)/8,000 = 0.3 m) (10-3)

English: fs/16.666 = (1 in. = 200 ft)/16.666 = 12 in.) (10-4)

10-6. Workstations

The accuracy of orthophotos is also directly related to the quality and accuracy of the hardware and software utilized in the data processing and manipulation steps that generate the orthophotos. Orthophoto workstations include several key hardware and software components. The systems must have the capability to generate and process accurate elevation models and high-resolution scanned images from transparent media (i.e., film or diapositives) or remote sensors. The system must be capable of incorporating vectorized line maps and raster images.

a. Hardware. A basic component of an orthophoto workstation is the central processor. The processor must be capable of interactively processing elevation models and gray-tone images. Primary requirements are high processing (RAM and ROM) speed, large memory and mass storage, high-speed graphics processor, and input and output devices. See Figure 10-3.

Other supplementary devices may be necessary for communication, data transfer, network links, film writing, screen digitizing, high-resolution metric scanners, and various printing devices. These devices must be compatible with the accuracy of the final orthophoto products. For example, the scanner must be capable of producing the required scanned image necessary for the final orthopohoto accuracy.

Figure 10-3. Orthophoto workstation (courtesy of Surdex Corporation)

b. Software. Several basic software packages are required:

(1) Operating system for the workstation.

(2) Application software required for the processing image matrices and the creation of elevation models.

(3) Orthophoto package used to rectify the image pixel matrix with the elevation model in the final step to create the orthogonal image.

10-7. Production Procedures

It is not the intent of this engineer manual to describe all of the processes by which an orthophoto image is created. Rather, a general procedure is offered. Imagery and ground control must first be properly planned and collected. The design of the image and ground control must be based on the required accuracy of the orthophotos. Orthophoto accuracy involves both the accuracy of distances and areas within the orthophoto and relative accuracy of features with respect to their true location on the earth. Distance and area accuracy is based on the pixel size. Relative feature accuracy is based on the accuracy of the DTM. The relative accuracy cannot be more accurate than the accuracy of the DTM. Image manipulation software and techniques used today negate the requirement for special aerial flight parameters for orthophotos in most cases. Additional overlap of photography to minimize image overlap is generally not required. See Chapter 2 for additional information and criteria.

a. Image rectification. There are two types of rectification that are employed in adjusting a pictorial image to the ground: simple rectification (also called rubber-sheeting) and differential rectification. Simple rectification is a single-step procedure, which rectifies an image to several points. This process is relatively inexpensive. Map users should employ this method with caution. The reason being is that the image is not sufficiently accurate throughout its bounds to provide reliable measurements. Depending on project accuracy requirement, simple rectification may be adequate for photographs containing no more relief in feet than the scale in feet to the inch multiplied by the factor 0.03. This assures that the displacement resulting from relief of any photographic image will not exceed the specification limit for planimetric features. For example, simple rectification may be used for a photograph with a scale of 200 ft to the inch in an orthophoto map project made from photographs taken with a 6-in. focal length camera lens if the relief in that photograph does not exceed 6 ft. Differential rectification is a phased procedure which uses several XYZ control points to georeference an aerial photograph to the ground, thereby creating a truly orthogonal image which can provide accurate measurements throughout its bounds. Production of orthophotographs requires the use of differential rectification procedures which are significantly more expensive than simple rectified images. If stringent accuracy specifications are required, orthophographs are recommended. Simple rectified images should not be confused with orthophotographs.

b. Image scan. If a remotely sensed image, generated by a data sensor or a digital camera, is available, the data are already in digital form and need not be subjected to this process. The processes discussed herein are similar for color and gray-scale, except that if a color image is involved it may necessarily be scanned three times, once each for the primary colors of red, green, and blue. This is dependent upon whether the scanner is constructed as a single-pass or multipass instrument. Therefore, the database is three times as large and each of the phases requires at least three times as much processing time. Currently, data gathered by an analog camera are much more precise than a digital camera, because of the construction and limited data gathering capacity of the digital camera. In the case of a photograph exposed in an analog camera, the image must be translated into digital form. It may be best to scan an autododged second-generation transparency (diapositive), rather than the negative, because this procedure may yield better radiometric values. The diapositive is placed in a densitometric scanner, which produces a gray-tone matrix of pixels of a specific size. Each pixel consists of a radiometric value plus an X,Y coordinate set. Digital aerial cameras are also available to produce aerial photography in digital data format. Radiometric grayscale of a single picture element may fall between reflectance values 0-255. Zero is no reflectance (black) and 255 is full reflectance (white). Both quality and economy must be factored into the selection of the pixel size. Pixel and scanned image file size are easily calculated. See Table 10-1. The proper flight altitude and scan rate must be designed for the orthophoto design horizontal scale. Reducing pixel size greatly increases database magnitude, which affects storage capacity and processing time. A single aerial photograph may require as much as 100Mb of memory, depending on the pixel resolution. Contrarily, smaller pixels may assure greater accuracy. Once the data are scanned, histograms can be developed. These are used to adjust radiometric contrast in the formation of a more pleasing overall image tone.

Table 10-1
Digital Orthophoto File Size Based on Neat Double (7.2" H 6.3") Model for Black and White Uncompressed Images

Scan Sample Rate (in micron and dpi)	7.5 microns	15 microns	22.5 microns	30 microns
	3,386 dpi	1,693 dpi	1,128 dpi	846 dpi
File Size (in megabytes)	496 meg	124 meg	55 meg	31 meg

c. Transport image data. If linked to a network, the radiometric matrix may be imported directly to the workstation. Otherwise, a data conversion may be required before it is transferred. At this point the image is not georeferenced to the ground.

d. Orientation. The radiometrically corrected database may be transformed into a digital image by a digital workstation. A two-step orientation procedure is required to georeference the image to the ground.

(1) *Interior orientation* (also known as "inner"). Precision aerial cameras are periodically subjected to an inspection by the United States Geological Survey, Reston, VA, and a Camera Calibration Report is prepared. Such data as the fiducial marks positions, principal location, and radial distortion factors are input into the transformation equation. Using a reference marker, the fiducial marks are identified on the screen of a

workstation. Then the software causes the radiometric matrix to be resampled in a new database related to the fiducial marks.

(2) *Exterior orientation* (also known as "absolute"). Spatial coordinates of photo control points determined by an aerotriangulation procedure (see Chapter 7) are imported into the workstation or stereoplotter. The operator of the instrument identifies each control point with a reference marker. Then the computer searches out its geometric position data. Through a mathematic spatial adjustment the radiometric pixels are transformed into a matrix which is georeferenced (XY coordinates) to the ground.

e. Produce elevation model. An elevation model must be created in a stereoplotter or softcopy workstation. The elevation model may be created in several ways.

(1) Cost and time savings can be obtained in this process if the elevation model is only to be used for the rectification of the orthophoto image. An elevation model utilizing mass points and breaklines to denote the major changes in topography (DTM) can be generated in the stereoplotting device. The DTM can then be used to produce a Triangulated Irregular Network (TIN) of the topographic surface. Software can then generate an accurate grid of points over the TIN. The grid is at a specified interval posting. The closer the spacing the more accurate the ground character.

(2) A grid of points along with mass points and breaklines denoting abrupt changes in topography can be read and captured from direct readings on stereo images in a stereoplotter or softcopy workstation. This method would theoretically provide the most accurate elevation model. However, the time and subsequent cost difference over other less costly method would increase. Each point must be read by the stereooperator. In most cases this method of elevation data collection is not warranted.

(3) A software process known as autocorrelation may be employed to establish a grid of mass points at a specified interval. This method uses software that allows the computer to automatically collect points at a specified grid over a stereo image. This method is very quick. However, editing must be accomplished to ensure that the vertical location of all points is on the earth surface at the specified location. The initial vertical location can sometimes be the top of a tree or building. Software and stereooperator editing must then be accomplished to edit these type of points and establish their vertical location on the earth surface. The mass points and breaklines are then captured in a manner similar to that described above. This method may save time and cost in certain areas (i.e., areas with minimal vegetation and planimetric features).

An elevation model is important because the geometric integrity of spatial pixels in an orthophoto is dependent on a reliable vertical aspect. Therefore, in order to maintain accuracy of the ortho image, it is imperative that the accuracy range of the elevation model points be compatible with the scale of the orthophoto. The elevation model, as well as the image source, ground surveys, and image scan resolution must be designed for the orthophoto design horizontal scale. For instance, production of an orthophoto to scale 1 in. = 2,000 ft (1:24,000) may utilize a DEM suitable for the production of 20-ft contours, available from the U.S. Geological Survey for a modest price. Be advised, this level of DEM would not be suitable to produce a 1-in. = 50-ft (1:600) ortho image. A DEM suitable for 1-in. = 50-ft orthophoto images would cost significantly more time, effort, and funding.

f. Geometric transformation. However the DEM is collected, its data can be used to create an elevation (Z coordinate) for each radiometric pixel, thus forming a matrix of spatial points. Each picture element is assigned a gray-tone value and a spatial (XYZ) coordinate. In small-scale image construction, the simpler nearest-neighbor or bilinear interpolation algorithms may provide an acceptable product. For large-scale precision mapping projects which require discrete measurement confidence, the image rectification should employ an algorithm that can maintain an accuracy equal to or greater than that which is assured by resampling with a cubic convolution transformation.

g. Mosaicking. Orthophotos are made from single model images, but many projects are not limited to the area of a single orthophoto. In these situations multiple images must be mosaicked into block coverage. Radiometric matching must be accomplished in boundary areas between individual images. Orthophoto projects multiple images must be designed to accommodate the hardware and software limitations of the end user. The size of blocks of ortho images can become very large very quickly and can exceed the limitations of hardware and software. Block size should be addressed in the SOW. Compression routines used to minimize file size should be selected carefully to insure that critical data is not lost during compression. Compression efforts should also be addressed in the SOW.

h. Film writing. Once the scanned and rectified data file is collected, high-quality hardcopy reproductions can be generated by an instrument known as a film writer. This equipment allows the radiometric pulses from the database pixels energize three electro-optical light valves at a high rate of passage, converting the pixels into a fine-resolution dot matrix image on a sheet of film. Instrumentation supports raster files of text and/or graphics and produces continuous tone color or black-and-white positives or negatives.

10-8. Enlargement Factor

The enlargement from the aerial photo scale to the final orthophoto map is critical in the orthophoto process. The enlargement factor is dependent upon several items and conditions that may be unique to the contractors equipment and or the project area. Unique considerations may be the contractors camera type, type of terrain and vegetation the images are to cover, final scale of the orthophotos, and the elevation model accuracy to be used in the orthophoto process. The enlargement factor may vary between 4 to 10 times the photo negative scale as shown in Table 10-2.

Table 10-2
Digital Orthophoto Enlargement Factor from Negative Scale

Class 1	4X TO 6X
Class 2	7X TO 8X
Class 3	9X TO 10X

10-9. Limitation of Orthophotography

The original aerial negative from which the orthophotograph is made is a central projection and, as such, displays relief displacement and obscuration of features. For example, a building will obscure the terrain that lies behind it. This obscuration results in gaps of information that can be gotten only from other sources of information, such as field survey or separate photograph. In order to meet position accuracy requirements, special considerations may be necessary at locations where the ground elevation changes abruptly, as at vertical cliffs, retaining walls, overpasses, and bridges. If the equipment used cannot accommodate such a sudden vertical change, it may be necessary to prepare two orthophotographs of such areas: one that depicts faithfully the upper level of the feature and another that depicts faithfully the lower level of the terrain. The two shall then be combined by special image editing techniques or by removing a portion from one orthophotograph and inserting it into the other. The resulting montage shall meet all dimensional and aesthetic specifications. No attempt shall be made to place the tops of buildings, tanks, towers, trees, etc. in map position; rectification shall be at a ground level.

Chapter 11
Airborne LIDAR Topographic Surveying

This chapter provides a general overview of the basic operating principles and theory of Airborne Light Detection and Ranging (LIDAR) systems. There are two basic types of LIDAR systems, those used for topography and those used for bathymetry. This chapter will deal mainly with topographic systems and uses. For bathymetric systems, see EM 1110-2-1003, "Hydrographic Surveying," Chapter 13, for additional information. The references listed at the end of this chapter should be used for more detailed background of all the topics covered in this chapter.

11-1. General

There are many methods/tools that can be used to collect elevation for input into an elevation model, including conventional ground surveys, photogrammetry, and remote sensing. One method/tool for collecting elevation data is LIDAR. LIDAR is an active sensory system that uses light, laser light, to measure distances. When mounted in an airborne platform (fixed wing or rotary wing), this device can rapidly measure distances between the sensor on the airborne platform (See Figure 11-1a and b) and points on the ground (or a building, tree, etc.) to collect and generate densely spaced and highly accurate elevation data. LIDAR mapping technology is capable of collecting elevation data with an accuracy of 15 cm (6 in.) and horizontal accuracies within 1/1000th of the flight height. In order to achieve these accuracies, LIDAR systems rely on the Global Positioning System (GPS) and an inertial reference system (IRS). See Figure 11-2 for concept diagram.

a. Closeup of sensor **b. Overall view of sensor**

Figure 11-1. Lidar sensor in aircraft (courtesy of Atlantic Aerial Technology)

11-2. Operating Principles

A LIDAR device mounted in an airborne platform emits fast pulses from a focused infrared laser which are beamed toward the ground across the flight path by a scanning mirror. Upon capture by a receiver unit, the reflectance from the ground, tops of vegetation, or structures are relayed to a discriminator and a time interval meter which measures the elapsed time between the transmitted and received signal. From this information, the distance separating the ground and airborne platform is determined. While in flight, the system gathers information on a massive base of scattered ground points and stores them in digital format. An interfaced Inertial Measurement Unit (IMU) records the pitch, roll, and heading of the platform. A kinematic airborne GPS system locks on to at least four navigation satellites and registers the spatial position of the aircraft. Additionally, many systems include a digital camera to capture photographic imagery of the terrain that is being scanned. Some systems have incorporated a video camera for reviewing areas collected. Figure 11-2 is a generalized schematic of a LIDAR system. The raw LIDAR data are then combined with GPS positional data to georeference the data sets. Once the flight data are recorded, appropriate software processes the data which can be displayed on the computer monitor. These data can then be edited and processed to generate surface models, elevation models, and contours.

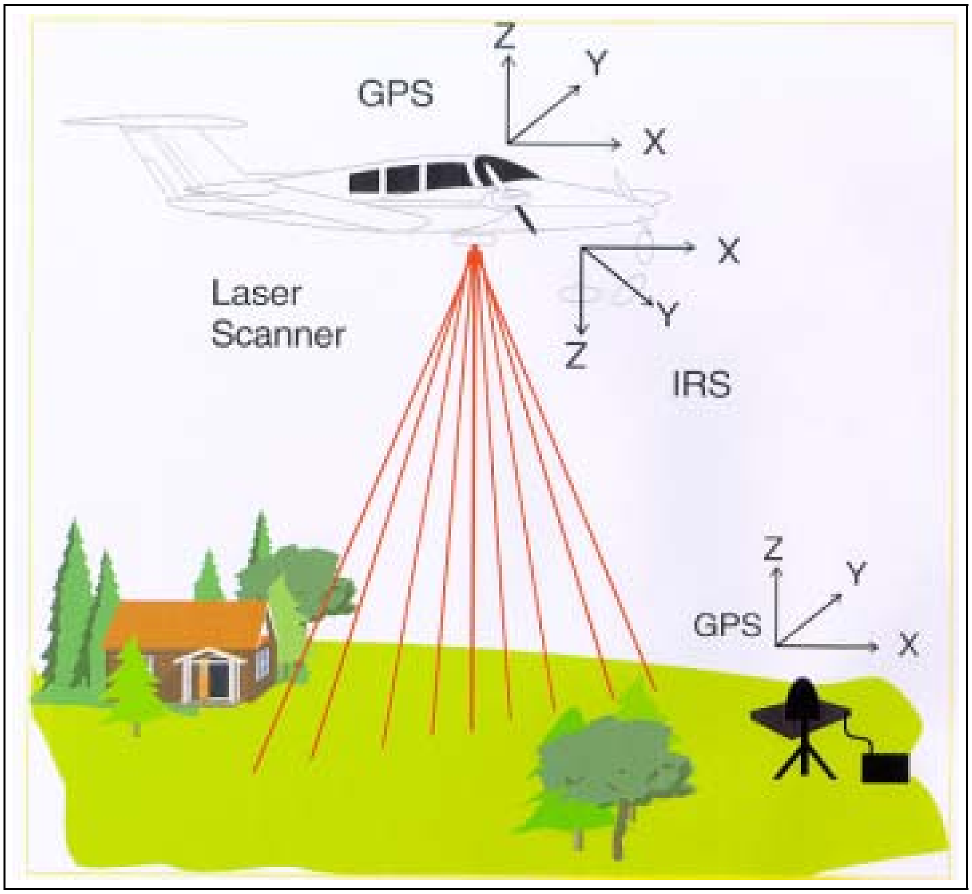


Figure 11-2. Lidar system (author unknown)

11-3. Uses of LIDAR within the Corps

LIDAR is being used for many applications within the Corps when topographic mapping, particularly those requiring elevation data, is needed. Several applications include levee profiling, dredge deposit evaluation, corridor mapping, floodplain mapping, topographic mapping of environmental or hazardous areas, and shore beach surveys, to name a few. Additional applications include large-scale Digital Elevation Models (DEM), forest management, coastal zone surveys, urban modeling, disaster response, and damage assessment.

a. Levee profiling. LIDAR systems can be used to rapidly and accurately map levee systems along rivers and waterways. Profiles and cross sections can be produced and compared to previous collected profiles and cross sections. The resulting LIDAR data sets can also be used to develop a 3-D view of the levee system identifying problems that might have otherwise been missed. The New Orleans District has used LIDAR to map sections of levee along the Mississippi River allowing them to create cross sections and identify floodwall structures near the levees and areas on the levee needing repair. They have also used the same system for planning of levee construction projects.

b. Dredge deposit evaluation. Data collection from a LIDAR system can be used to plan and monitor areas for depositing dredge material.

c. Corridor mapping. Like levee profiling, LIDAR provides an efficient and cost effective means of collecting elevation data along long corridors and linear parcels of land. The St. Louis District is using LIDAR to collect data along proposed high-speed rail corridors and rail/road crossings for accurate mapping and assessment of road grade crossings.

d. Floodplain mapping. LIDAR systems provide a cost effective means of collecting elevation data to be used in various models for floodplain modeling. Several districts have begun using LIDAR for these types of projects. The Federal Emergency Management Agency (FEMA) has also partnered with the state of North Carolina for the first statewide floodplain mapping project.

11-4. Background

The use of lasers for measuring distance have been around since the 1960s. Most surveyors are familiar with the use of laser technology in electronic distance measurement devices, either stand-alone instruments in the 1970s or on total stations in the 1980s. In the 1970s, several agencies including National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA), the USGS and the Defense Mapping Agency (DMA) began developing LIDAR type sensors for measuring oceanographic and topographic properties. In the 1990's, with the development of On-The-Fly (OTF) GPS techniques, small relatively inexpensive IMU systems, and portable computing systems, it became possible to commercialize the technology and LIDAR sensors mounted in airborne platforms began to achieve more consistent and better accuracy. The number of LIDAR vendors has grown in the last 5 years from 3 in 1995 to about 50 in 2000 worldwide.

11-5. Capabilities and Limitations

a. Capabilities. LIDAR mapping systems are capable of rapid and accurate collection of topographic and elevation data without having to set out panel points or large control networks. Only one ground control station is needed within 30 km of the project/collection site. Depending on the flying height, swath width, scan angle, and scan and pulse rates, the shot spacing can range from 25 points per square meter to one point every 12 m (144 sq m). LIDAR is ideal for corridor mapping projects and can provide accurate information for shoreline/beach delineation. Laser mapping is feasible in daylight, overcast (provided that clouds are above the aircraft platform), or night time operations. Day time collection is not dependent upon adequate sun angle as is conventional aerial photography. Several vendors have developed algorithms to classify and remove vegetation to produce bare earth models of the data where some of the LIDAR data points are able to penetrate the vegetation cover.

b. Limitations. LIDAR sensors can only collect during cloud coverage if the clouds are above the height of the airborne platform. LIDAR sensors can only collect data in reasonably good weather and cannot collect data in rain, fog, mist, smoke, or snowstorms. In areas of dense vegetation coverage, the LIDAR pulses, in most cases, will not be able to penetrate through the foliage to the ground unless ample openings in the vegetation exist and the spot size of the pulse is small and densely spaced. Imagery data (digital photos or satellite imagery) are needed to perform proper vegetation classification and removal when producing bare earth models from multiple return LIDAR data.

11-6. Comparisons with Existing Technologies

a. Photogrammetry. The use of LIDAR for topographic mapping and collection of elevation data compares very well with competing technologies, such as traditional aerial photogrammetry, especially in areas where the LIDAR pulse can penetrate foliage. Not only does the data collection compare well, but the data processing of LIDAR, because it is simple X, Y, Z point data, can be more automated with minimal user interaction, unlike photogrammetric processing which requires a lot of user interaction. Table 11-1 lists the comparisons between LIDAR and traditional photogrammetry on some of their basic parameters. In many cases, photogrammetry (usually digital photography) is used in conjunction with LIDAR bare earth processing techniques.

Table 11-1
Comparison between Lidar and Photogrammetry

	LIDAR	**Photogrammetry**
Energy source	Active	Passive
Geometry	Polar	Perspective
Sensor type	Point	Frame or linear scanning
Point measurement	Direct	Indirect
Sampling	Individual points	Full area
Associated image	None or monochrome	High quality spatial and radiometric
Horizontal accuracy	2-5 times less than vertical accuracy	1/3 better than vertical
Vertical accuracy	10-15 cm (~10 cm per 1,000 m over heights of 2,500 m)	Function of flying height and focal length of camera
Flight planning	More complex due to small strips and potential data voids	Overlap and side lap need to be considered
Flight restrictions	Less impact from weather, day/night, season, cloud condition	Must fly during day and need clear sky
Production rate	Can be more automated and faster	
Budget	25%-33% of photogrammetric compilation budget	
Production	Proprietary software: processing performed by vendors, operators	Desktop software available to end-user
Limited contrast area acquisition	Can acquire data: used extensively for coastal mapping	Difficult and expensive

b. Radar technologies. LIDAR can provide higher accuracy and more detailed information about the landscape than radar technologies such as Interferometric Synthetic Aperture Radar (IFSAR). Elevation data obtained from IFSAR is collected in a side-looking mode, that is, off to one side, which can result in data voids in nonopen areas. LIDAR data are collected 10-20 deg either side of vertical to minimize data void areas and to collect direct vertical measurements to the ground or tops of features. IFSAR, however, can fly higher to obtain larger areas in shorter periods of time and is not affected by cloud cover. Current investigations are examining the benefits of combining IFSAR and LIDAR for use in enhancing the strong points of both systems.

11-7. LIDAR System Components

There are four basic components of a LIDAR system. The system includes the laser and scanning subsystem, GPS, IMU, and the operator and pilot display for flight navigation. Many systems also have an integrated digital camera to provide digital images used in bare earth modeling algorithms and feature classification procedures. Some systems have an integrated video camera to record the area scanned by the laser.

a. LIDAR sensors. The types of LIDAR sensors used for topographic applications operate in the near infrared band of the electromagnetic spectrum whereas those used for bathymetric applications operate in the blue/green band. The majority of the sensors on the market today all perform the same way in that they measure distances from the sensor to the ground or desired feature. The differences in the systems are in the power of the laser, the spread of the beam or spot size, swath angle, and the number of pulses per second transmitted. Several systems on the market today also have the capability of measuring multiple returns of each pulse sent out and the intensity of the return. Multiple returns are beneficial in areas of sparse vegetation or tree cover where the first return would hit the top of the tree and the last would penetrate down to the ground. First and last return sensors in some instances may provide bare earth models with less manual editing. See Figure 11-3 . Projects that require "bare earth" data collection should define the term "bare earth." Employing LIDAR technology to develop bare earth models is not standardized. Care should be taken in development of a scope of work to ensure a complete understanding between all parties of the intended use of the data sets. This should include sufficient definition of terms such as bare earth and reflective surface models, etc. Typical sensor characteristics are listed in Table 11-2.

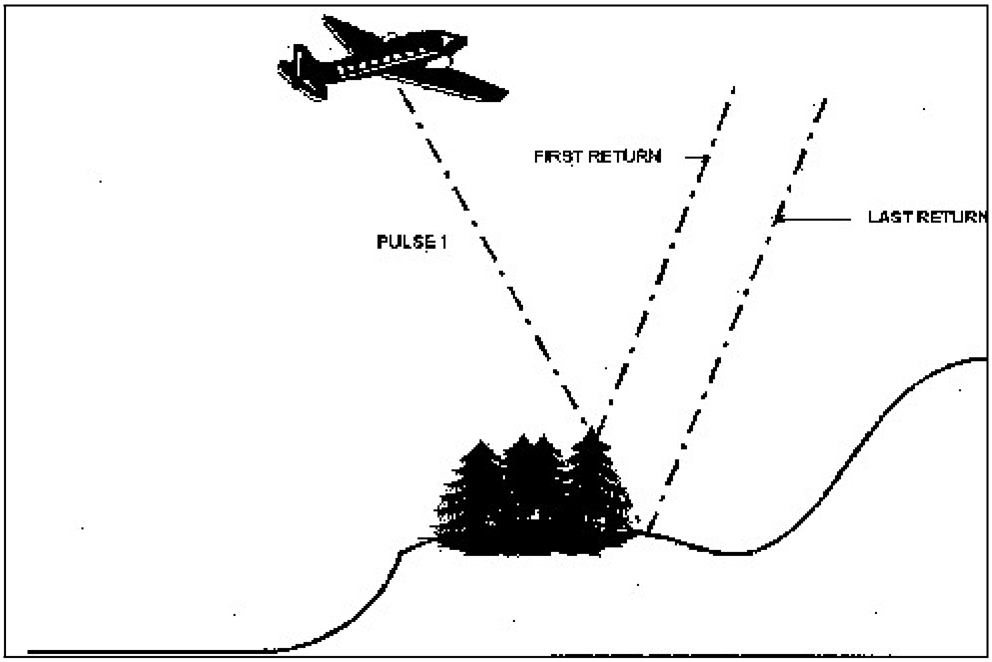


Figure 11-3. First and last return sensors (courtesy of Atlantic Aerial Technology)

Table 11-2
Typical Sensor Characteristics

Parameter	Typical value(s)
Vertical accuracy (cm)	15
Horizontal accuracy (m)	0.2 - 1
Flying height (m)	200 – 6,000
Scan angle (deg)	1 – 75
Scan rate (Hz)	0 – 40
Beam divergence (mrads)	0.3 – 2
Pulse rate (KHz)	05 – 33
Footprint diameter (m) from 1,000 m	0.25 – 2
Spot density (m)	0.25 – 12

b. GPS. The GPS component provides timing and positional information to the LIDAR system. The LIDAR pulses are time tagged using the time from the GPS receiver to later correlate them with the GPS solution summary. The type of GPS receiver used within the system should be capable of measuring/collecting the L1/L2 carrier phase data at a rate of 1 Hz (1 measurement per second). The same type of GPS receiver is required for ground control stations. The processing of the GPS data between the receiver onboard the aircraft and the receiver(s) on the ground control station(s) is known as On-The-Fly (OTF) Differential GPS. OTF, also referred to as Kinematic OTF or Real-Time Kinematic (RTK), allows for high-accuracy (<10-cm) 3-D positioning of a moving platform without static initialization.

c. IMU. The inertial measurement unit measures the LIDAR system orientation in roll, pitch, and heading. These values are combined with the GPS positional information and the laser range data scan values with rigorous geodetic calculations to yield the X, Y, Z of the points collected.

d. Operator and pilot displays. The operator display provides valuable information as data are being collected to the operator on the number of measurements returned, the status of the GPS satellites, IRS, and laser sensors, and the progress of the aircraft along the flight line. The pilot has a display of the aircraft along the flight line path with left/right/elevation indicators. This allows the pilot to navigate along the preprogrammed flight line.

e. Digital imagery/video. In some systems, a digital camera is used to provide an image of the areas being collected. The X,Y,Z data from the LIDAR can be overlaid on this imagery and used in the classification process. On a few systems, a down-looking video camera may also be mounted next to the laser and used to record the area scanned by the laser sensor. Time, latitude, and longitude are usually recording as part of the video display. This information is used by the operator to view the area being collected during the flight as well as used in post processing of the LIDAR data. The audio portion of the recording is used by the operator to note items or features of interest.

11-8. Planning a LIDAR Data Collection

There are several items, which need to be known when planning a project where LIDAR can be used, including when a collection should take place and requirements for ground control.

a. General. The bounding coordinates of the project area need to be known since it is critical in searching for control and setting up the flight lines to be used during the data collection. The type of area where the data collection will take place needs to be examined for amount of vegetation, trees, buildings, and other features that might impact the data collection. For example, if a bare earth elevation model is the end product, then there must be adequate spacing between the vegetation cover to allow the laser pulse to penetrate and obtain ground elevations. A bare earth DEM from LIDAR data in vegetated areas may also require a system with a higher scan rate, slower flying speed, smaller beam angle, or lower flying altitude to obtain a denser point spacing and have the laser pulses penetrate to the ground.

b. When to collect. Unlike photogrammetry, LIDAR data collection is not affected by sun angle and does not require collection to be performed in late fall or early spring for leaf-off conditions. However, it is advantageous to collect LIDAR data during leaf-off conditions in areas with dense deciduous trees, especially when the end requirements are for a bare earth DEM. Since the positioning of the LIDAR sensor relies on the GPS, specifically the kinematic solution of L1/L2 carrier phase processing, satellite ambiguity resolution must occur from data collected during times of low Position Dilution of Precision (PDOP), less than five, and with a minimum of five satellites. Most GPS postprocessing packages include mission planning software for checking PDOP and the number of satellites available for a specified time period. See EM 1110-1-1003, “NAVSTAR Global Positioning System Surveying,” for more information on data collection with GPS and DGPS.

c. Ground control. The project ground control consists of the base stations, calibration control, and the project area control. All control throughout the project should be tied to a single geodetic network for consistency, blunder detection, and overall reliability. All GPS measurements should be made where the carrier phase (L1/L2) data are collected at each station and postprocessed using geodetic techniques. If orthometric heights are required as the final result, it is important that control points be used that have known North American Vertical Datum of 1988 (NAVD 88) heights for proper geoid modeling. See ETL 1110-1-183, "Using Differential GPS Positioning for Elevation Determination," for additional information on performing geoid modeling. A good source for locating high-accuracy control points in your project area is the National Geodetic Survey's (NGS) on-line data sheet search (www.ngs.noaa.gov, click on Data Sheets). Control points can be searched for in multiple ways (radial from project center, by USGS quad, bounding coordinates, …). Reconnaissance of control to be used should be done prior to data collection to make sure that control still exists and has no obstructions for satellite visibility.

(1) Base stations: These control stations must be within 30 to 40 km of the project area. In some case, the base station is set adjacent to the aircraft at takeoff and landing. The aircraft unit is initialized with the aircraft on the ground and stationary; following a brief initialization period the aircraft flies the project, then returns to the same location for a brief stationary period prior to closing the GPS session. Some vendors also collect data from two base stations to provide redundancy and backup in case one of the GPS receivers fails. By initializing the GPS ambiguities with the aircraft and base station receivers in close proximity, the ambiguity (hence GPS solution) may be carried over very long ranges. A conservative recommendation is a 50-km distance between the base station and the project site. Using a minimum of two points will also allow for processing between stations for a check on control. It is important that the control points used have the required horizontal and vertical accuracy to meet the need of the project accuracy.

(2) Calibration control: In order to make sure the LIDAR system is working properly, a calibration site may be established at or near the project site. Usually this calibration site is established at the airport where the plane begins the data collection mission. This requires additional calibration control at the airport as shown in Figure 11-4. The aircraft would fly over the airport immediately following takeoff to calibrate, or confirm calibration, of the total system.

(3) Project area control: The project area control is utilized to test the accuracy of the system and the final products. The quantity of control points is totally project dependent on the project and must consider the vegetative and terrain types in the project area. Selection of the control locations should give consideration to the fact that, in dense vegetation or steep terrain, errors in the final products may be functions of the slope or vegetative characteristics and not the LIDAR system itself.

11-9. LIDAR Data Collection

a. Calibration and quality control. Successful processing of LIDAR data normally requires both system calibration and quality control data collection. These requirements should be included in flight plan instructions to the flight crew. The following calibration and quality control requirements should be designed into each flight.

(1) Airport bidirectional and cross flight lines. A bidirectional and cross flight should be conducted over the airport for every flight using project specific parameters. The minimum critical parameters include altitude, field of view, scan and pulse rate, and aircraft speed. The results from this data set can be used to verify the accuracy of the system for the mission, and/or to make final adjustments to the calibration values used in the computations.

(2) Project cross flight lines. A cross flight line is a line that is perpendicular to and intersects the job flight lines. The primary function of the cross flight is to detect systematic errors such as a false increase in elevation of data away from nadir or line to line, detection of anomalies in individual lines, and to demonstrate the repeatability of results. It is important for these lines to cross all project flight lines. To provide the maximum information content, the cross lines should intersect the primary job lines in clear open areas with no vegetation, if possible.

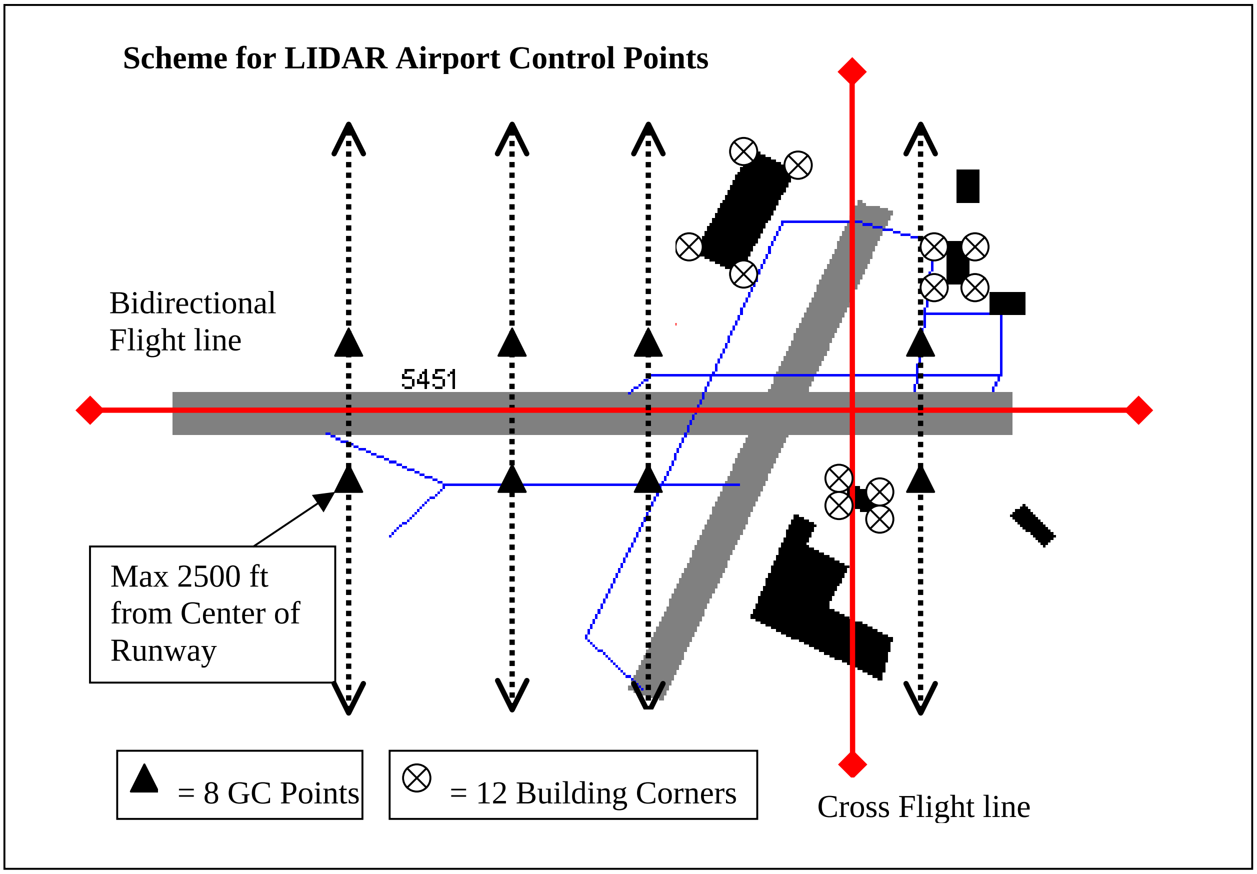


Figure 11-4. Airport calibration control scheme (courtesy of Earthdata International)

(3) Calibration site and project ground control. A series of geodetic ground control points at the airport calibration site and throughout the project are required for a complete quality control plan. Although LIDAR is very consistent between individual measurements, it is simply a two-way ranging system and is therefore susceptible to bias. To detect and correct for any bias, and as an overall quality check of the data, a series of control points should be established at the project airport as shown in Figure 11-4 and throughout the project site.

b. Base station ground control. Since positioning of the LIDAR sensor will be performed relative to the ground control stations used, proper setup and configuration of the GPS antennas and receivers is very important. This includes using tripods and tribrachs or fixed-height tripods that are calibrated and plumbed properly and receivers that are configured to collect at the same measurement rate as the receiver connected to the LIDAR sensor. GPS receiver/antennas should be set up and collecting L1/L2 carrier phase data prior to the aircraft's entering the data collection area.

c. LIDAR collection. Once the system is configured and flight lines are established, the operator monitors the progress of the data collections to ensure data are being received back to the sensor. In almost all cases, the system operator will know if the laser is working correctly because lasers work or do not work. The operator can watch for erratic data from the IMU and the GPS to determine if those systems are working correctly. In general, flight lines are created to provide a 30-percent overlap of the previous flight line collection swath with the current lines swath. All of the LIDAR returns are GPS time-tagged to correspond with the postprocessed DGPS solution.

11-10. LIDAR Data Processing

a. Once the data are collected, the first step is to download the GPS carrier phase data from the control station and the aircraft receivers. These data are then input into the GPS postprocessing software package to compute the high-accuracy kinematic solution trajectory of the aircraft (Figure 11-5). There are several vendors that produce GPS processing software capable of this type of processing. The trajectory is then merged with the IMU data for a complete position and orientation solution. The laser ranging data are then merged, using geodetic algorithms, to the position and orientation to derive the end result, a X,Y,Z position for each pulse return measured by the sensor.

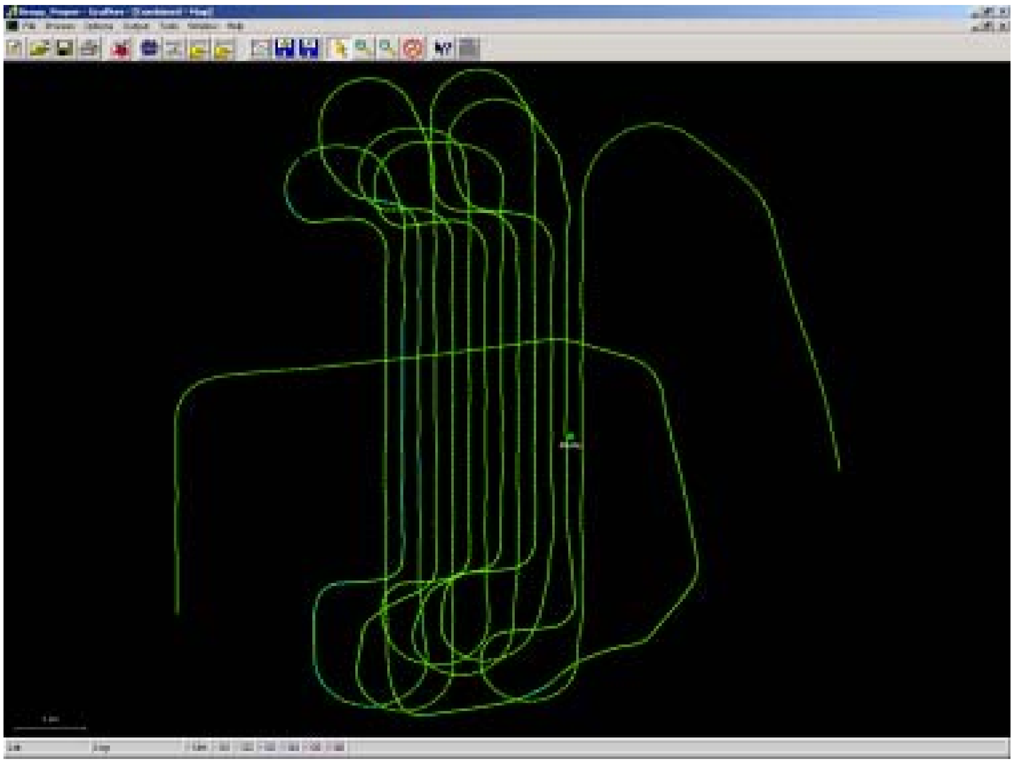


Figure 11- 5. DGPS processed trajectory of aircraft (courtesy of Rapid Terrain Visualization Program)

b. During data processing, a quality control review must examine the data for anomalies, systematic errors, or any potential horizontal or vertical bias. These anomalies could be a result of misalignment in any axis (roll, pitch, or yaw), system timing offsets, atmospheric conditions, GPS bias, or extreme spectral conditions of the natural terrain scene. Each of these anomalies can be detected with careful review and generally resolved in the data processing if required.

11-11. Results

a. Raw LIDAR data. Raw LIDAR data sets are simply a mass of X,Y,Z points for the object that the laser hits, measures, and records the distance to. The points are processed and referenced to the datum requested. See Figure 11-6.

b. Contour plots. The point data itself may or may not be of sufficient quality for a project. Often the end product required is contours of the earth surface. The accuracy requirements for the contours may require the collection of aerial imagery to assist in the collection of mass points and breaklines in the

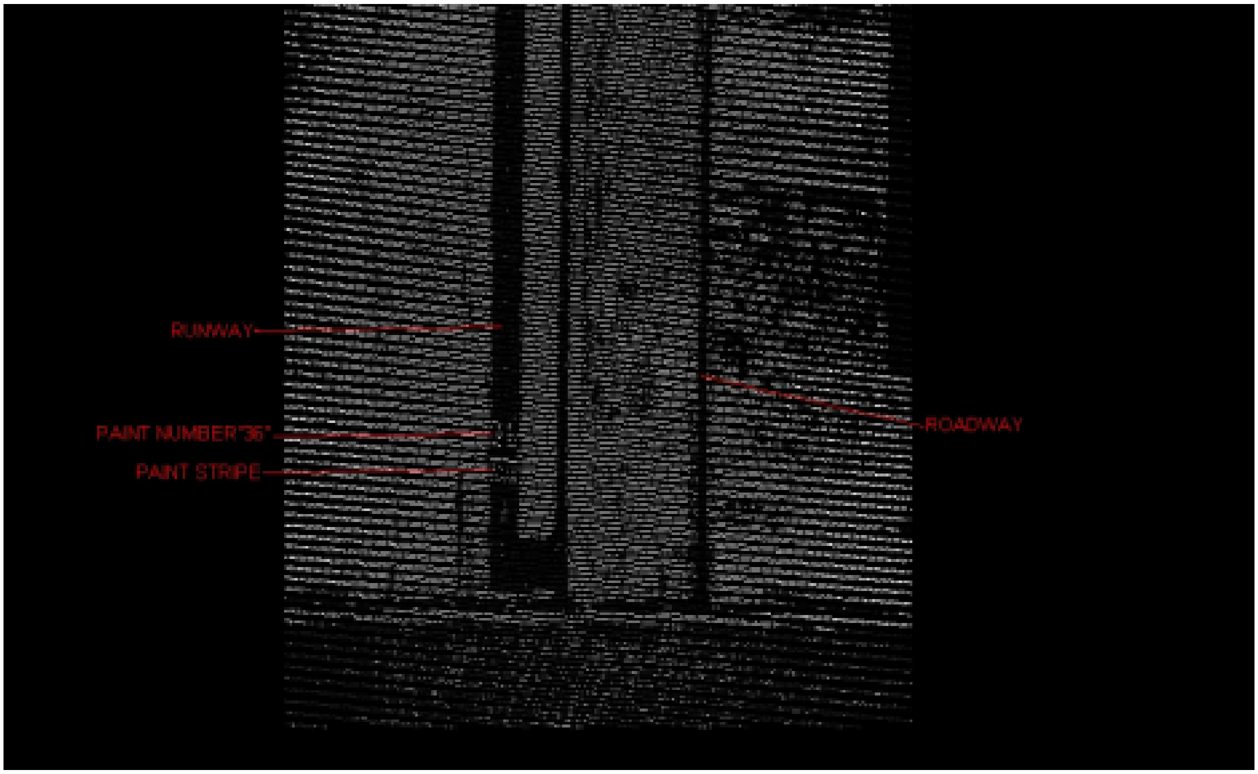


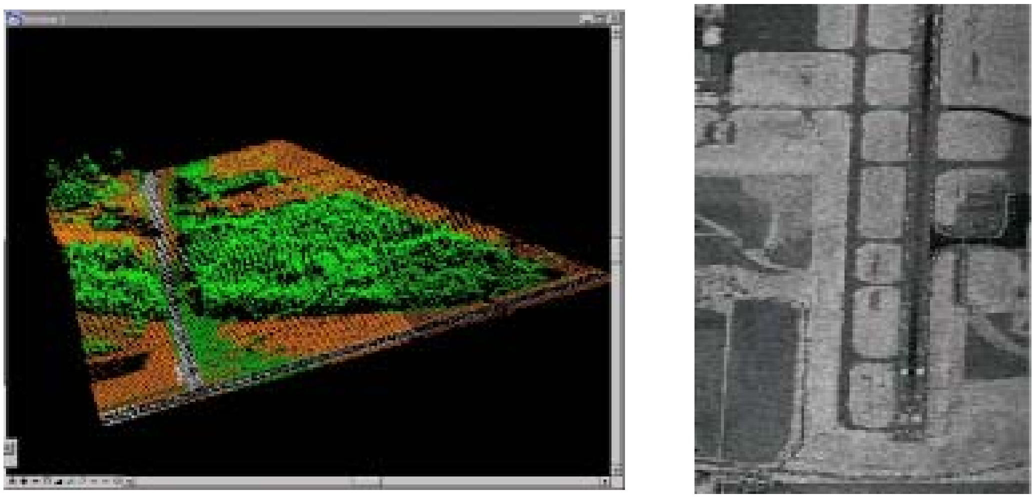
Figure 11-6. Raw LIDAR data (courtesy of Atlantic Aerial Technology)

locations required to adequately depict the character of the earth surface. Note, the sensor generally cannot see through dense vegetation or structures. In areas such as these, other tools such as ground surveys will be required to supplement LIDAR data sets and can add to the cost. When contours are required, the scope of work should state an expected accuracy according the ASPRS Standards as indicated in Chapter 2. LIDAR is simply one of the many tools that may be used to generate an elevation model. Other tools may be required in conjunction with LIDAR data to generate the type of products requested.

c. Surface modeling. These data from the sensors also may provide easy surface model generation. Surface model generation is accomplished by assigning colors or shades of gray to reflectance intensity from the sensor pulses. See Figure 11-7 a and b. Care should be taken in using surface models generated from LIDAR data sets. Note, the points utilized in the model are collected at the first or last return of the pulse. This is not necessarily to the edge of a building, ground surface, etc. A LIDAR generated surface model does not have the accuracy of an orthophoto image.

11-12. Data Classification

In order to produce an accurate contour plot of the ground elevations or to develop surface models from LIDAR data, especially in nonopen area (areas with trees, vegetation, structures, …), classification of these objects must be made in order to remove them from the final product. Most companies that provide LIDAR services have methods for performing data classification. Many of these methods are proprietary but all have the basic intention of identifying objects that are not ground features and need to be removed to develop a bald or bare earth model.



a. b.

Figure 11-7. Surface models generated from LIDAR data (courtesy of Atlantic Aerial Technology)

11-13. Quality Control

Performing QC on projects involving LIDAR data collection can be accomplished several ways, including comparisons between ground stations, comparisons between kinematic survey solutions, and ground truth data collection.

a. Comparisons between ground stations. The use of two ground control stations can allow for processing of GPS data between both stations to check for agreement of the published coordinate values for each station. The kinematic trajectory from each station to the aircraft can be processed and compared to each other to determine if the differences are within the accuracy tolerance or not. If one control point is closer to the project site than the other, then it is expected that there will be slight differences in the two DGPS trajectory solutions.

b. Comparisons between kinematic solutions. GPS data collected on a moving platform such as an all terrain vehicle or car, across the collection area, can be postprocessed and used for comparison to the LIDAR X,Y,Z data. Several companies will collect this type of data along roads that traverse across the collection flight line and roads in the same direction of flight lines.

c. Ground truth data collection. The intensity image produced from the LIDAR collection or the image from a digital camera, if it was operated during the collection, can be used to pick areas where ground truth data collection could be collected. In areas of flat terrain or areas where detail is important it can be used as areas to collect X,Y,Z ground truth data for accessing the accuracy of the LIDAR data. Ground truth data can be collected using conventional survey techniques or DGPS techniques. Digital ortho quarter quads (DOQQ) may also be used in the ground truthing process.

11-14. Contracting Issues

a. A Contractor should provide experience in the production of the type of data required for a project. Quality control data for LIDAR projects is imperative. A Contractor should provide proof of quality of data collection for projects similar to that requested by a U.S. Army Corps of Engineers office. Quality control should include accuracy assessment of the final products and not simply the accuracy of individual point. The FEMA has a standard specification for LIDAR collection and processing. The FEMA specifications can be accessed on the FEMA web site. These specifications may be used in conjunction with or referred to in a SOW for a photogrammetric mapping project that will utilize LIDAR technology.

b. It is important for a project that might involve using LIDAR to state the accuracy of the final products in terms of DEM, Digital Terrain Model (DTM), or contours produced with the LIDAR data. For example, the accuracy should be stated in terms like "The final DTM produced will be of a quality that will meet or exceed ASPRS Class I Standards for the production of 1 foot contours." The ASPRS Standards allow for hidden (dashed contours) in areas where the ground is obscured, since data collected with LIDAR may have such areas.

c. LIDAR data collection can offer scheduling and cost advantages over labor-intensive airphoto mapping because it offers rapid data collection and fast postprocessing. Estimating the cost of LIDAR data collection is not standardized at this time. Only a few firms have the equipment and capability to collect the data, thus creating a varied market value. Cost can vary significantly based on the size, time of year, and location of a project. For some projects where elevation data are very critical, very large-scale mapping LIDAR may be cost prohibitive.

11-15. Sources of Additional Information

Several web sites exist that contain more in-depth information on LIDAR. One in particular is www.airbornelasermapping.com, which provides links to information about LIDAR, on-going research efforts, and service providers and manufacturers.

Glossary

Notation

a	Distance accuracy denominator
b	Elevation difference accuracy ratio
B	The air distance between consecutive exposure stations; air base between exposures in a strip of photographs
d	Distance between survey points; distance between control points in kilometers measured along the level route; photograph image distance; image displacement; negative format dimension
D	Density; ground dimension of a central panel of a target; horizontal ground distance
D-min	Minimum density
D-max	Maximum density
E_{lap}	Required photo end lap
f	Camera focal length
g	Gradient
G	Ground coverage of one side of a square format photograph
h	Elevation above datum of the point
h_{ave}	Average ground elevation in a photograph
h_{base}	Elevation at the object base above datum
h_p	Ground elevation of point p
ht	Vertical height of an object
H	The flight height above mean ground height
m_{ij}	Nine direction cosines expressing the angular orientation
N	Geoid separation above an ellipsoid
p	Parallax; photo width
P_a	Parallax of the image point
r	Radial distance from the principal point to the image point

s Propagated standard deviation of distance between survey points obtained from a weighted and minimally constrained least squares adjustment

S Photographic scale at a point

S_{ave} Average photographic scale

S_{lap} Required side lap

t Photo tilt angle

W The ground distance between adjacent flight lines

y' Auxiliary photocoordinate

x,y Photocoordinates

x_o,y_o Principal point photocoordinates

x_p,y_p Photocoordinates of point *p*

X,Y Horizontal ground coordinates

X,Y,Z Ground point coordinates

X_L,Y_L,Z_L Exposure station coordinates

X_p,Y_p Ground coordinates of point *p*

ω,φ,κ System defining angular rotation in a photograph in which ω is a rotation about the x photographic axis, φ is about the y-axis, and κ is about the z-axis

Abbreviations

A-E Architect-Engineer

AM/FM Automated Mapping/Facility Management

ANSI American National Standards Institute

ASP American Society of Photogrammetry

ASPRS American Society for Photogrammetry and Remote Sensing

AWAR Area Weighted Average Resolution

CADD Computer-aided design and drafting

CF Contour factor

CI	Contour interval
CONUS	Continental United States
COR	Contracting Officer's Representative
CRT	Cathode-ray tube
CW	Civil Works
DEM	Digital Elevation Modeling
DOT	U.S. Department of Transportation
DTM	Digital Terrain Model
EDM	Electronic distance measurement
F-hgt	Flight height
FAA	Federal Aviation Administration
FGCC	Federal Geodetic Control Committee
G&A	General and Administrative Overhead
GIS	Geographic Information System
GPS	Global Positioning System
IDT	Indefinite delivery type
IGE	Independent Government Estimate
JTR	Jount Travel Regulations
LIDAR	Light Detection And Ranging
LIS	Land Information System
MGE	Mean ground elevation
NAD 27	North American Datum of 1927 (for additional information, see *Datum* in paragraph B-3)
NAD 83	North American Datum of 1983 (for additional information, see *Datum* in paragraph B-3)
NAVD 88	North American Vertical Datum of 1988 (for additional information, see *Datum* in paragraph B-3)
NGRS	National Geodetic Reference System

NGVD 29	National Geodetic Vertical Datum of 1929 (for additional information, see *Datum* in paragraph B-3)
NGS	National Geodetic Survey
OCONUS	Outside the continental United States
ODC	Other Direct Charges
OMB	Office of Management and Budget
QA	Quality assurance
QC	Quality control
QUAN	Quantity
RMSE	Root mean square error
SI	International System of Units
SPCS	State Plane Coordinate System
TIN	Triangulated irregular network
U/M	Unit measure
U/P	Unit price
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
USNMAS	U.S. National Map Accuracy Standards
UTM	Universal Transverse Mercator

Terms

Accuracy
Degree of conformity with a standard. Accuracy relates to the quality of a result and is distinguished from precision, which relates to the quality of the operation by which the result is obtained.

Adjustment
Process designed to minimize inconsistencies in measured or computed quantities by applying derived corrections to compensate for random or accidental errors.

Aerotriangulation (or Bridging)
The process of developing a network of horizontal and/ or vertical positions from a group of known positions using direct or indirect measurements from aerial photographs and mathematical computations.

Air Base
The line segment, or length of the line segment, joining two adjacent camera stations.

Airborne Global Positioning System
Airborne GPS employs on the fly surveys techniques for initialization of a receiver while it is in motion. This technique can be used to minimize the amount of ground control points required for aerotriangulation and mapping.

Analytical Stereoplotter
A digital optical Instrument system for plotting a map by observation of stereomodels formed by pairs of photographs. This type of system combines computer software and hardware with an optical viewing system. Film diapositives (hardcopy) of stereopairs is an integral part of an analytical stereoplotter.

Antivignetting Filter
A filter used with wide-angle photography to produce uniform lighting over the whole photograph.

Azimuth
Horizontal direction reckoned clockwise from the meridian plane.

Basic Control
A survey over the entire extent of a project that establishes monumented points of known horizontal position and monumented points of known elevation.

Bench Mark
Relatively permanent material object, natural or artificial, bearing a marked point whose elevation above or below an adopted datum is known.

Between-the-Lens Shutter
A shutter located between the elements of a camera lens.

Cadastral
Pertaining to extent, value, and ownership of land. Cadastral maps show property corners and property lines.

Calibration Plate
A glass photographic plate exposed in the aerial camera and developed to give a record of the relative positions of the fiducial marks (also called flash plate).

Camera Axis
A line through the camera rear nodal point, perpendicular to the film plane.

Camera Station
The point in space where the forward node of the camera lens was located at the instant the photographic exposure was made.

Cartography
Science and art of making maps and charts. The term may be taken broadly as comprising all the steps needed to produce a map: planning, aerial photography, field surveys, photogrammetry, editing, color separation, and multicolor printing.

C-factor and Assumed C-factor
Empirical ratio between flight height and contour interval used to indicate the capability of photogrammetric systems. (C-factor multiplied by contour interval desired equals flight height of aerial photography.) C-factor, unless otherwise indicated, is based on the use of 6-in. focal length lenses with a 9- by 9-in. film format.

Color Separation
Process of preparing a separate drawing, engraving, or negative for each color required in the printing production of a map or chart.

Comparator
A precise instrument that measures two-dimensional coordinates on a plane (usually a photograph).

Compilation
Process of drafting a new or revised map or chart, or portion thereof, from existing maps, aerial photographs, field surveys, and other sources.

Contact
A method of making copies of photography in which the photography is placed in contact with the photosensitive material during exposure, producing a copy of exactly the same size as the original.

Contour
Imaginary line on the ground, all points of which are at the same elevation above or below a specified datum.

Contour Interval (CI)
Difference in elevation between two adjacent contours.

Contouring Factor
The ratio of the flight height to the smallest contour interval that a photogrammetric system can consistently map to specification accuracy (also called C-factor).

Contrast
The difference between the densities of the lightest and the darkest areas of a photograph.

Control, Mapping
Points of established position or elevation, or both, used as fixed references in positioning and correlating map features. Fundamental control is provided by stations in the national networks of triangulation and traverse (horizontal control) and leveling (vertical control). Usually it is necessary to extend geodetic surveys, based on the fundamental stations, over the area to be mapped to provide a suitable density and distribution of control points.

Supplemental control points are those needed to relate the aerial photographs used for mapping with the system of ground control. These points must be positively photo identified; that is, the points on the ground must be positively correlated with their images on the photographs.

Control Station
Point on the ground whose position (horizontal or vertical) is known and can be used as a base for additional survey work.

Coordinates
Linear and/or angular quantities that designate the position of a point relative to a given reference frame.

Coordinates, Origin of
Point in a system of coordinates that serves as a zero point in computing the system elements or in prescribing its use.

Cover
In mapping, vegetation over the terrain.

Crab (Aerial Photography)
The condition caused by failure to orient the camera with respect to the track of the airplane. In vertical photography, crab is indicated by the edges of the photographs not being parallel to the ground track of the aircraft.

Culture
Features constructed by man under, on, or above the ground that are delineated on a map. These include roads, trails, buildings, canals, and sewer systems. In a broad sense, the term also applies to all names, other identification, and legends on a map.

Datum (Plural Datums)
In surveying, a reference system for computing or correlating the results of surveys. There are two principal types of datums: vertical and horizontal. A vertical datum is a level surface to which heights are referred. In the United States, the generally adopted vertical datum for leveling operations is the National Geodetic Vertical Datum of 1929. The horizontal datum, used as a reference for position, is defined by the latitude and longitude of an initial point, the direction of a line between this point and a specified second point, and two dimensions that define the spheroid.

Datum, National Geodetic Vertical
See National Geodetic Vertical Datum of 1929.

Deflection of the Vertical
At any point, the deviation of the vertical (plumb line) from the normal to the spheroid.

Develop
Subject an exposed photographic material to proper chemical solutions to change the latent image to a visible image.

Diapositive
A positive transparency for use in a precision photogrammetric instrument.

Diazo Process
Rapid and inexpensive method for reproducing documents.

Displacement
Any shift in the position of an image on a photograph resulting from tilt during photography, scale changes in the photographs, and relief of the area photographed.

Displacement Due to Relief
An essential characteristic of vertical aerial photography that causes high terrain points to appear farther from the center and low points to appear closer to the center of the photograph than would the map positions of the points.

Distortion
A lens aberration that causes a difference between the position of any part of the image and its theoretically correct position.

Dodging
Selectively shading or masking a portion of a photograph, while making a copy, to reduce extremes of contrast. Automatic dodging selectively varies illumination over the photograph in proportion to the average density of each area on the photography.

Doppler Effect
An apparent change in frequency of a signal caused by relative motion between the source and the point of observation.

Double Projection Stereoplotter
A stereoplotter in which the three-dimensional model is formed optically by projecting portions of the two photographs into the model space.

Easting
In a plane coordinate system, the coordinate that varies in a general east-west direction, increases to the east.

Electronic Distance Measuring (EDM) Devices
Instruments that measure the phase difference between transmitted and reflected or retransmitted electromagnetic waves of known frequency, or that measure the round-trip transit time of a pulsed signal, from which distance is computed.

Elevation
Vertical distance of a point above or below a reference surface or datum.

Emulsion
Suspension of a light-sensitive silver salt (especially silver chloride or silver bromide) in a colloidal medium (usually gelatin), which is used for coating photographic films, plates, and papers. Types of photographic emulsions commonly used are panchromatic (black and white), color negative, color positive, color infrared, and black-and-white infrared.

End Lap
Overlap of any two successive photographs in the direction of the flight line. Also called forward overlap.

Extraterrestrial Surveying System
A surveying system using radio signals from satellites that are received by receivers on monumented points and processed by computers to determine geodetic coordinates (longitude, latitude, and height above spheroid) of the occupied point. The two extraterrestrial surveying systems discussed in this manual are the Satellite Doppler System and the Global Positioning System.

Feature Separation
Process of preparing a separate drawing, engraving, or negative for selected types of data in the preparation of a map or chart.

Fiducial Marks
Reference marks formed on photography by marks held in a fixed relationship to the camera lens. The intersection of the lines connecting opposite fiducial marks usually defines the principal point of the photograph.

Fix
Render a developed photographic image permanent by chemical solutions that remove unaffected light-sensitive material.

Flight Altitude
The vertical distance of the aircraft above mean sea level.

Flight Height
The vertical distance from average terrain elevation to the point from which an aerial photograph is taken.

Flight Line
A line on the ground, on a map, or on vertical aerial photography designating the path along which the aircraft is to fly when photographing.

Flight Plan
All factors related to aircraft and camera operation contributing to producing suitable photography. A flight plan includes flight altitude, flight lines, and photograph spacing.

Focal Length
The distance from the rear nodal point of a lens to the plane on which the lens causes parallel rays of light to converge.

Fog (Photographic)
The visual reduction in light transmission caused by the base material (usually polyester) of the film plus the unexposed emulsion of the photographic medium.

Geodesy
Science concerned with the measurement and mathematical description of the size and shape of the earth and its gravitational field. Geodesy also includes the large-scale extended surveys for determining positions and elevations of points in which the size and shape of the earth must be taken into account.

Geodetic Coordinates
The position of a point described by latitude, longitude, and height above the ellipsoid.

Geodetic Survey
A survey that considers the surface of the earth to be curved.

Geoid
An equipotential surface coinciding with mean sea level for the oceans and extended in land areas so the surface is always perpendicular to the direction of gravity.

Global Positioning System
The GPS consists of the NAVSTAR satellites in six different orbits, five monitor stations, and the user community.

Graticule
Network of parallels and meridians on a map or chart.

Grid
Network of uniformly spaced parallel straight lines intersecting at right angles. When superimposed on a map, it usually carries the name of the projection used for the map—that is, Lambert grid, transverse Mercator grid, or universal transverse Mercator grid. However, care must be taken not to confuse a projection grid with the underlying network of geographic meridians and parallels (i.e., graticule) generated by the projection.

Halftone
A picture in which the gradation of light is obtained by the relative darkness and density of tiny dots produced by photographing the subject through a fine screen.

Imagery
Visible representation of objects and/or phenomena as sensed or detected by cameras, infrared and multispectral scanners, radar, and photometers. Recording may be on photographic emulsion (directly as in a camera or indirectly after being first recorded on magnetic tape as an electrical signal) or on magnetic tape for subsequent conversion and display on a cathode-ray tube.

Inertial Surveying
A total surveying instrumentation package using accelerometers, gyroscopes, and a computer to sense, compute, and record the three-dimensional position of the instrument as it is moved from point to point.

Interpretation
The result of stereoscopic examination of aerial photography augmented by other imagery to obtain qualitative information about the terrain, cover, and culture that might influence the location of a highway.

Intervalometer
A device that operates the camera shutter at a selected interval of time.

Latitude
Angular distance, in degrees, minutes, and seconds, of a point north or south of the equator.

Lens Distortion
Lens aberration shifting the position of images off the axis causing objects at different angular distances from the axis to undergo different magnifications.

Leveling
Surveying operation in which elevations of objects and points are determined relative to a specified datum.

LIDAR
Light Detection and Ranging. Laser range and distance measurements of the earth from an aircraft. Can be used to generate a dense grid of elevation points for various mapping products to include DEM, and DTM data sets.

Line Copy (Line Drawing)
Map copy suitable for reproduction without the use of a screen; a drawing composed of lines as distinguished from continuous-tone copy.

Longitude
Angular distance, in degrees, minutes, and seconds, of a point east or west of the Greenwich meridian.

Magazine
The part of an aerial camera that holds the film and includes the mechanism for advancing the film.

Map
Graphic representation of the physical features (natural, artificial, or both) of a part or the whole of the earth's surface, by means of signs and symbols or photographic imagery, at an established scale, on a specified projection, and with the means of orientation indicated.

Map, Engineering
Map showing information that is essential for planning an engineering project or development and for estimating its cost. It usually is a large-scale map of a small area or of a route. It may be entirely the product of an engineering survey, or reliable information may be collected from various sources for the purpose, and assembled on a base map.

Map, Flood Control
Map designed for studying and planning flood control projects in areas subject to flooding.

Map, Hypsographic
Map showing relief with elevations referred to a geodetic vertical datum.

Map, Landuse - Map showing the various purposes for which parcels of land are being used.

Map, Line
Map composed of lines as distinguished from photographic imagery maps.

Map, Orthophotographic
Map produced by assembling orthophotographs at a specified uniform scale in a map format.

Map, Planimetric
Map that presents only the horizontal positions for features represented; distinguished from a topographic map by the omission of relief in measurable form. The features usually shown on a planimetric map include rivers, lakes, and seas; mountains, valleys, and plains; forest and prairies; cities, farms, transportation routes, and public utility facilities; and political and private boundary lines. A planimetric map intended for special use may present only those features essential to the purpose to be served.

Map, Thematic
Map designed to provide information on a single topic, such as geology, rainfall, population.

Map, Topographic
Map that presents the horizontal and vertical positions of the features represented; distinguished from a planimetric map by the addition of relief in measurable form.

Map Projection
Orderly system of lines on a plane representing a corresponding system of imaginary lines on an adopted terrestrial or celestial datum surface; also, the mathematical concept of such a system. For maps of the earth, a projection consists of a graticule of lines representing parallels of latitude and meridians of longitude or a grid.

Map Series
Family of maps conforming generally to the same specifications and designed to cover an area or a country in a systematic pattern.

Mean Sea Level
The average of the heights of the surface of the sea at all stages of tide.

Meridian
A plane curve on the surface of the earth passing through the axis of rotation and any given point on the earth's surface. All points on a given meridian have the same longitude.

Monocomparator
A comparator that measures on a single photograph (see *comparator*).

Monument (Surveying)
Permanent physical structure marking the location of a survey point. Common types of monuments are inscribed metal tablets set in concrete posts, solid rock, or parts of buildings; distinctive stone posts; and metal rods driven in the ground.

Mosaic
An assembly of vertical aerial photographs to form a continuous representation of the terrain covered by the photography.

National Geodetic Vertical Datum of 1929
Reference surface established by the US Coast and Geodetic Survey in 1929 as the datum to which relief features and elevation data are referenced in the conterminous United States; formerly called "mean sea level of 1929."

Nodal Point
One of two intangible points in a camera lens that have the characteristic that any ray of light directed to the front nodal point will exit parallel to itself through the rear nodal point.

Northing
In a plane coordinate system, the difference between two positions as a result of movement to the north.

Oblique Photograph
A photograph taken with the axis of the camera intentionally directed between vertical and horizontal.

Origin of Coordinates
Point in a system of coordinates that serves as a zero point in computing the system's elements or in prescribing its use.

Orthophotograph
Photograph having the properties of an orthographic projection. It is derived from a conventional perspective photograph by simple or differential rectification so that image displacements and scale differences caused by camera tilt and terrain relief are removed.

Orthophotomap
An orthophotograph to which has been added a grid, contour lines, names, and/or other information characteristic of a map but missing on the orthophotograph.

Orthophotomosaic
Assembly of orthophotographs forming a uniform-scale mosaic.

Overlap
The amount by which one photograph overlaps another, customarily expressed as a percentage. The overlap between aerial photographs in the same flight line is called the end lap, and the overlap between photographs in adjacent parallel flight lines is called the side lap.

Overlay
A printing or drawing on a transparent or translucent medium intended to be placed in a register on a base map or other graphic. The overlay depicts information that does not appear on the base or require special emphasis.

Panchromatic
A photographic emulsion for black-and-white photography that is sensitive to all colors of the visible spectrum.

Parallax
An apparent change in the position of one object with respect to another because of a change in the position of observation.

Pass Point
A point whose horizontal and/or vertical position is determined from photographs by photogrammetric methods and is intended for use as a control point in the orientation of the photographs.

Photogrammetry
Science or art of obtaining reliable measurements or information from photographs or other sensing systems.

Photography
Photographic film, exposed and processed.

Photoindex
An assembly of photographs in their proper relative positions, generally annotated and copied at a reduced scale.

Photomap (Photographic Map)
Map made by adding marginal information, descriptive data, and a reference system to a photograph or assembly of photographs.

Plane Coordinate System
A system of usually perpendicular lines on a plane surface. Distances from the system to points on the surface represent coordinates.

Plane Survey
A survey that treats the surface of the earth as though it were a plane.

Planimetry
Plan details of a map—those having no indications of relief or contour (i.e., buildings).

Platen
The flat surface of an aerial camera against which the film is pressed while exposure is made.

Precision
The variance of repeated measurements from their average; the degree of refinement with which an operation is performed.

Principal Point
The foot of a perpendicular from the rear nodal point of the camera lens to the plane of a photograph.

Print
A copy made from a transparency by photographic means.
Process
Develop and fix exposed photographic material.

Quadrangle
Four-sided area, bounded by parallels of latitude or meridians of longitude used as an area unit in mapping (dimensions are not necessarily the same in both directions).

Rectification, Differential
The process of scanning and reprojecting small areas of a photograph onto a plane from different perspectives to remove displacements resulting from tilt and relief. The process may be accomplished by any one of a number of instruments developed specifically for the purpose.

Rectification, Simple
The process of projecting a photograph onto a horizontal plane by means of a rectifier to remove displacements resulting from tilt of the camera.

Relief
Elevation variations of the land or sea bottom.

Representative Fraction
Scale of a map or chart expressed as a fraction or ratio that relates unit distance on the map to distance measured in the same unit on the ground.

Root Mean Square Error (RMSE)
The square root of the quotient of the sum of the squares of the errors divided by the number of measurements, or

$$RMSE = \sqrt{(\sum e^2)/n}$$

in which e is the error at each point (the difference between the value used as a standard and the value being tested), and n is the total number of points tested.

Scale
The ratio of the size of the image or representation of an object on a photograph or map to its true size. Scale may be expressed as a representative fraction (as 1/10,000) or ratio (as 1:10,000) or it may be expressed as the number of feet to an inch. Scales are referred to as "large" if the ratio is large (the denominator is small) and as "small" if the ratio is small (the denominator is large).

Side Lap
Overlap of photographs in adjacent (parallel) flight strips.

Softcopy Workstation
Computer workstation for plotting a map by observation of stereomodels formed by pairs of photographs. These workstations differ from a stereoplotter because they do not require hard copy imagery in the system. Images are scanned and viewed in three dimensions on a high-resolution monitor with the aid of software and special glasses.

Spheroid

A surface easily defined mathematically that closely represents the geoid. It is produced by rotating an ellipse on its minor axis.

Spot Elevation
Point on a map or chart whose height above a specified datum is noted, usually by a dot or a small sawbuck and elevation value. Elevations are shown, on a selective basis, for road forks and intersections, grade crossings, summits of hills, mountains and mountain passes, water surfaces of lakes and ponds, stream forks, bottom elevations in depressions, and large flat areas.

State Plane Coordinate System
Coordinate systems established by the US Coast and Geodetic Survey (now the National Ocean Survey), at least one for each State.

Stereocomparator
A comparator using the binocular vision of the operator that measures the two photographs on a stereoscopic pair simultaneously (see *comparator*).

Stereocompilation
Drafting of a map or chart manuscript from aerial photographs and geodetic control data by means of photogrammetric instruments.

Stereoscopic
Pertaining to the use of binocular vision for observation of a pair of overlapping photographs or other perspective views, giving the impression of depth.

Supplemental Control
Surveys between basic control points to establish the additional points necessary to control the detailed mapping.

Target
A contrasting symmetrical pattern placed around a point on the ground to facilitate locating and measuring the image of the point in a photograph.

Target Map Scale
The intended design scale of the map or digital data file element.

Tilt
For vertical aerial photography, the angular deviation of the camera axis from a vertical line.

Topography
Configuration (relief) of the land surface; the graphic delineation or portrayal of that configuration in map form, as by contour lines; in oceanography the term is applied to a surface such as the sea bottom or a surface of given characteristics within the water mass.

Transparency
A photograph on a transparent (glass or plastic) base, which can be viewed by transmitted light.

Traverse
Sequence of lengths and directions of line segments connecting a series of stations, obtained from field measurements, and used in determining positions of the stations.

Triangulation
Method of extending horizontal position of the surface of the earth by measuring the angles of triangles and the included sides of selected triangles.

Trilateration
Method of surveying wherein the lengths of the triangle sides are measured, usually by electronic methods, and the angles are computed from the measured lengths.

Universal Transverse Mercator (UTM) Grid
Military grid system based on the transverse Mercator projection and applied to maps of the earth's surface extending from the Equator to the 84-deg latitudes.

Vertical Photograph
A photograph taken with the camera axis directed downward along (or nearly along) a vertical line.