13 PHOTOGRAMMETRY SURVEYS

Photogrammetric surveys establish targeted, and occasionally non-targeted, photo control on the ground to relate aerial photographs to a project's horizontal and vertical datums.

The photo control is used by the Office of Photogrammetry (OoP) to create topographic and planimetric maps for Design, Environmental, Traffic, Hydrology, Planning, and other functional units within the Department as well as by consultants.

This chapter is to be used for Department-involved transportation improvement projects, including special funded projects. It shall be used by all Department employees, local agencies, and consultants performing photogrammetric tasks. It is their responsibility to adhere to all relevant processes, workflows, and specifications stated in this chapter. Questions about this chapter should be discussed with the District Photogrammetry Coordinator (DPC), Surveys, and/or the Contract Manager.

This chapter provides policies, general information, and procedures regarding the photogrammetry process. It describes a statewide model of responsibilities and workflow. Unique circumstances in a project may warrant deviations from this model. The Survey Manager, DPC, and the OoP Manager will jointly agree upon any modifications to the model.

13.1 Policy

It is the Department's policy that a photogrammetric survey shall be requested as early as possible in a project to ensure a timely delivery of the final product from OoP.

It is also the Department's policy regarding photogrammetric surveys to provide photo control in a timely manner, surveyed to all of the requirements in the Department's Surveys Manual, for use by OoP in producing topographic and planimetric maps.

Additionally, it is the Department's policy to examine emerging photogrammetric methods for potential use by the Department. As newly developed photogrammetric methods are adopted by the Department, new specifications will be developed and existing specifications will be changed.

13.2 General Information

Photogrammetry Defined

Photogrammetry: *The art, science, and technology of obtaining reliable information about physical objects, and the environment, through processes of recording, measuring, and interpreting images and patterns of electromagnetic radiant energy and other phenomena. (Manual of Photogrammetry, 4th Ed., ASPRS, 1980)*

13.2-1 When to Use Photogrammetry

Each project has a unique set of conditions that will determine which mapping techniques should be utilized. Surveys in consultation with the Project Manager will determine if photogrammetry will be used on a project.

The following are factors to consider when deciding to use Photogrammetry:

- Photogrammetry is a cost efficient surveying method for mapping large areas.
- Photogrammetry may be safer than other surveying methods. It is safer to take photographs of a dangerous area than to place surveyors in harms way.
- Photogrammetry provides the ability to map areas inaccessible to field crews.
- Photogrammetry creates a photographic record of the project site (snapshot in time).
- Photogrammetry produces useful digital products such as orthophotos.
- Photogrammetry produces electronic terrain models.

13.2-2 When Not to Use Photogrammetry

Photogrammetry is not the solution for all mapping situations. Photogrammetry may not be appropriate under the following conditions:

- The accuracy required for a mapping project is greater than the accuracy achievable with photogrammetric methods.
- The scope of the work is not large enough to justify the costs of surveying the photo control and performing the subsequent photogrammetric processes. However, when unsafe field conditions are encountered, safety shall hold a higher weight than cost in the decision process.

13.2-3 Caltrans Photogrammetry Information Sources

In addition to this chapter, there are several sources for information on photogrammetry within the Department.

- The first and foremost is the DPC. The DPC is familiar with the products and services that can be obtained through photogrammetric techniques. The DPC is also familiar with OoP staff and which staff members to contact for answers to specific questions.
- The second source is OoP's publication, *User's Guide to Photogrammetric Products and Services.* This guide provides information and guidance for those in need of mapping or other photogrammetric products.
- The third source is OoP's intranet web site at: http://onramp.dot.ca.gov/hq/esc/sdsee/photogrammetry/index.shtml
- OoP also has a web site accessible via the internet at: http://www.dot.ca.gov/hq/esc /PHOTOGRAMMETRY

13.2-4 Photogrammetric Products Available

The following list summarizes photogrammetric products available from OoP.

- New Aerial Photography: Precision photography as well as general photography.
- Photo Reproduction and Enlargement: OoP provides by contract with outside vendors photography lab services for reproduction and enlargements of images captured on conventional aerial film.
- Topographic Mapping: Precision maps used for project studies, project design, and other purposes are compiled as three-dimensional vector representations of permanent features and terrain, provided in the Department's standard CAD format.
- Digital Terrain Models (DTM): Three-dimensional digital surfaces of the terrain derived from topographic mapping and often combined with field data provided in the Department's standard DTM format. See example 13.10-4.
- Scanning: OoP has a high-resolution, high accuracy aerial film scanner suited for large volume scanning of roll film.
- Photo Rectification: Simple digital rectification of photographs to known ground positions, such that the resulting digital images can be used for public display and other non-engineering tasks.
- Digital Orthophotography: High accuracy digital images produced from stereo photography and digital terrain information that can be used with reliability approaching that of conventional photogrammetric mapping.
- Digital Highway Inventory Photogrammetry Program (DHIPP): Provides intranet accessible geo-referenced ortho-rectified digital color aerial images of the California highway system for non-engineering applications.
- Satellite Imagery: High altitude, low-resolution images are available from remote sensing satellite operators, and are appropriate for public displays and other non-engineering functions.
- Light Detecting and Ranging (LIDAR): LIDAR provides a high-density digital elevation model of a site by using an airborne laser to scan the terrain producing a large number of geo-referenced points.

13.3 Responsibilities

Teamwork is vital for the efficient completion of the photogrammetric mapping process. The following list illustrates the necessity of communication and teamwork by detailing the responsibilities of the staff involved in the photogrammetric mapping process.

13.3-1 Project Manager

The Project Manager leads the Project Development Team and is responsible for overall project planning and completion.

It is the responsibility of the Project Manager to:

- Facilitate communication between all parties involved in a project.
- Develop the Project Workplan (schedule and resources) with input from functional managers.
- Open the appropriate project phases.
- Work with the DPC to ensure that the expenditure authorization and special designations are in place before work begins.
- Establish and communicate the priority of the project within the District/Region.
- Coordinate with OoP and other functions to ensure timely delivery of photogrammetry products.
- Ensure that the Request for Surveying and/or Request for Photogrammetric Services is submitted in a timely manner.
- Negotiate and communicate the timetable for the final delivery of the photogrammetry products with the functional units.
- Monitor the progress of the project.
- Notify the DPC of any changes in the project that may affect the scope, schedule, or resourcing of the photogrammetry products.

13.3-2 Project Engineer

The Project Engineer is responsible for overseeing the design of transportation facility improvements.

It is the responsibility of the Project Engineer to:

- Confer with the DPC regarding project requirements.
- Submit a Request for Photogrammetric Services form to the DPC for all required photogrammetry products in a timely manner.
- Determine the limits of the area to be mapped and to communicate those limits at the beginning of the photogrammetry project.
- Determine the limits of the DTM, if needed, and if those limits are different from the mapping limits.
- Review and accept delivery of photogrammetric products from the DPC.

13.3-3 Surveys

It is the responsibility of Surveys to:

- Ensure that field crews have been trained in the proper techniques for setting photo control targets and establishing values on the photo control.
- Ensure that field crews have access to the Department's Surveys Manual.
- Ensure that resources are assigned to photogrammetry projects in a timely manner.
- Ensure that the marked control prints and the photo control are checked and delivered to the DPC in a timely manner.
- Stay in communication with the DPC on all issues related to the progress of the photogrammetric project.
- Manage all imagery and photogrammetric products stored within the District/Region.

13.3-4 Party Chief

The Party Chief is responsible for overseeing the work of a survey field crew.

It is the responsibility of the Party Chief to:

- Ensure that the accuracy standards stated in Chapter 5, Classif cations and Accuracy Standards for photogrammetric surveys are met when establishing photo control.
- Ensure that the specifications for surveying photo control set forth in the Department's Surveys Manual are followed.
- Ensure that photo control targets are established at the positions or within the positional tolerances indicated on the flight plan or in the positions agreed upon with the DPC.
- Maintain communication with the DPC on any issues or concerns related to photo control.
- Locate, if practical, all photo control prior to acquiring photography.
- Ensure that all photo control targets are in place immediately prior to the scheduled aerial photogrammetry flight.

13.3-5 District Photogrammetry Coordinator (DPC)

The DPC is a surveyor who serves as the liaison and single point of contact between OoP and District functional units concerning photogrammetric issues.

It is the responsibility of the DPC to:

- Coordinate photogrammetry related activities within the District.
- Coordinate the District/Region's photogrammetric needs in emergency situations.
- Work with the Project Manager to ensure that expenditure authorization and special designations are in place before work commences.
- Confer with the Project Engineer concerning photogrammetric products, either existing or to be produced, required for a project.
- Attend District Project Development Team meetings and consult with the team on photogrammetric products and services that may be required for a project.
- Assist in the preparation of Request for Photogrammetric Services.
- Assist OoP in establishing District photogrammetry project priorities.
- Notify the Project Manager of any changes in the photogrammetric products and services that may affect the scope, schedule, cost, or resources for the project.
- Attend and participate in the annual DPC's meeting and all DPC teleconference meetings.
- Act as the liaison for questions, concerns, materials, and information between District staff and OoP staff.
- Coordinate the field review of a photogrammetric project to determine the suitability of photogrammetric surveying methods.
- Coordinate District aerial photography and mapping databases.
- Authorize the acquisition of photography by the aerial photography service provider once the Party Chief has communicated that the area is ready for photography.
- Maintain familiarity with photogrammetry contracts and specifications, and new photogrammetric methods.
- Coordinate photographic reproduction work with OoP.
- Coordinate the oversight review of consultant photogrammetry projects.
- Assist public and private entities with research of photogrammetric products available within the District.

13.3-6 Office of Photogrammetry (OoP)

The various Branches and Units within OoP perform specialized tasks and work cooperatively to produce photogrammetric products.

The specialized tasks performed by OoP staff include quality control and quality assurance (QC/QA) of photogrammetric work by contractors as well as performing photogrammetric work directly.

The following are the responsibilities of the OoP Branches and Units.

Photogrammetry Project Management

Photogrammetry Project Management is responsible for coordinating the resources of the OoP.

It is the responsibility of the Photogrammetry Project Management Coordinator to:

- Ensure the Department's goals for photogrammetry project delivery are met.
- Negotiate with the Project Manager work agreements to secure resources for photogrammetry project activities.
- Confer with the DPC, Project Manager, and Project Engineer on photogrammetry project matters and resource allocations.
- Act as the primary liaison with the DPC.
- Prioritize photogrammetry projects within OoP.
- Schedule photogrammetry projects and maintain photogrammetric project status databases.
- Receive Request for Photogrammetric Services and assign work to the appropriate OoP Unit.
- Monitor and maintain OoP databases.

Flight Planning

The Flight Planning Unit is staffed with surveyors within the Planning and Aerotriangulation Branch in OoP.

It is the responsibility of the Flight Planning Unit to:

- Assign mapping and aerial photography service contract order numbers.
- Review mapping limits and requested products submitted by the DPC on the Request for Photogrammetric Services.
- Obtain resource grade base-maps of an area where engineering grade photogrammetry mapping is requested.
- Plan the flight lines and the photo control layout for all precision photography.
- Produce working maps for field crews and aerial photography contractors.
- Provide approximate coordinates of all planned photo control.
- Produce the contract order letter.
- Perform quality checks and contract compliance checks on photographic products.
- Monitor and contribute to OoP databases.

Aerotriangulation

The Aerotriangulation Unit is staffed by surveyors and photogrammetrists within the Planning and Aerotriangulation Branch of OoP.

It is the responsibility of the Aerotriangulation Unit to:

- Plan and execute photogrammetric control densification (Aerotriangulation).
- Work with the DPC to resolve photo control issues.
- Review and approve flight plans.
- Assist in checking the quality of the photography.
- Maintain a camera database.
- Manage aerotriangulation records.
- Monitor and contribute to OoP databases.

Quality

The Quality Branch is staffed with surveyors and photogrammetrists in OoP.

It is the responsibility of the Quality Branch to:

- Perform QC/QA when appropriate.
- Produce digital topographic and planimetric mapping, digital orthophotos and other products by using photogrammetric methods.
- Perform accuracy checks on all photogrammetric mapping produced by or for OoP.
- Check photogrammetric mapping for compliance with the Department's CAD standards.
- Monitors and contributes to OoP databases.

Digital Terrain Data

The Digital Terrain Data Branch is staffed with surveyors in OoP.

It is the responsibility of the Digital Terrain Data Branch to:

- Check mapping for digital terrain model (DTM) adequacy.
- Create DTMs from photogrammetric mapping.
- Incorporate field survey data into the photogrammetric DTMs.

Contract Administration

The Contract Administration for OoP contracts is done by the OoP unit that has expertise in the technical objective of the contract.

It is the responsibility of Contract Administration to:

- Ensure that all relevant processes, workflows, and specifications stated in this chapter are complied with.
- Provide management and oversight for all Caltrans photogrammetry contracts.
- Assign photogrammetric compilation not performed by the Quality Unit to contract compilation resources.
- Develop and administer contracts for the production of photogrammetric products.

13.4 Initial Photogrammetry Contact

The Project Manager shall consult with Surveys and the DPC on the need for photogrammetry products and services as the work plan is being developed. To make this determination, the Project Manager shall meet with all the functional units that will be participating in the project to gather the information necessary to determine if photogrammetric mapping will be required and to accurately define the scope of that mapping. The Project Manager shall provide complete project information such as scope, products, the use of the products, and schedule to the DPC so that existing terrain data can be researched and utilized, and/or a Request for Photogrammetric Services can be prepared and forwarded to OoP.

Fully defining the scope of a photogrammetry project at the earliest stage possible results in fewer changes and has a positive effect on the entire process. Expanding the mapping limits in areas where there is some uncertainty may be better than performing additional mapping later in the project life cycle.

Once the Project Manager confirms that the project will require photogrammetric mapping the Project Manager in conjunction with the Project Engineer shall:

- Define the area to be mapped.
- Establish the priority level and the proposed schedule of delivery of the photogrammetric mapping.

The Project Engineer shall contact the DPC in a timely manner to initiate the photogrammetry work. The areas to be discussed at that meeting shall include:

- The area to be mapped.
- The project datums.
- Potential safety problems.
- Scale of the final mapping.
- The required photogrammetric deliverables and delivery dates.
- The preparation and submittal of the Request for Photogrammetric Services.

13.5 Request for Photogrammetric Services

All photogrammetric services are initiated by a written request from the Project Engineer. Requests should be submitted to the DPC on a Request for Photogrammetric Services form for review and approval. The DPC then sends the request to OoP. See OoP's intranet web site for a downloadable version of this form.

The Request for Photogrammetric Services shall contain the following information:

- Requestor's name, phone number and functional area.
- Approximate mapping limits, defined as thoroughly as possible, to be refined after photography is obtained.
- DTM limits, if different from mapping limits.
- Expenditure authorization(s) and special designation(s).
- County, Route, Post Mile, and key intersections for the beginning and ending of the photogrammetric project.
- Horizontal and vertical datums.
- State Plane Coordinate zone.
- Caltrans Design Plane.
- Photogrammetric products required.
- List of data furnished with request.
- List of existing mapping to be edge-tied.
- Date the photogrammetric products are required. The DPC shall confirm the date with the Photogrammetry Project Management Coordinator.

STATE OF CALIFORNIA - DEPARTMENT OF TRANSPORTATION

REQUEST FOR PHOTOGRAMMETRIC SERVICES

DPD - 3009 (PROPOSED) REV. 10/6/05

Date ________

Requestor ________________

Division ________ Mail Stop ________________

Phone ________ E-mail ________

Project Manager ________________

Phone ________ E-mail ________

Date all Material Required* ________

TO BE COMPLETED BY DES:

Project ASC ________

Aerial Photo ASC ________

Models ________

Material Requested:

________ Topographic Map SCALE ________

________ DTM C.I. ________

________ Descartes Rectification

________ Ortho Rectification

County ________ **District** ________

Route ________ **Charge** ________

PM ________ **EA** ________

Project in delivery plan dated** ________

PS&E Date (MS-380) ________

Other or comments ________________

DATUM

English or Metric ________

Horizontal ________

Vertical ________

CT Design Plane ________

Zone ________

Data Furnished:

Location: / ________________

________ District Map Showing Location

________ Digital Mapping Limits

________ Flight Plans (1"=100') ________ Control Plans

________ ASC of Existing CADD File

________ Edge Ties, ASC # ________________

________ Photo Control ________ DTM Field Surface

________ Other ________________

Oversight Review: ________ Item A ________ Item B ________ Item C ________ CT Design

Name ________________ Date ________ Phone ________

District Photogrammetry Coordinator

________ Expedite Project (2km or less)

Approved ________________ Date ________

District Surveys Manager

Approved ________________ Date ________

DES Photogrammetry Project Management Coordinator

*Date should be consistent with the *User's Guide to Photogrammetric Products and Services* Time Requirements.

**If not in Delivery Plan, please indicate if this is this a minor A or B job in comment field.

13.6 Office Preparation

The Photogrammetry Project Management Coordinator shall assign an aerial service contract number (ASC#) and assign the project to the Flight Planning Unit of the Planning and Aerotriangulation Branch after receiving the Request for Photogrammetric Services.

The Flight Planning Unit shall conduct or oversee the production of all precision photography flight plans.

The Aerotriangulation Unit shall review and approve all flight plans for use in obtaining precision aerial photography prior to distribution.

13.6-1 Flight Planning

Flight plans are maps depicting the location of the photo control and the beginning and ending of flight lines upon which aerial photography is to be obtained. A flight plan must adequately convey the required information to both the field crews and the aerial photography contractor.

The goal of the flight planning process is to produce a flight plan that will provide the best balance between safety, accuracy and economy. This is accomplished by considering the location and amount of photo control to be set, the number of photographs to be obtained, and the required accuracy of the photogrammetric products requested.

In order to produce an effective flight plan the Flight Planning Unit shall have an understanding of neat models, stereoscopic coverage, relief displacement, and control schemes. See Appendix 13B for more information on these topics.

13.6-2 Planning Basemap

The Flight Planning Unit shall initiate the flight planning process by obtaining an appropriate basemap. These basemaps traditionally have been United States Geological Survey (USGS) 7.5-minute quadrangle maps.

High altitude uncontrolled photography may be used to add information for the flight planning process in areas that have undergone significant changes since the USGS quads were produced. A base map that is a digital composite of USGS quad maps for elevation and location purposes and part aerial photography for increased detail has become the standard for flight planning. After the planning basemap has been obtained or produced, the approximate mapping limits from the Request for Photogrammetric Services are plotted on the map. The improved detail achieved using a composite map helps in accurately plotting the mapping limits and in selecting target positions that afford easy access and safety. Satellite images or other imagery can also be used to achieve a more detailed flight planning basemap.

Note: The accuracy of the basemap coordinates is approximately 60 feet horizontally and 30 feet vertically. Coordinates derived from these maps are intended for reference only and are not meant to be the definitive location of the required photo control.

13.6-3 Control Schemes

The Flight Planning Unit shall select an appropriate control scheme. The control scheme selected by the Flight Planning Unit depends on what photogrammetric products will be produced and their required accuracy. It also depends on the following factors:

- Safety.
- The size and shape of the area to be mapped.
- The accuracy requirements of the photogrammetric products required.
- The terrain of the project area.
- Accessibility to areas where photo control is to be placed.

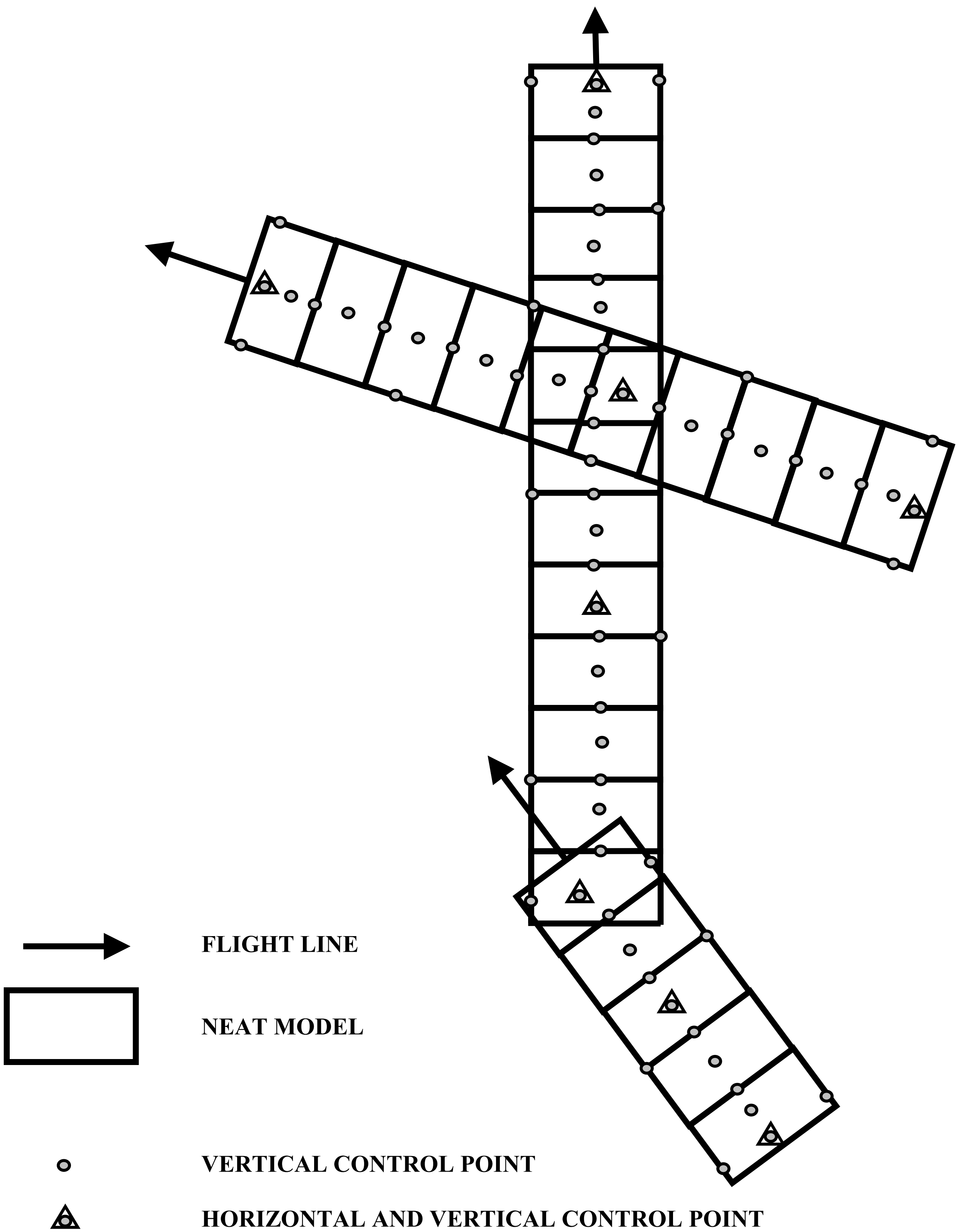
The Flight Planning Unit will plan adequate photo control in order for the Aerotriangulation Unit to accurately perform their tasks. Through a combination of practical experience and research results OoP developed the control schemes shown in the examples labeled 13A-13D on the following pages. The Flight Planning Unit will select the appropriate control scheme or combination of schemes for individual jobs. The amount of photo control required for each control scheme is necessary to reliably achieve the required accuracy for the products to be produced The flight lines are then laid out on the planning basemap in accordance with that control scheme.

The ideal photo control positions, as shown on the example schemes, are occasionally not selected because adequate locations close to the ideal positions may be selected by the Flight Planning Unit. The Flight Planning Unit considers the following when considering locations of the photo control:

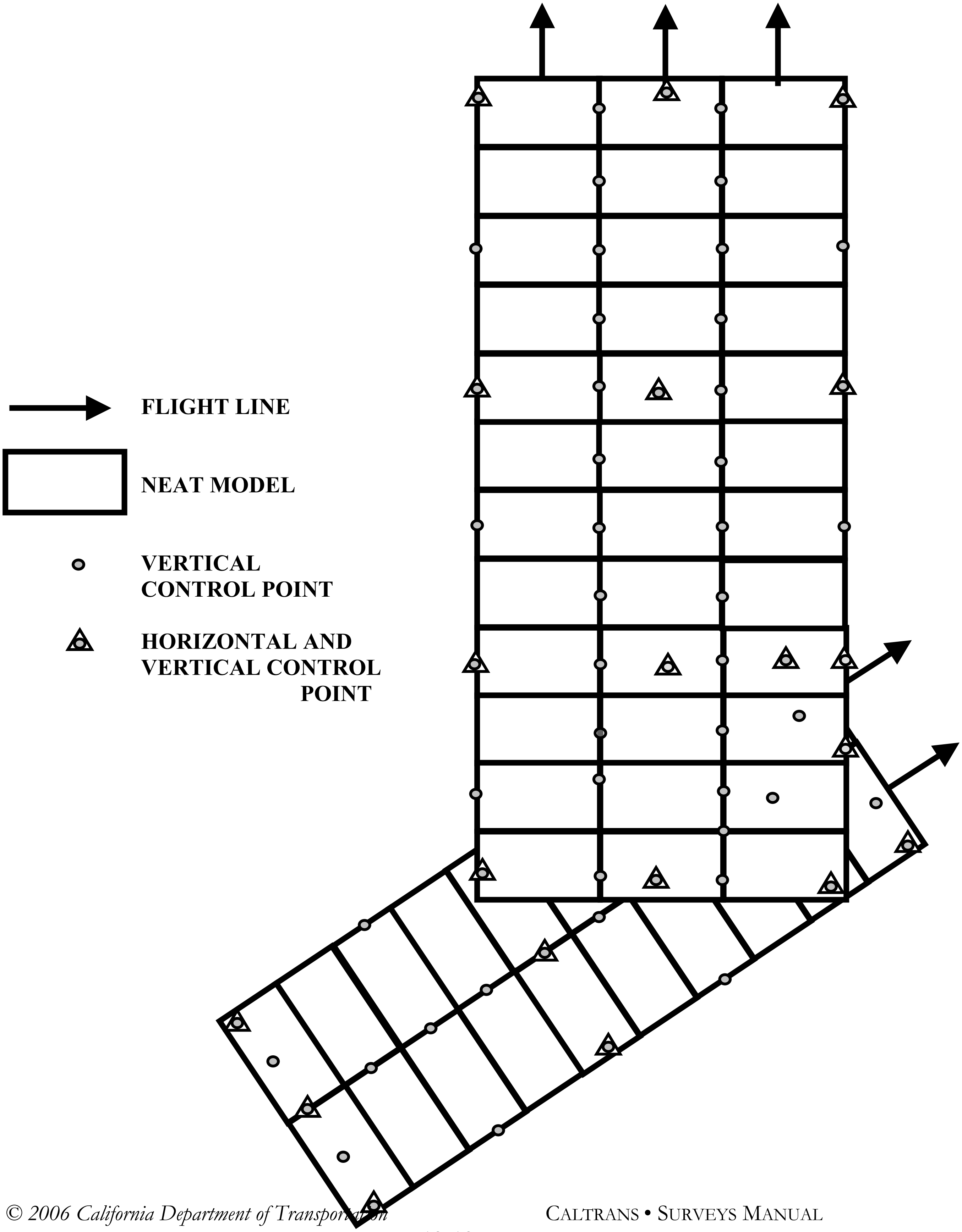
- A safe work zone, such as a surface street with light traffic, as opposed to a freeway.
- Easier access with vehicles, such as a parking lot instead of a golf course.
- A hard surface upon which a durable target can be painted, as opposed to a location that would require a cloth target.
- Other advantages that may be project specific.
- Or any combination of the above.

The following pages depict examples of control schemes and provide information on the purpose of each.

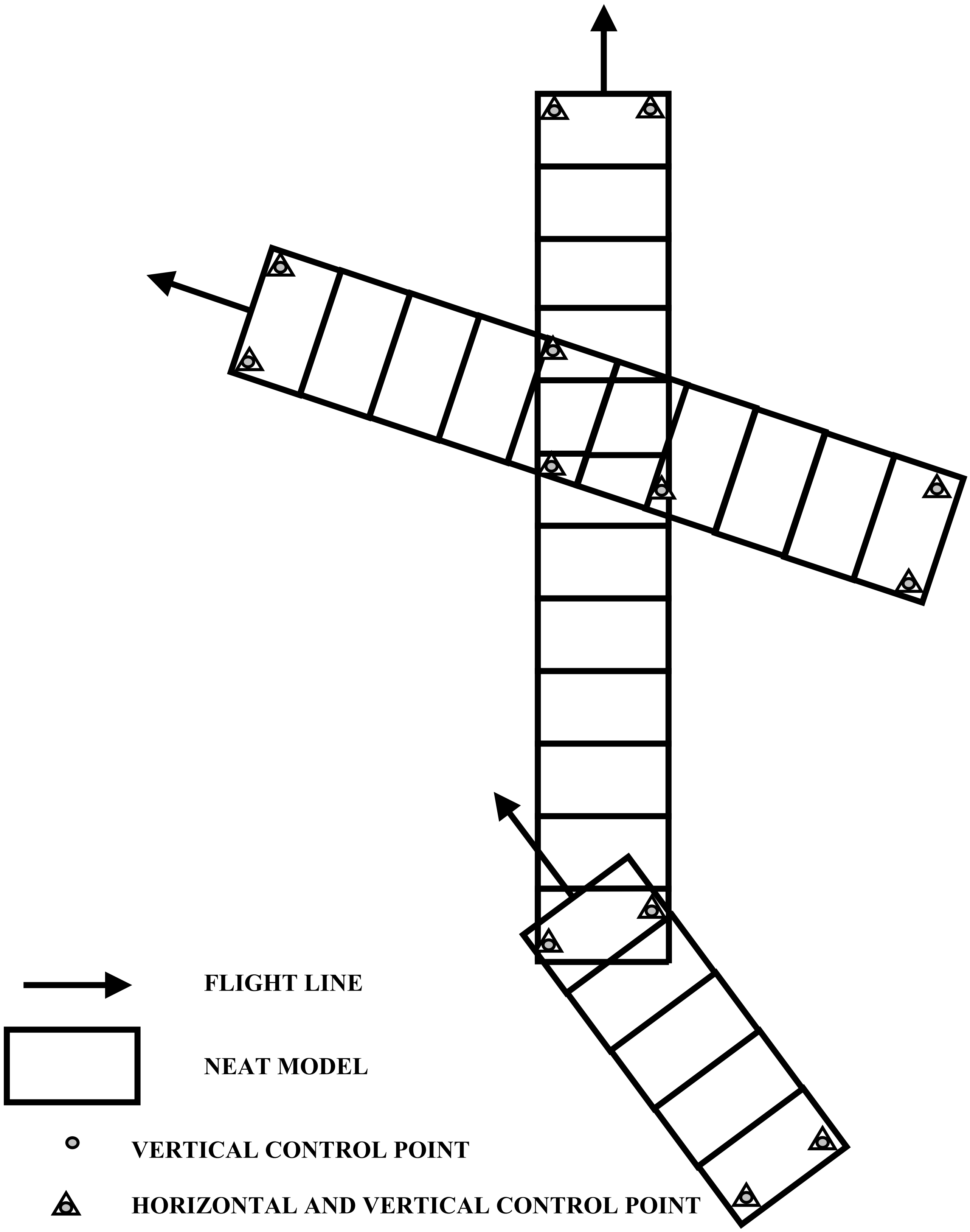
TYPICAL CONTROL CONFIGURATION STANDARD STRIP PHOTOGRAPHY



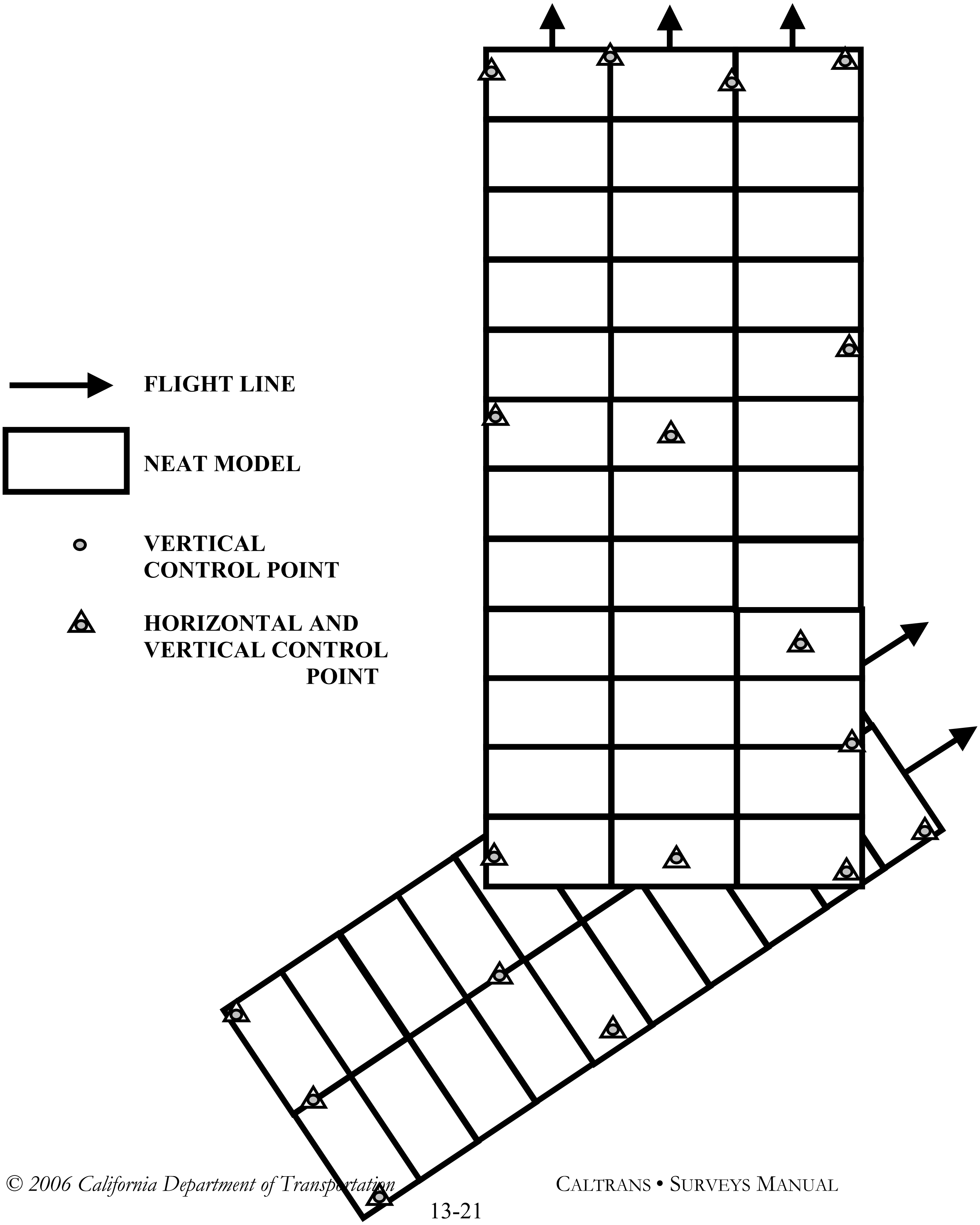
TYPICAL CONTROL CONFIGURATION STANDARD BLOCK PHOTOGRAPHY



TYPICAL CONTROL CONFIGURATION
STANDARD STRIP PHOTOGRAPHY FOR AIRBORNE GPS



TYPICAL CONTROL CONFIGURATION STANDARD BLOCK PHOTOGRAPHY FOR AIRBORNE GPS



13.6-4 Mapping Scale

The following chart depicts various mapping scales and their applications.

Mapping Scale and Application

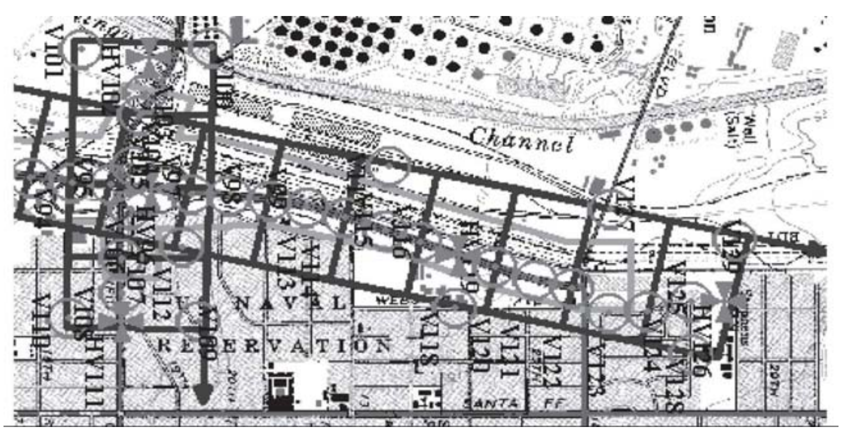
MAP SCALE	**CONTOUR INTERVAL**	**MAPPING APPLICATION**
1”= 20’	1 foot	Bridge and Structure Sites
1”= 50’	2 foot	Standard Mapping for Engineering Design (PS&E)
1”= 100’	5 foot	Environmental, Feasibility, and Planning (PA&ED)
1”= 200’	10 foot	New Route Corridor Studies

13.7 Flight Planning Deliverables

OoP shall provide the flight planning deliverables to the DPC. The following is the standard delivery package:

- Three copies of the final flight plan. This is a plot of the basemap with the flight lines and the planned locations of the photo control depicted thereon.
- The planned coordinates (in the project datum) for the photo control in both digital and hardcopy format.
- The positional tolerances for movement of the photo control from the planned coordinates, usually shown on the flight plan.
- A copy of the order letter for the aerial photography contract.

The DPC shall review the final flight plan. Any concerns or questions with the flight plan should be resolved with the Flight Planning Unit at this time.



13.8 The Field Package

In cooperation with Surveys Field Office, the DPC assists in assembling information and materials required for a field crew to successfully complete a photogrammetric control survey including but not limited to the following:

- Three copies of the flight plan showing the planned photo control locations and the positional tolerance for movement of the photo control.
- Data collector files containing the tentative photo control locations and coordinates.
- Control recovery information, and coordinate and/or elevation values.
- Datum and Zone Information.
- Right's of Entry information.
- Property owner contact information.
- Local street maps.

Items required may vary depending on the project area.

13.9 Field Surveys

All photo control surveys shall be conducted in accordance with all of the pertinent requirements of Chapter 5, Classif cations and Accuracy Standards.

All photo control targets shall be in place before photography is acquired.

It is recommended that all photo control surveys be completed before photography is acquired.

13.9-1 Placement of Photo Control

Safety

Safety of the field personnel shall be the top priority when placing photo control targets and conducting photo control surveys. Refer to Chapter 2, "Safety" for safety information.

Setting Photo Control Targets

Wherever possible the Party Chief shall set the photo control targets on paved surfaces or other hard surfaces. The targets shall be painted with flat black and flat white paint. If it is not possible to set a target on a paved surface or other hard surface then a cloth target shall be set.

When the location of the target is likely to be disturbed by vandalism, construction, agricultural or other activities, the Party Chief shall set a durable reference monument and the target placed accurately on this mark.

Photo Control Target Placement Tolerance

Each flight plan shall list a positional tolerance that limits the movement of the proposed photo control target from the flight plan location. This is especially important with respect to the wing points. Properly positioned wing points are critical to the aerotriangulation process. In general, the Party Chief may move wing points parallel to the flight line, but should avoid moving the wing points perpendicular to the flight line as the wing point may then fall outside the photography or too close to the middle of the photography, reducing the wing point's effectiveness.

If the limits shown on the flight plan must be exceeded, the Party Chief shall contact the DPC. The DPC, in conjunction with OoP, will determine the best location for alternate photo control.

Photo Control Target Location Tips

The care exercised by the Party Chief in the selection, targeting and positioning of the photo control affects all subsequent photogrammetric processes and the final delivered products.

The planned location of the photo control provided with the flight plan will direct the Party Chief to the general area where the targets are to be placed. Once in the general area, the positional tolerance given on the flight plan and the following tips should be used by the Party Chief to select the final target locations.

Tips on selecting locations for the setting of photo control targets:

- Use the flight plan to anticipate the position of the aircraft and avoid tall objects between the plane and the targets. Stand on the proposed target locations and imagine the plane traveling along the flight line while looking for obstructions.

- Avoid tall objects that may obstruct the image of the target in one or more exposures. If there are unavoidable tall objects near a target then move the target within the tolerances indicated on the flight plan or set additional targets to ensure that the area will be properly controlled for the subsequent photogrammetric processes.
- Avoid shaded areas. Visit the tentative target locations at the approximate time photography is to be obtained. Relocate the target to a sunny spot if there are shadows in the planned location. Set additional targets if needed.
- Avoid overhead wires. It is difficult for the Aerotriangulation Unit to measure the elevation of the photo control when there are wires suspended above the targets.
- Remove grass from under cloth targets so that the growth of the grass doesn't distort the cloth target between the time it was set and the date of photography. Check the cloth target for "ballooning" caused by growing vegetation immediately prior to ordering photography.
- Choose a level spot if available. A hard surface that will accept paint is ideal, as painted targets are more durable.

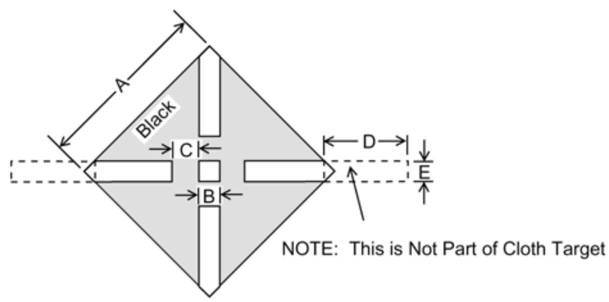
Photo Control Target Orientation Tips

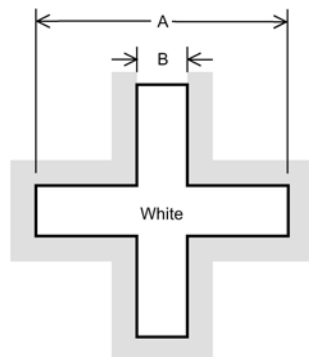
Tips on the orientation of the photo control targets:

- When possible, photo control targets should be placed so that the legs are aligned perpendicular and parallel to the flight line.
- When photo control targets must be placed on a steep slope, the target should be oriented so that two of the legs that form a straight line lie along the slope at approximately the same elevation.

13.9-2 Target Specifications

Cloth Target





Target Sizing

	CLOTH TARGET OR PAINTED REPLICA		CROSS	CROSS
PHOTO SCALE	**1:3000**	**1:6000**	**1:12000**	**1:24000**
A	45 in	45 in	12 ft	24 ft
B	4 in	4 in	1 ft	2 ft
C	7 in	7 in		
D	Not Required	24 in		
E	Not Required	6 in		

13.9-3 Accuracy Requirements

The accuracy requirements for photogrammetry surveys stated in Chapter 5, Classif cations and Accuracy Standards shall be met.

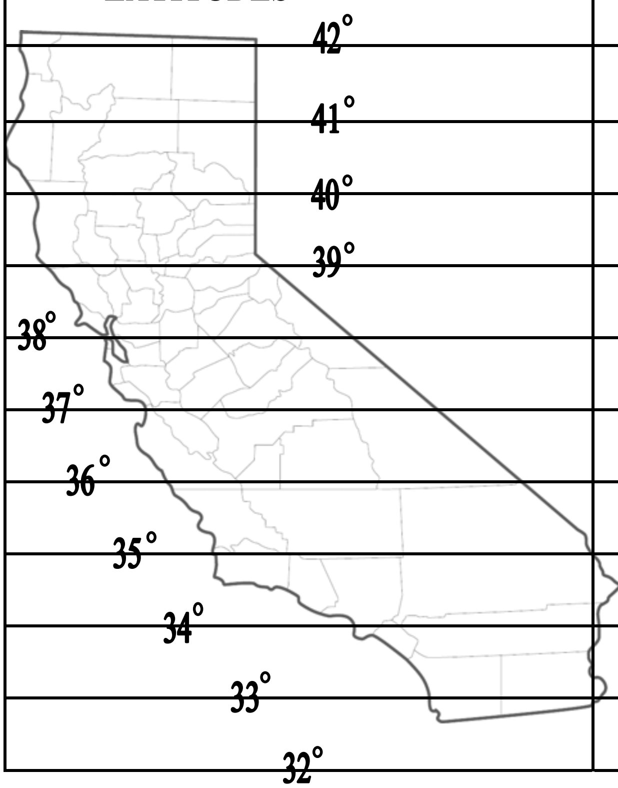
All observations on photo control shall be adjusted in a least squares network.

Whenever possible, observations on photo control should be adjusted in a single least squares adjustment.

13.9-4 Solar Altitude Angle and Effects on Aerial Photography

The DPC should advise Surveys in scheduling field surveys to avoid obtaining photography when the solar altitude angles are less than 30 degrees. Precision aerial photography is normally scheduled between 10 AM and 2 PM when the solar altitude angle is highest in the sky. A minimum angle of 30 degrees above the horizon is necessary to avoid long shadows in areas with tall buildings, tall trees, and/or steep terrain. If photography must be acquired during these periods, the DPC should contact OoP for advice. The following chart indicates the dates and times when photography should NOT be taken for various latitudes.

Dates and Times the Solar Altitude Angle is Below Degrees 30°



BETWEEN LATITUDES	Fly Between 10am to 2pm	Do NOT Fly	Fly Between 11am to 1pm
	Feb 22-Oct 17	Nov 9-Feb 7	Feb 8-Feb 21, Oct18-Nov8
	Feb 19-Oct 18	Nov 12-Feb 4	Feb 5-Feb 18, Oct 19-Nov 11
	Feb 16-Oct 19	Nov 15-Feb 1	Feb 2-Feb 15, Oct 20-Nov 14
	Feb 14-Oct 23	Nov 21-Jan 29	Jan 30-Feb 13, Oct 24-Nov 20
	Feb 12-Oct 27	Nov 27-Jan 23	Jan 24-Feb 11, Oct 28-Nov 26
	Feb 10-Oct 31	Dec 3-Jan 17	Jan 18-Feb 9, Nov 1-Dec 2
	Feb 8-Nov 5	Dec 9-Jan 11	Jan 12-Feb 7, Nov 6-Dec 8
	Feb 6-Nov 9	Dec 15-Jan 5	Jan 6-Feb 5, Nov 10-Dec 14
	Feb 2-Nov 16	Dec 15-Jan 5	Jan 6-Feb 1, Nov 17-Dec 14
	Jan 29-Nov 19	Dec 15-Jan 5	Jan 6-Jan 28, Nov 20-Dec 14

NOTE: This chart is approximate and was developed from solar altitude nomograms for Pacific Standard Time.

13.9-5 Obtaining Aerial Photography

It is the responsibility of Surveys or the Party Chief to keep the DPC informed of the progress of the job so that the scheduling of the photography can be coordinated.

The DPC shall be in contact with the aerial photography contractor prior to the anticipated date of photography to coordinate the scheduling of the flight.

On the day of photography, before the photography is obtained, the Party Chief shall verify that the photo control targets are in good shape. If any target is missing, a replacement target shall be set prior to photography.

Day of Photography Responsibilities:

District/Region Photogrammetry Coordinator:

- Initiates the aerial photography flight.
- Consults with the Party Chief regarding the weather conditions at the project site.
- Informs the Party Chief when the photography has been obtained.

Party Chief:

- Maintains communication with the DPC regarding weather conditions.
- Informs the DPC of any disturbed targets and sets replacement targets before photography is obtained.
- Ensures that the GPS Base Stations are running if required for Airborne-GPS Photogrammetry.
- Checks the targets to ensure that they are in good shape for the photography.

13.10 Post-Photography Processes

Stereo photographs are the foundation of all photogrammetric products. Good image quality is vital to the efficient and accurate use of photogrammetric techniques.

The Flight Planning Unit shall examine the photography for endlap coverage, sidelap coverage, stereo coverage, and image quality.

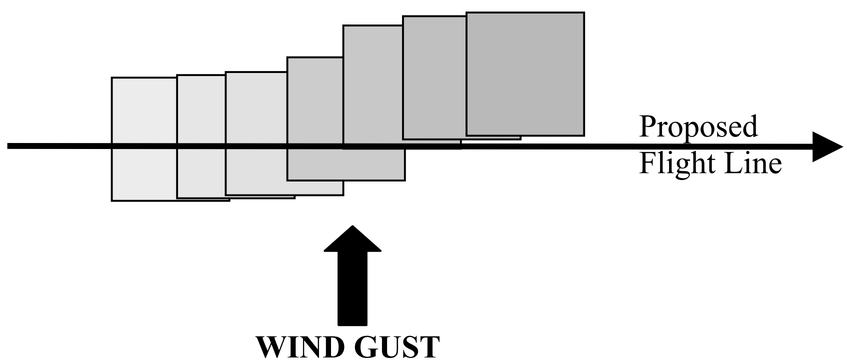
13.10-1 Endlap, Sidelap, and Stereo Coverage

The Flight Planning Unit shall check the aerial photography for the endlap and sidelap coverage between the photos. If the photography lacks adequate endlap and sidelap coverage, then the Flight Planning Unit shall request the photography to be redone. Ideally, the endlap coverage will be 60%; however, endlap coverage ranging from 55% to 65% will produce adequate results. The sidelap coverage percentages will vary with the photogrammetry job.

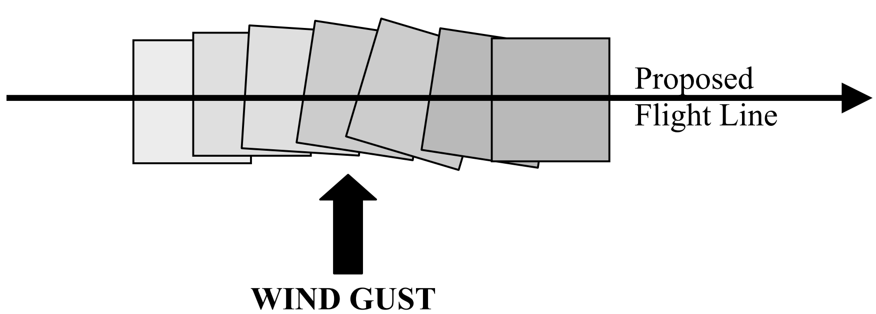
The Flight Planning Unit shall also verify the stereo coverage within the project limits. It is important to have adequate stereo coverage since an object cannot be mapped if it appears in only a single photograph.

Stereo coverage and endlap can be adversely affected by the flight trajectory of the aircraft. These are most commonly manifested in either "crab" or "drift". "Crab" occurs when constant corrections to the flight path cause the photos to twist with respect to one another. "Drift" occurs when the plane deviates from the intended flightline. Examples of each are shown below.

Example of Drift

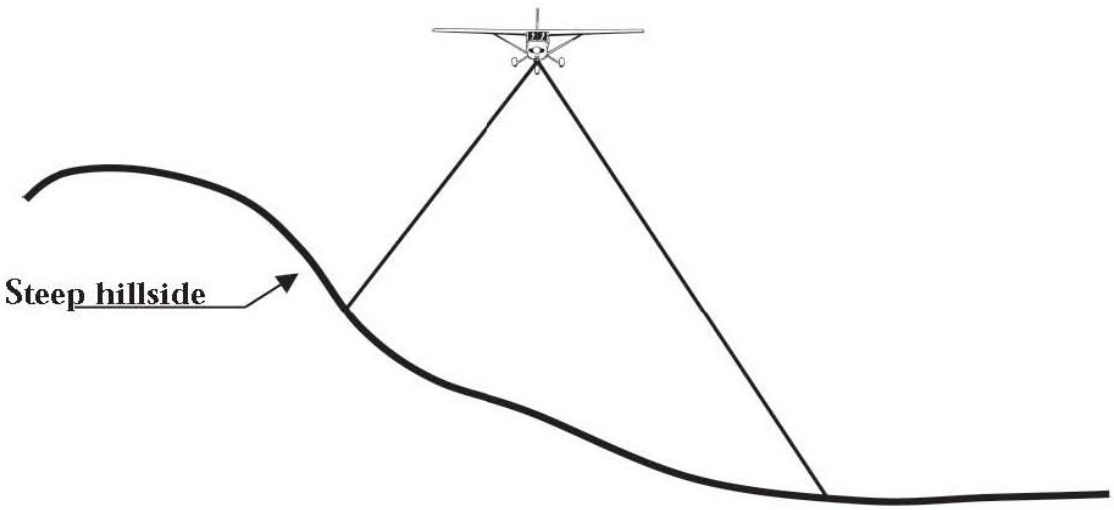


Example of Crab

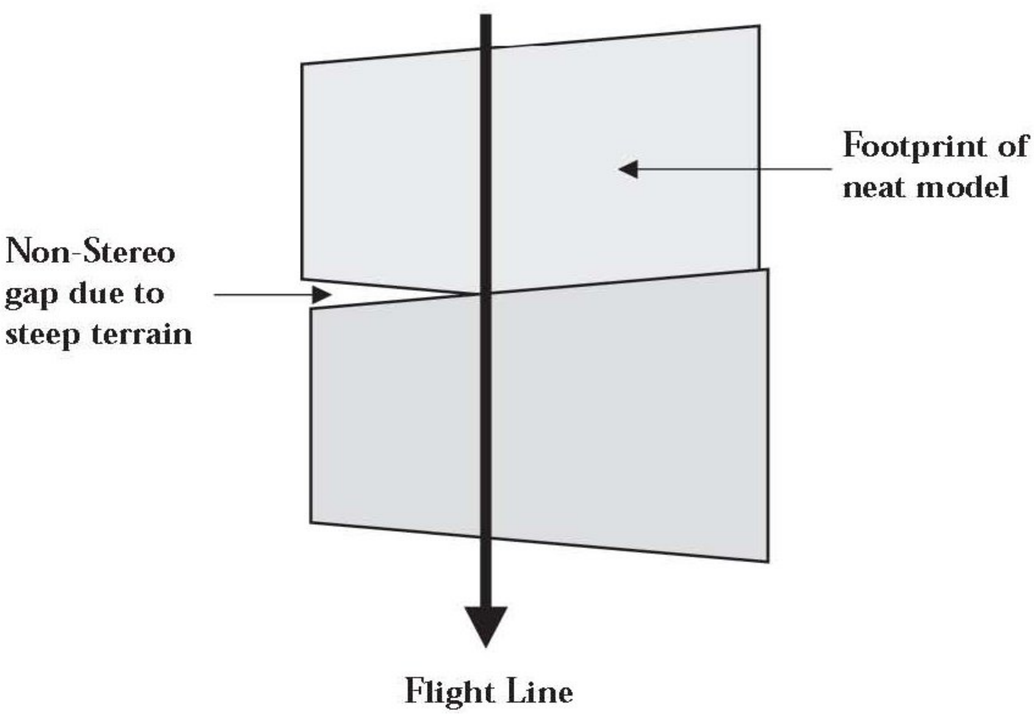


In steep terrain the endlap coverage may need to be increased to avoid sliver shaped gaps in stereo coverage between exposures.

SIDE PROFILE VIEW



TOP OVERHEAD VIEW

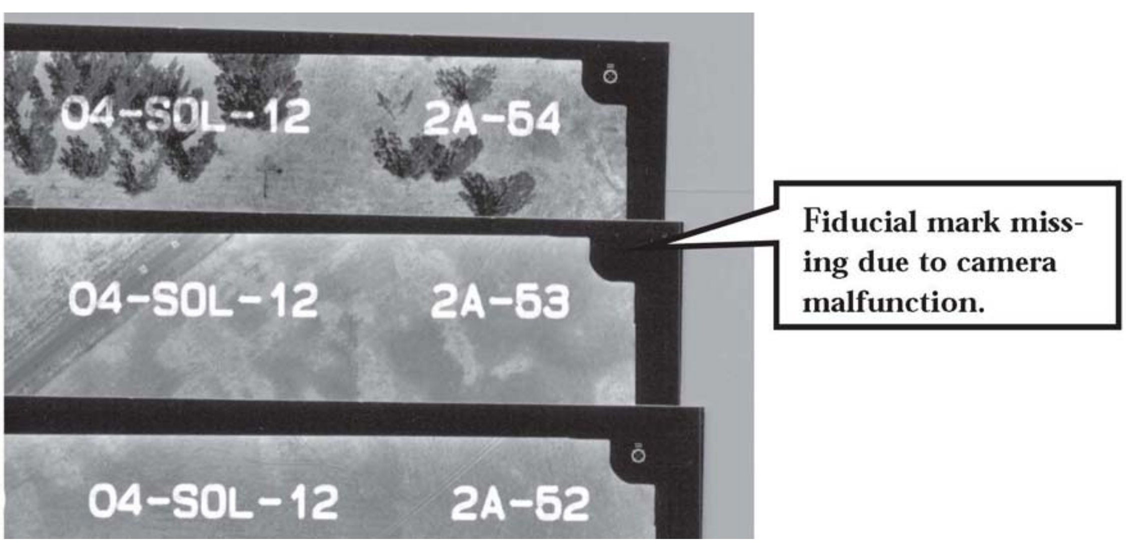


13.10-2 Image Quality

After the Flight Planning Unit has determined that adequate coverage has been achieved, they shall check the quality of the images. Even if the photographs cover the required area, good mapping can be difficult to produce if features on those photographs are not clearly visible.

The qualities the Flight Planning Unit shall check are:

- Image Motion: Elongation of features on the photograph caused by the movement of the aircraft during exposure.
- Halation: Spreading of an image beyond its proper boundaries, particularly common for bright or reflective objects.
- Graininess: Results from poor developing techniques yielding large grain size, decreasing the resolution of the photograph.
- Contrast: The difference in density between the whitest and the blackest areas of the photograph being either too great or too small, can cause problems seeing detail, especially in shadowy areas.
- Hot Spot: A bright area of low detail caused by low sun angles.
- Fiducial mark defects: Fiducial marks are imaged by the camera on each exposure and are used to orient photogrammetric instruments to the camera coordinate system. If these fiducial marks are not present photogrammetric measurements cannot be made.



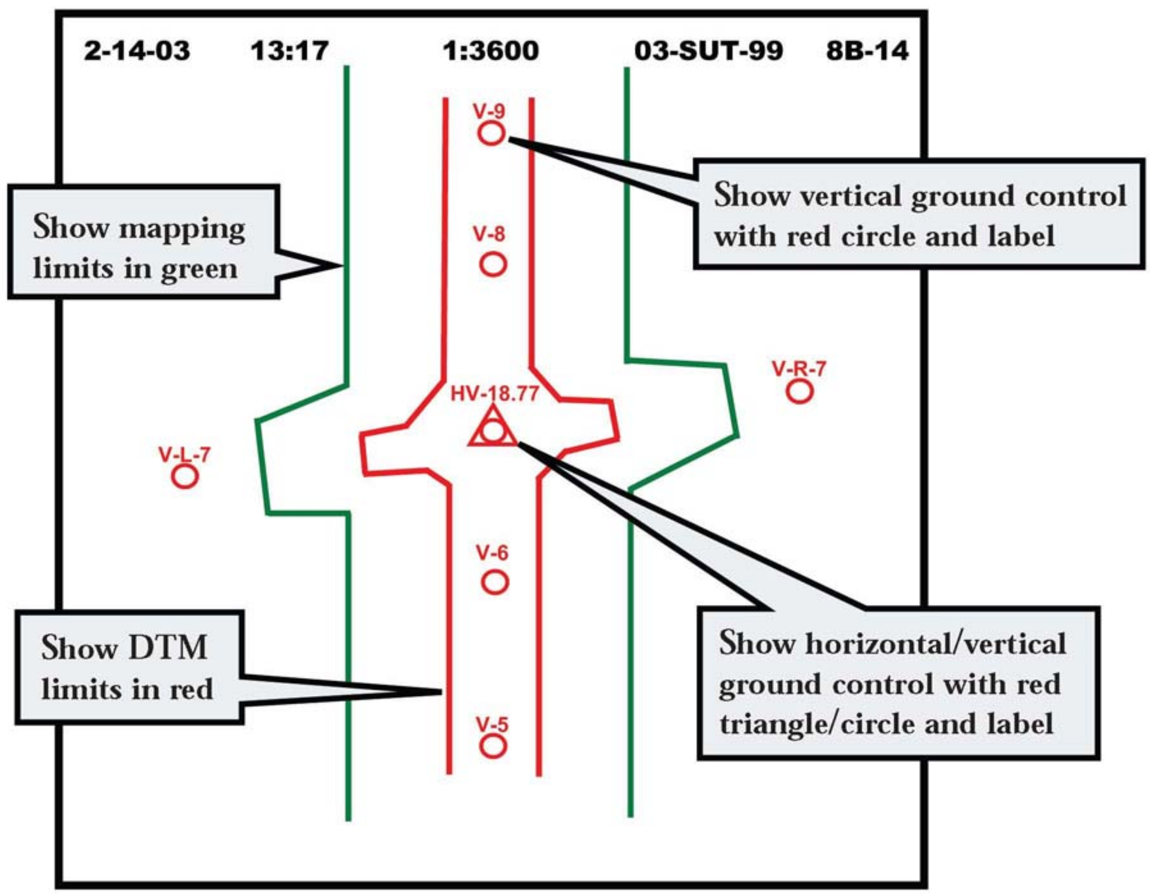
13.10-3 Marking Control Prints

Surveys shall produce annotated control prints to aid OoP in the location of the photo control in the photography.

Annotated control prints for delivery to OoP are produced from a set of edited contact prints with the following information marked on each photograph:

- All vertical photo control indicated by a red 0.02’ diameter circle.
- All horizontal control indicated by a red triangle, 0.03’ per side.
- All photo control names neatly printed in red text oriented parallel to the annotation at the top of the photograph.

EXAMPLE OF ANNOTATED CONTROL PRINT



The Project Engineer in conjunction with the DPC shall mark the following limits:

- Mapping limits shown in green and shall form a continuous line over every other photo.
- DTM limits, if different from the mapping limits, shown in red and shall form a continuous line over every other photo.

Photo Identified Control

Occasionally photo control cannot be located in the photography, requiring that a photograph identified control point be established. The Aerotriangulation Unit shall select a distinct point readily identified on both the ground and in the photographs to be surveyed by the Party Chief. The Party Chief shall produce a clear and detailed sketch indicating the field location of this control point. A digital photograph may also be produced.

13.10-4 Delivery of Materials and Information to the Office of Photogrammetry

Surveys shall ensure that the photo control data, control prints, and any other pertinent information are delivered to the DPC in a timely manner.

The information delivered shall include:

Control Prints

Delivered and marked as described in section 13-10.3.

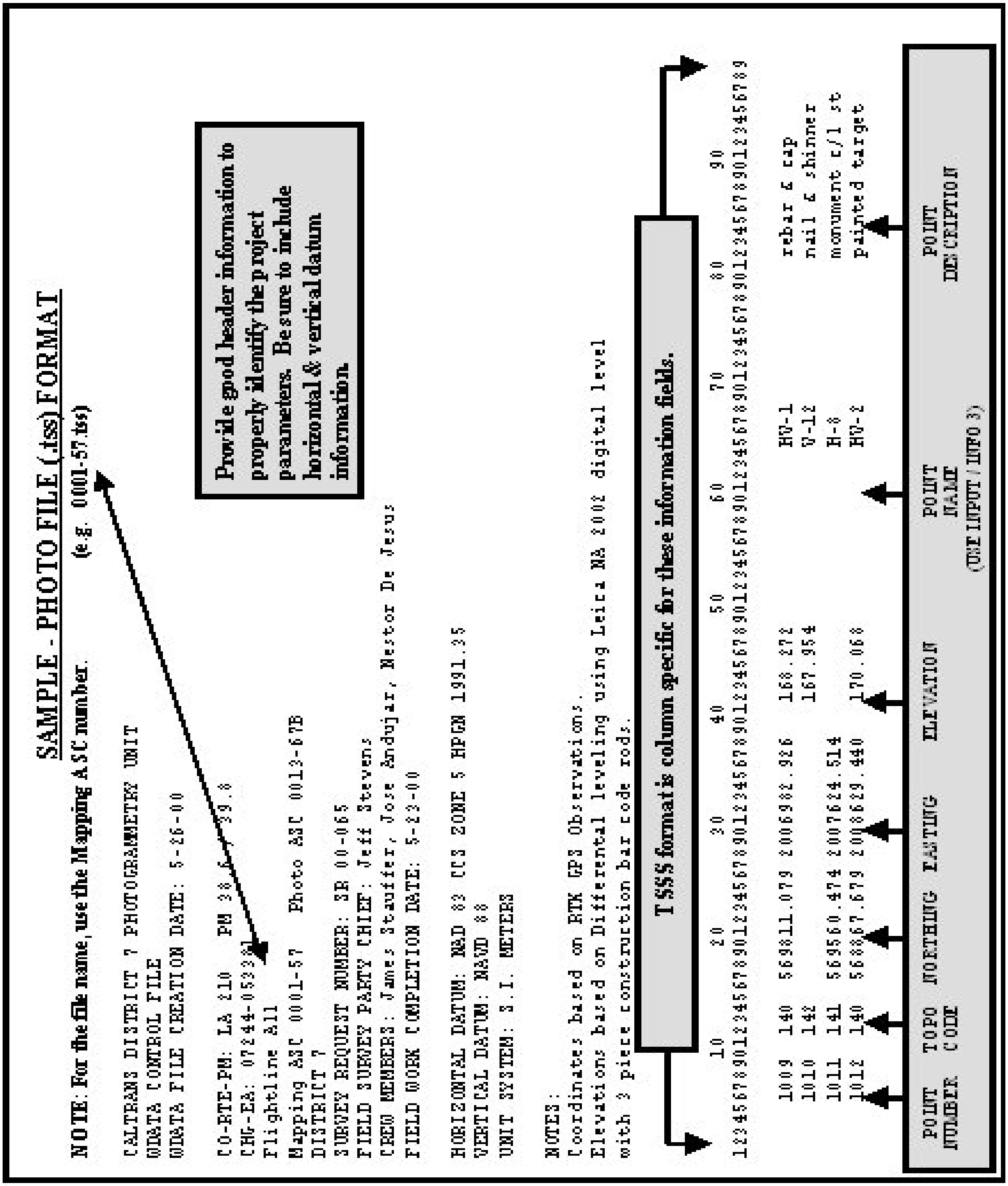
Standard Errors

Surveys shall provide adjustment results indicating the standard errors for the photo control so that proper weights can be applied to the photo control in the aerotriangulation process.

TSS File

Surveys shall provide the photo control data to the DPC electronically in the Department's standard format.

The header of the file should include the information shown in the following example.



EXAMPLE OF TSS FILE

Shipping with Tracking

The DPC shall ship the control prints via a carrier that provides tracking of parcels to minimize the chance that they are lost in shipping.

It is recommended that control prints be shipped using an overnight service. If a receiving record is not received from the OoP the next morning, tracking should be initiated

13.11 Office of Photogrammetry Mapping Processes

The Aerotriangulation Unit receives the photo control information package from the DPC and is responsible for densifying the control to produce properly controlled stereo models.

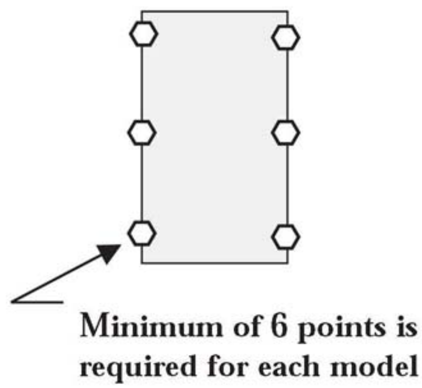
13.11-1 Aerotriangulation

Aerotriangulation, also known as analytic bridging, uses mathematical concepts to densify the photo control network with artificial points, also known as analytic points. The analytic points are added to produce adequate control for each stereo model.

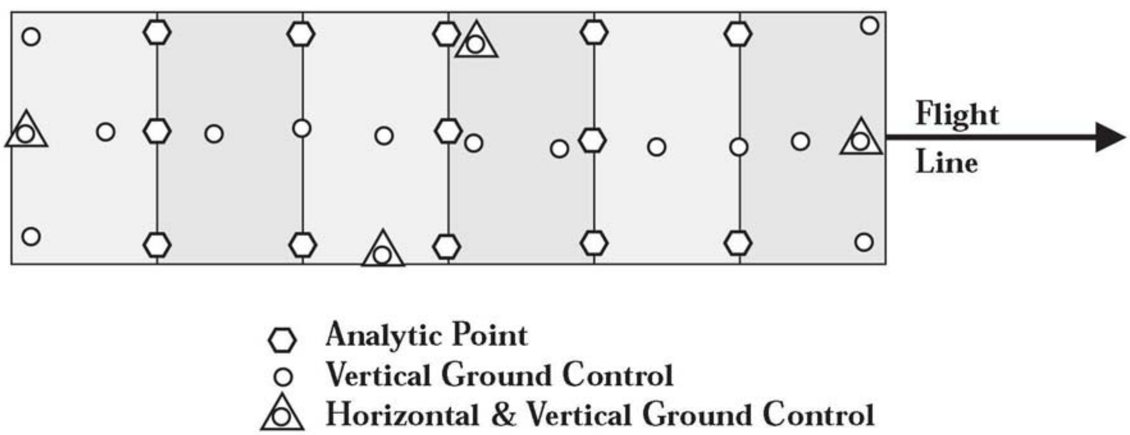
Requirements for the analytic points combined with the photo control:

- The analytic points shall have a maximum diameter of 50 microns.
- The combination of photo control and analytic points shall be a minimum of 7 points per neat model.
- There shall be an analytic point or photo control at each corner of all neat models.
- The combination of photo control and analytic points shall be a minimum of 3 points in common between two adjacent neat models.
- Additional Tie points shared between flight lines should be created as geometrically warranted between overlapping flight lines.

EXAMPLE OF BRIDGED MODEL



EXAMPLE OF BRIDGED FLIGHT LINE WITH GROUND CONTROL



Mensuration

The Aerotriangulation Unit places the photographs into a stereoscopic instrument where the positions of the photo control and the marked analytic points are measured.

Requirements for the mensuration of the fiducial points:

- The affine transformation residuals shall be a maximum of 20 microns for each fiducial point.

- The standard error of the mean of the affine transformation fiducial points shall be a maximum of 6 microns.

Requirements for the mensuration of the photo control and the analytic points:

- The relative orientation shall be achieved prior to mensuration.
- The maximum residual shall be 20 microns on the mensuration of a photo control or analytic point.
- The standard error of the mean shall have a maximum value of 6 microns for the mensuration of the photo control and analytic points.
- No mensuration shall take place outside of a neat model's symmetric plane.

Aerotriangulation Adjustment

The Aerotriangulation Unit processes the measured positions of the photo control and the analytical points with an independent unconstrained adjustment to determine if there are any problems with the photo mensuration.

Any concerns with respect to the aerotriangulation measurements of the photo control and the analytic points shall be resolved. The Aerotriangulation Unit shall examine errors that may have occurred in the aerotriangulation process to resolve any discrepancies.

The Aerotriangulation Unit then places the values of the photo control into the input data in order to perform a constrained adjustment.

Requirements for the analysis of the constrained aerotriangulation adjustment:

- The standard error of the mean of the adjusted image shall have a maximum value of 5 microns.
- The standard error of the mean of the adjusted photo control and analytic point's elevation shall have a maximum value of 1/10,000 of the flying height.
- The standard error of the mean of the adjusted photo control and analytic point's horizontal coordinates shall have a maximum value of 1/15,000 of the flying height.

To complete the aerotriangulation process the position and attitude, or tilt, of the aircraft at each exposure, or exposure station, is determined by the Aerotriangulation Unit by resecting the position from the known photo control. The values of the unknown analytic points are then determined by performing an intersection from two or more exposure stations through the analytic points to the ground.

The Aerotriangulation Unit shall confirm all areas in the aerotriangulation process to resolve any problems with the adjustment results. If the Aerotriangulation Unit is unable to resolve the problems, then the Aerotriangulation Unit shall notify the DPC of the unresolved problems.

The Aerotriangulation Unit shall provide the DPC with:

- A list of the names of the photo control that is suspected of having problems.
- A written description of the possible reasons a problem with the photo control could exist.
- A list of the aerotriangulation residuals on the suspected problem photo control.

The DPC works with Surveys Field Office and the Aerotriangulation Unit to resolve any photo control problems. All potential error sources should be examined before asking the Party Chief to re-observe any photo control. Only as a last resort should the Party Chief be asked to re-observe the photo control.

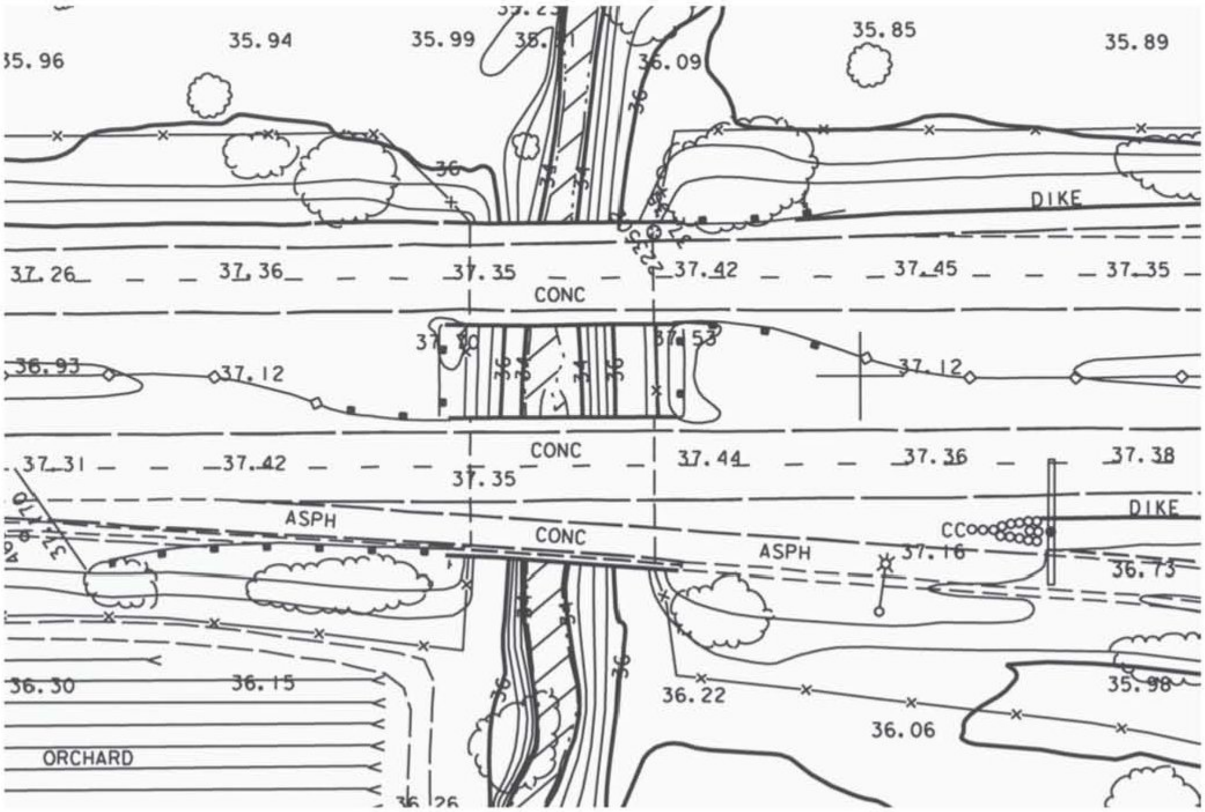
13.11-2 Map Compilation

The production of photogrammetric mapping products begins when aerotriangulation has been completed. There are a variety of photogrammetric mapping products available as indicated in section 13.2-4 of this Chapter and in the Department's User's Guide to Photogrammetric Products and Services. The most common photogrammetric mapping product is 1"=50' scale 3D mapping.

3D mapping is produced by using stereoscopic mapping systems that generate coordinates and elevations for features measured and assigns symbology to those features.

The maps produced are digital three-dimensional vector or point representations of the features photographed. The following is an example of a Department standard 1"=50' scale map.

SAMPLE OF TOPOGRAPHIC MAP



13.11-3 Quality

The Quality Branch shall check the completed mapping to verify that it meets Department's mapping standards.

Mapping Accuracy Standards

The standards used by the Department are the "Specifications for Aerial Surveys and Mapping by Photogrammetric Methods for Highways", prepared by The Photogrammetry for Highways Committee of The American Society of Photogrammetry, for the United States Department of Transportation, Federal Highway Administration, 1968. An excerpt of these specifications can be found in Appendix 13C.

Pre-Check

The Quality Branch begins the checking process by examining the maps for file corruption, errors in symbology, aesthetics, coordinates, elevations, and mapping scales, and to ensure proper coverage. If the pre-check does not reveal significant errors the Quality Branch shall grant preliminary acceptance of the maps, informs the DPC of the maps availability, refers the maps to the Digital Terrain Data Branch for digital terrain model pre-check, and schedules the maps for the comprehensive checking process.

Comprehensive Check

The Quality Branch shall thoroughly check the mapping with a stereoscopic instrument for three-dimensional positional accuracy and compliance with Caltrans' mapping standards. Once errors/omissions have been resolved, the Quality Branch shall grant final acceptance and send the maps to the Digital Terrain Data Branch.

13.11-4 Digital Terrain Models

The Digital Terrain Data Branch is responsible for converting the digital mapping into a three-dimensional digital terrain model (DTM).

Pre-Check

The Digital Terrain Data Branch checks the preliminary maps for significant errors in symbology and accuracy that would have a negative impact on the suitability of the mapping to be converted into a DTM.

Line Styles Converted to Codes

The Digital Terrain Data Branch shall convert the mapping symbology into a coordinate list with description codes. The coordinates and associated codes are imported into a DTM software package to produce a three dimensional DTM.

Field Data

Additional survey data may be included into the DTM produced by the Terrain Data Branch. The survey data shall be an edited, checked DTM provided by District Surveys to the DPC who will then send it to Digital Terrain Data Branch. The document, "Standard Delivery Format for Precise Field Survey Data," can be located at OoP's intranet web site.

13.11-5 Final Deliverables to District

OoP will provide the final photogrammetric products to the DPC. Products delivered to the district may include any of those described in section 13.2-4. Typically, the products delivered are 1:500 scale mapping, a DTM, and raster imagery produced by either Descartes or orthophotographic techniques.

It is the responsibility of the DPC to review products received and forward them to the requestor.

Appendix 13A: Glossary

Aerotriangulation (AT or Bridging) – Triangulation for the extension of horizontal and/or vertical control accomplished by means of aerial photographs, including such procedures as analytic triangulation, and older methods such as stereotriangulation, radial triangulation, stereotemplates.

Airborne Global Positioning System (ABGPS) – The use of satellite positioning technology to determine the location of an aerial camera at the moment of exposure. This system will result in a significant decrease in the number of photo control targets required for photogrammetry. The decrease in the number of targets will result in a significant safety advantage for field surveyors.

Analytic Point – A point added to each neat model to produce adequate horizontal and/or vertical control and to eliminate a photo control target that otherwise would have required field survey effort. Also known as an artificial point or a Pug Point.

Basemap – Existing maps and/or photography used for the purpose of planning map-ping extents and requirements.

Block – A set of flight lines processed simultaneously to cover an area not possible with one flight line.

Bridging – *See Aerotriangulation.*

Contrast – The difference in density between the whitest and the blackest areas of a photograph.

Control Densification – A process characterized by making small marks in the emulsion of the photographs at ideal positions to control each neat model. These points take the place of photo control that otherwise would have been set on the ground. This makes the photogrammetric process more cost effective by reducing the fieldwork required and allows for mapping in areas that are inaccessible to field crews.

Control Layout –A type of control scheme employed in the production of photogrammetric products. There is a variety of control schemes used by OoP for the production of various photogrammetric products. The appropriate control scheme, or combination of control schemes, is determined by what photogrammetric products will be produced and the required accuracy of those products.

Control Print – A contact print marked with the photo control, DTM limits, and mapping limits.

Crab – The condition caused by failure to orient the camera with respect to the track of the airplane due to side wind.

Digital Highway Inventory Photogrammetry Program (DHIPP) – The program that provides digital geo-referenced ortho-rectified color aerial images of the California highway system for non-engineering applications.

Digital Orthophotography – A digital photographic copy, prepared from a perspective photograph, in which the displacements of images due to tilt and relief have been removed.

Digital Terrain Model (DTM) – A three-dimensional model of digital surfaces of topographic features.

Digital Terrain Models (DTM) Limits – The extent of a requested project's three-dimensional digital surface. These limits may vary from mapping limits.

Drift – The lateral shift or displacement of an aircraft from its course, due to the action of wind or other causes.

Emulsion – The coated side or surface of a photographic product consisting of light sensitive material suspended in gelatin.

Endlap – The amount by which one photograph includes the same area as covered by another photograph along a single flight line, customarily expressed as a percentage.

Fiducial Marks – Index marks rigidly connected with the camera lens through the camera body and forming images on the negative, which generally define the principle point of the photograph. If these fiducial marks are not present, photogrammetric measurements cannot be made.

Flight Line – A line drawn on a map or chart to represent the track of the aircraft during the period of taking aerial photographs.

Flight Plan – A map that shows tentative photo control target locations and flight lines.

Floating Mark – The introduction into a stereoscopic image of a distinctive mark that seems to float in the stereoscopic image. The floating mark is the basis for the three-dimensional measurement of a stereoscopic image.

Flying Height – The height of the camera above the mean elevation of the ground at the instant of exposure.

Focal Length – A general term for the distance between the rear node of a lens (or the vertex of a mirror) and the point at which the image of an infinitely distant object comes into critical focus.

Focal Point – A point along the lens axis where the image of an infinitely distant object comes into critical focus. *See also Focal Length.*

Grain – One of the discrete silver particles resulting from the development of an exposed light sensitive material.

Graininess – Lack of detail in the image due to film type or improper exposure or developing techniques. Typically, faster film (for low light) yields a grainier image.

Ground Control – *See Photo Control*

Halation – The spreading of an image beyond its proper boundaries, particularly common in bright objects. Hot Spot – A bright area of low detail caused by low sun angles.

Image Motion – Smears in the photography caused by the movement of the aircraft during exposure.

Index Map – A map that shows the position and relationship of all map sheets to each other, as compiled for a survey project.

Light Detecting and Ranging (LIDAR) – A system that provides a high point density DTM of a site by using a laser to scan the terrain producing a large number of geo-referenced points.

Map Compilation – A collection of observable points to create a three-dimensional vector representation of photogrammetric measurements of the Earth's surface.

Mapping Limits – The required extents of mapping needed for a project.

Mensuration – The act of measuring photo control and marked analytic points through the use of a stereoscopic instrument. These observations can be measured to an accuracy of 3/1,000,000 of a meter, or 3 microns, on the image.

Neat Model – The area common to two photographs lying between the principal points of each photograph.

Overlap – The common area between adjacent photography, customarily expressed as a percentage.

Photo Control – A targeted position with a known x, y and/or z coordinate that can be observed in the photography and used as a reference in the aerotriangulation process.

Photogrammetry – The art, science, and technology of obtaining reliable information about physical objects, and the environment, through processes of recording, measuring, and interpreting images and patterns of electromagnetic radiant energy and other phenomena. (**Manual of Photogrammetry**, 4th Ed., ASPRS, 1980)

Request for Photogrammetric Services – A form used to request any photogrammetric product.

Photography Identified (PID) Control Point – A distinct point readily identified on both the ground and in the final aerial photography to help control the photogrammetry process.

Photo Rectification – A simple correction of photographs to known ground positions so the images can be used for public display and other non-engineering functions Photo Scale – The relationship existing between a distance on a photograph and the corresponding distance on the earth. Photo scale may be expressed as an equivalence, usually by different units, that is, 1 inch = 1000 feet; or as a numerical fraction or ratio, 1/3600 or 1:3600.

Photo Terrain Line (PTL) – High precision Photogrammetry where the photographs are taken from a helicopter.

Planimetric Map – A map which presents the horizontal positions only for the features represented; distinguished from a topographic map by the omission of relief in measurable form.

Planimetry – 1) The science of measuring plane surfaces. 2) Parts of a map which represent everything except relief.

Principal Point – The foot of the perpendicular from the interior perspective center to the plane of the photograph (i.e., the foot of the photograph perpendicular. Also known as the indicated principal point (IPP).

Relief Displacement – The displacement of images radially inward or outward from the nadir point of the photograph. It is caused by differences in elevation of the corresponding ground objects whether below or above, respectively, the elevation of the ground nadir.

Satellite Imagery – Images provided by satellites.

Sidelap – The amount by which one photograph includes the same area as covered by another photograph lateral to the flight line, customarily expressed as a percentage.

Solar Altitude – The angle between the horizon and the sun.

Stereoscopic Coverage – The total area of a project contained within neat models.

Strip – A group of adjacent photographs taken in a single direction at a predetermined altitude. *See also Flight Line.*

Tilt – The angle at the perspective center between the photograph perpendicular and the plumb line; also, the dihedral angle between the plane of the photograph and the horizontal plane.

Topographic Map – A map of the features of the actual surface of the earth considered collectively as to form. A single feature such as a mountain or valley is termed a topographic feature.

Wing Point – A photo control point located at each of the four corners of the model.

Yaw – *See Crab.*

Appendix 13B:

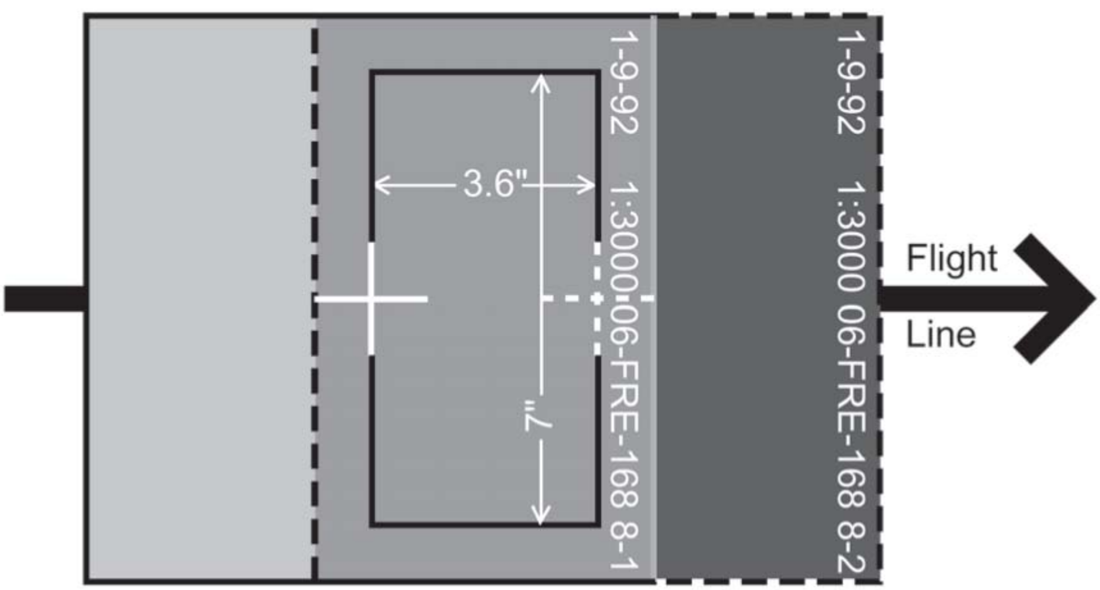
Photogrammetry Basics

Neat Model

The neat model is the basic unit of photogrammetric map compilation and thus the basic unit for all other photogrammetric processes, including flight planning.

The neat model consists of the area common to two sequential photographs in a single flight line, with approximately 60% overlap between them, lying between the principal (center) points of each photograph and approximately one inch from the edge of each photograph.

STEREO NEAT MODEL



The Controlled Neat Model

To produce photogrammetric products a neat model must be referenced to the ground by means of control points. Consequently, all steps involved in photogrammetric mapping, prior to the compilation process, are focused on producing well-controlled neat models.

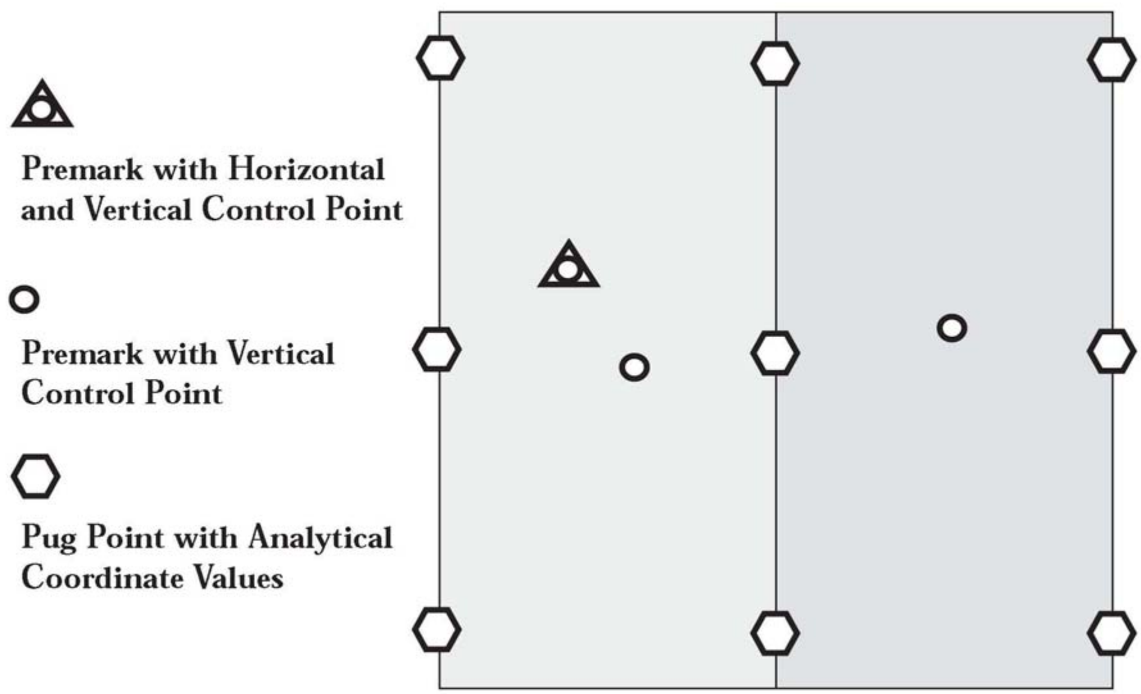
A properly controlled neat model requires the following points:

Three well distributed horizontal control points.

One vertical control point at each of the four corners of the model.

Note! A minimally controlled model will have 2 horizontal points and 3 vertical points. This results in single solution, provides no checks and is viewed as poor practice.

EXAMPLE OF TWO NEAT MODELS (FULLY CONTROLLED)



These points can be either traditional pre-marked targets or analytic points produced by the aerotriangulation process.

Stereoscopic Coverage

The total area of a project contained within neat models is commonly called stereo coverage, or more precisely stereoscopic coverage. The area in which mapping can be performed using photogrammetric methods is limited to the area of stereo coverage. Features existing on only one photograph cannot be mapped. This should be taken into account when planning a photography mission.

Photo Scale

The scale of the photography employed in producing mapping is a factor in determining the accuracy that can be achieved from the mapping process. It is important to know what accuracy will be required, and thus what photo scales will be acceptable before proceeding with the flight planning process.

The scale of a photograph is a function of the height above terrain at which the photograph was taken (h) and the focal length of the camera used (f). The focal length is the distance from the optical center of the lens to the plane of focus of the light passing through the lens. The focal length of cameras most often used in topographic mapping is 6 inches.

Scale = f / h

The scale of photography is generally written in the form of a unitless ratio, for example:

1:2400 means that 1 inch on the photo is equal to 2400 inches on the ground.

The following chart depicts standard flying heights employed by the Department when performing engineering mapping and the accuracy of mapping that can be achieved from those photography scales.

STANDARD FLYING HEIGHTS

Flying Height	Photo Scale	Mapping Scale and Application
1500 ft	1:3000	1”=20’ Bridge and Structure Sites (1’ Contours)
1500 ft	1:3000	1”=50’ Design Mapping using AB-GPS for control (2’ Contours)
1800 ft	1:3600	1”=50’ Design Mapping in flat urban areas (2’ Contours)
2100 ft	1:4200	1”=50’ Design Mapping in rural areas with steep terrain (5’ Contours)
2400 ft	1:4800	1”=100’ Environmental, Feasibility, and Planning (PA&ED) (5’ Contours)
4800 ft	1:9600	1”=200’ New Route Corridor Studies (10’ Contours)

Note:

The flying height represents the distance above the average ground elevation along the flight line. The maximum terrain relief along any given flight line shall never exceed 35 percent of the flying height.

The flying height is traditionally represented in feet in order to be compatible with the altimeter instrument used in the airplane.

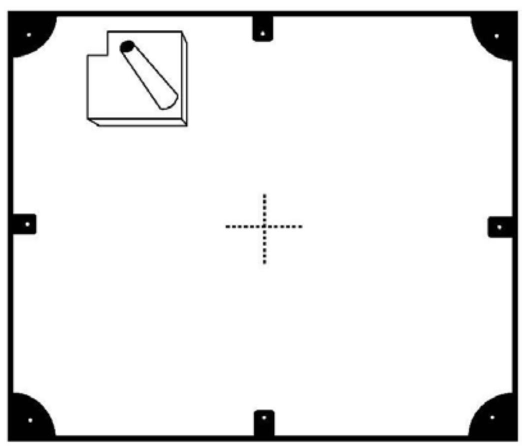
Assume focal length (f) to be 6 inches.

Relief Displacement

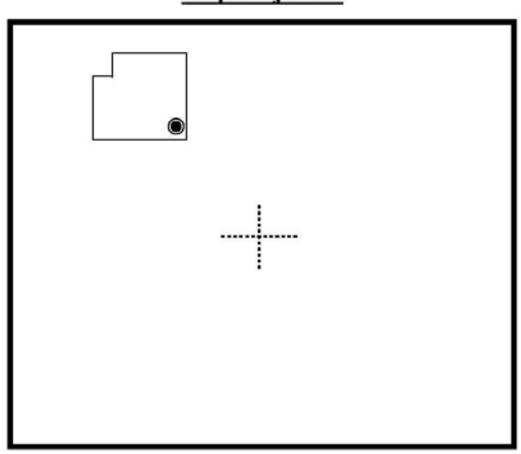
Relief displacement is the apparent leaning of objects within a photograph away from the photo center or principle point. Vertical aerial photographs are good examples of point projections where only the center image is correctly represented in its true position. From the center point outward, all objects are warped (radially displaced) away from the center point. Also, the displacement becomes greater the farther it is away from the center.

Examples of relief displacement can be most easily understood when viewing man-made objects. The graphic below depicts how a tall factory smokestack would appear in an aerial photograph and how it would be represented on an orthographic map projection.

Vertical Aerial Photograph

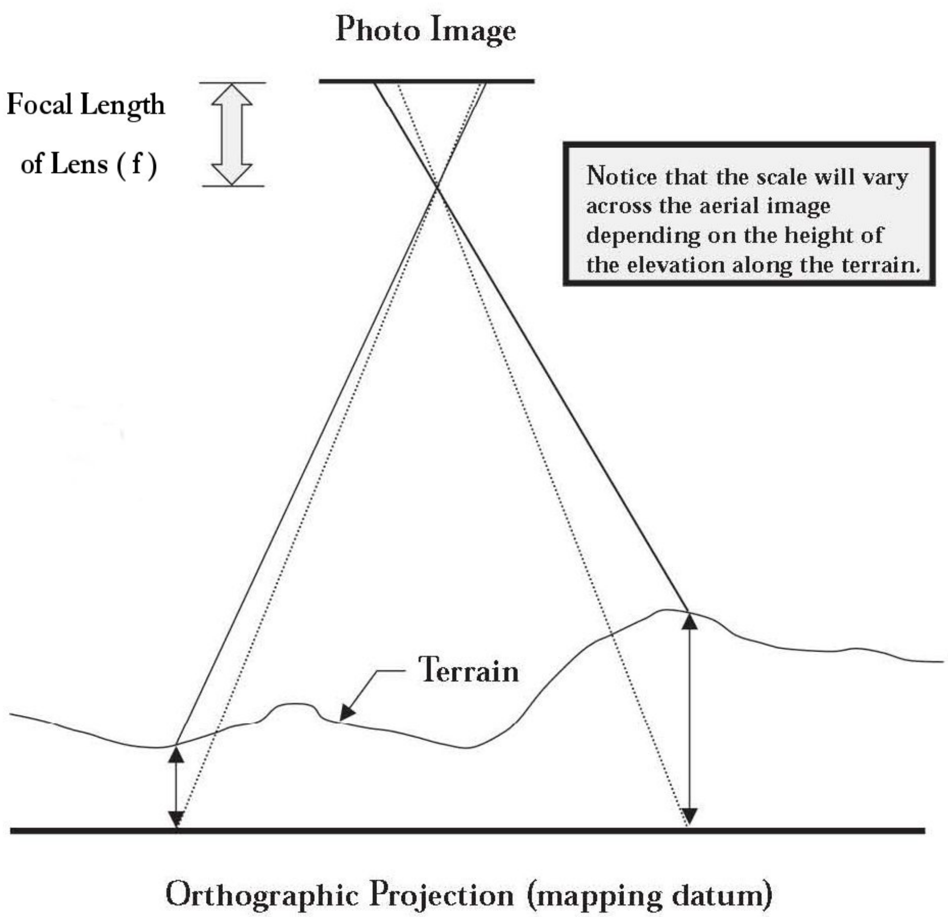


Map Projection



Effect of Terrain Relief on Photo Scale

As discussed above, flying height and focal length determine photo scale. The constant undulations of the earth's surface result in a different flying height above the terrain at every point within an aerial photograph. This fact causes the scale of an aerial photograph to vary as the elevations of objects within the photograph vary with respect to the exposure altitude of the photograph. Notice how this change in scale affects the photographic coverage of the ground in the diagram below:



As you see, the shorter the distance between the ground and the camera the larger the scale of the photograph at that point. The result is greater ground resolution and the potential for increased accuracy, however the coverage is reduced, increasing the number of photographs and ground control required for mapping a given area. This is where the balance between accuracy and economy has to be maintained.

These changes in ground coverage must be taken into account when planning a photography mission so that adequate stereo coverage for mapping is obtained and control points are properly positioned.

Appendix 13C:

Mapping Accuracy Standards

The standards used by The Department are the "Specifications for Aerial Surveys and Mapping by Photogrammetric Methods for Highways", prepared by The Photogrammetry for Highways Committee of The American Society of Photogrammetry, for the United States Department of Transportation, Federal Highway Administration, 1968.

Section 60. Planimetric Maps Prepared By Photogrammetric Methods, Also Profile and Cross Sections (Scales ranging from 40 feet to 1,000 feet to one inch)

REQUIREMENTS

60.301 Accuracy.

A. Coordinate Grid Lines –The plotted position of each plane coordinate grid line shall not vary by more than one one-hundredth (1/100) of an inch from true grid value on each map manuscript.

B. Horizontal Control –Each horizontal control point shall be plotted on the map manuscript within the coordinate grid in which it should lie to an accuracy of one one-hundredth (1/100) of an inch of its true position as expressed by the plane coordinates computed for the point.

C. *Planimetric Features* –Ninety (90) percent of all planimetric features which are well defined on the photographs shall be plotted so that their position on the finished maps shall be accurate to within at least one-fortieth (1/40) of an inch of their true coordinate position, as determined by the test surveys, and none of the features tested shall be misplaced on the finished map by more than one-twentieth (1/20) of an inch from their true coordinate position. The true coordinate position shall be determined by making accurate measurements originating and closing on station markers of the project basic control survey, which shall have a closure accuracy conforming with the requirements for the basic control.

D. Profile and Cross Sections With or Without Mapping –The elevation accuracy in feet of all tested points on profile and cross sections measured photogrammetrically at all centerline stations and at the points of change in ground slope shall be as specified in the itemization schedule, based upon use and conditions as indicated in the Explanation.

E. ***Special Requirements*** –When stipulated in special provisions that all specified features (planimetry and spot elevations) shall be delineated on the maps, regardless of whether they can or cannot be seen on the aerial photographs and on stereoscopic models formed therefrom, the consultant shall complete compilation of the required maps by field surveys on the ground so as to comply with all accuracy and completeness stipulations.

F. Spot Elevations –All spot elevations placed on the maps shall be in correct horizontal position to an accuracy of at least one-fortieth (1/40) of an inch of their true coordinate position. The root mean square error of the elevation in feet of all spot elevations measured shall not exceed one one-hundred-and-sixtieth (1/160) of the map scale expressed in feet to one inch. The elevation in feet of ninety (90) percent of all spot elevations shall be accurate at least to within one one-hundredth (1/100) of the scale of the map expressed in feet to one inch, and the remaining ten (10) percent shall be not in error by more than one-fiftieth (1/50) of the map scale.

Appendix 13D:

Airborne GPS Photogrammetry Surveys

An airborne GPS photogrammetry survey (ABGPS) utilizes Global Positioning System (GPS) technology to determine the three dimensional position of the camera at the instant of each photographic exposure. This results in an 80% reduction in the number of photo control and a corresponding increase in safety for the field surveyors. The safety improvement is created by the almost complete elimination of photo control within the right-of -way. The reduction in the photo control also provides economic and project timeline benefits by decreasing the scope and duration of the work required by Surveys.

The specifications in this appendix are based on a research project conducted by California State University Fresno requested by the Office of Photogrammetry (OoP) and funded by the Division of Research and Innovation. The researchers, in part, conclude and recommend that ABGPS projects reduce the base station and airplane GPS data with post-processed kinematic GPS methods. This process establishes 3D values at the photo center of the photographs, which will then be used in the Aerotriangulation (AT) process. The researchers also recommend that the final AT values be moved to the project vertical datum by imposing a project created geoid separation. The project geoid separation is created from 4 (or more) photo targets that have differentially leveled orthometric heights.

Specifications in this appendix will be revised as more ABGPS projects are performed and evaluated and/or the creation of new ABGPS techniques.

When performing an ABGPS photogrammetry survey, all standards and specifications for conventional photogrammetry survey projects as stated in this chapter shall apply except where modified by this appendix.

13D-1 Responsibilities

13D-1.1 District Photogrammetry Coordinator (DPC)

It is the responsibility of the DPC to:

- Coordinate with Surveys, the Party Chief, OoP, and the aerial photogrammetry contractor the use of the ABGPS project airport.
- Recommend potential photogrammetry projects as ABGPS projects to OoP when conditions are favorable.
- Work with OoP, Surveys, the Party Chief, and the aerial photography contractor to coordinate the schedule of the ABGPS project.

13D-1.2 Party Chief

It is the responsibility of the Party Chief to:

- Set and survey, if needed, the monuments for the base stations.
- Ensure that the provisions of this appendix are met when performing ABGPS surveys.
- Facilitate communication during the flight.

13D-1.3 Photogrammetry Project Management

It is the responsibility of Photogrammetry Project Management to factor GPS processing and adjustments required by ABGPS into resource requests.

13D-1.4 Flight Planning

It is the responsibility of Flight Planning to:

- Use the ABGPS control schemes from Section 13.6-3 as guides to produce flight plans for ABGPS projects.
- Consult with Aerotriangulation on the placement of check points to be targeted on the control scheme for each project.

13D-1.5 Aerotriangulation

It is the responsibility of Aerotriangulation to:

- Provide ABGPS advice and support.
- Process ABGPS data.
- Maintain a GPS antenna and antenna offset database.
- Simultaneously adjust photogrammetric data with ABGPS derived photo center coordinates.

13D-2 Project Selection

The DPC in conjunction with Surveys shall review the project site. The factors that they shall review are:

- Safety considerations.
- The terrain: Check if the terrain is predominately flat or hilly.
- Suitable GPS environment: See Chapter 6 of this manual for more information.
- Accessibility of potential targets The DPC shall indicate on the Request for Photogrammetric Services if the project is a candidate for use of ABGPS and shall recommend photogrammetry survey projects to OoP for consideration as an ABGPS projects.

OoP shall consult with the DPC to determine which photogrammetry survey projects will employ ABGPS. OoP will have the final approval authority for which projects will use ABGPS.

OoP shall select ABGPS based upon the following criteria:

- Recommendation of the DPC.
- Safety – Photogrammetry survey projects shall make use of ABGPS when safety is a major factor.
- Probability of success: The factors that OoP will consider are the terrain of the project area, the proximity of the project to the airport (within 24 miles of project site), and the project geometry.

13D-3 Control Requirements

The Party Chief shall perform the ABGPS field survey to the following requirements:

- The base stations horizontal coordinates shall be produced from a Caltrans first order or better GPS survey.
- The base stations ellipsoid heights shall be produced from the survey that produced the base stations horizontal values and have a standard error of not more than 0.06 foot at the one sigma level.from the minimally constrained least squares adjustment.
- The photo control horizontal coordinates shall be produced from a Caltrans second order or better GPS survey.
- The photo control ellipsoid heights shall be produced from the survey that produced the photo control horizontal values and have a standard error of not more than 0.06 foot at the one sigma level from the minimally constrained least squares adjustment.
- At least 4 photo control points evenly spaced throughout the ABGPS project shall have Caltrans second order differentially leveled orthometric heights.
- Caltrans second order differentially leveled orthometric heights on targets a maximum of every 1.2 miles throughout the ABGPS project. Note: These targets may be additional targets distinct from the photo control and will be used as checks.

See Chapter 5 of this Manual, Accuracy Classifications and Standards.

13D-4 Base Station Location Requirements

Party Chief shall select the base station locations based upon the following criteria:

- One Station within 0.6 mile of the Airport to be used for a static initialization of the airplane GPS equipment.
- One Station within 0.6 mile of each end of the project.
- Additional Stations a maximum of 24 mile spacing throughout the project.
- GPS suitability.

13D-5 Equipment Requirements

Base-Station Equipment Requirements

Surveys shall provide the following equipment for use at each base-station location:

- A dual frequency GPS Receiver
- A data logger capable of logging data at 2 hertz or better and that has adequate memory for logging data for up to 6 hours.
- A Geodetic Antenna.
- Batteries sufficient to power the GPS equipment for up to 6 hours.
- A fixed height tripod.

Airborne Equipment Requirements

The following equipment is required for use in the aircraft:

- A dual frequency GPS receiver.
- A data logger capable of logging data at 2 hertz or better and that has adequate memory for logging data for up to 6 hours.
- An event marker.
- Batteries sufficient to power the GPS equipment for up to 6 hours.
- All necessary cables and adaptors.

13D-6 Mission Planning

The DPC will coordinate with OoP, Surveys, the Party Chief, and the aerial photography contractor the planning of the ABGPS project to optimize the following:

- GPS Satellite configuration: A minimum of 5 or more satellites with a PDOP less than or equal to 4 for the entire period of observation.
- Solar altitude angle and weather conditions that allow for high quality imagery, see Section 13.9-4 for more information.
  The availability of required equipment and personnel
- The availability of the aerial photography contractor.
- A static initialization site for the airplane at the airport that has a good GPS environment and can be taxied to and from without entering areas with a bad GPS environment.

13D-7 Aircraft Equipment Setup

OoP shall approve the aircraft antenna and camera system prior to use on an ABGPS project. The aerial photography contractor shall provide OoP with the GPS antenna specifications and the GPS antenna offset survey data.

The Party Chief and/or OoP shall make the following connections per the aircraft specific checklist provided by OoP:

- Connect GPS receiver to the GPS antenna data only splitter port, the data collector, the event marker, and the battery.
- Connect the event marker to the camera.

If the receiver has a built in event marker then the Party Chief and/or OoP shall make a direct connection between the camera and the appropriate port or jack on the GPS receiver.

13D-8 Pre-flight Check

The Party Chief and/or OoP shall verify the following for the aircraft GPS equipment:

- Sufficient battery power for the ABGPS project.
- The GPS satellite configuration and the reception of all GPS signals.
- The activation of the camera shutter causes events to be logged in the GPS receiver.

13D-9 Pre-flight Static initialization

The Party Chief and/or OoP shall collect GPS data for 20 minutes prior to the flying of the project for a preflight static initialization and again verify that the activation of the camera shutter causes events to be logged. Also, they shall note the camera event number and the GPS receiver event number.

The Party Chief and/or OoP shall authorize the aerial photography contractor to begin the flight upon completion of the preflight static initialization.

13D-10 ABGPS Flight

The aerial photography contractor shall fly the flight paths shown on the OoP flight plan. Each flight line will be flown twice to minimize the risk of having to repeat the project due to image errors or loss of GPS signal lock.

13D-11 Post-flight check

The Party Chief and/or OoP shall verify that the camera events were logged in the GPS receiver after the ABGPS flight. If there is a discrepancy in the number of photographs taken compared to the number of events logged, the discrepancy shall be noted.

13D-12 Post-flight Static initialization

The Party Chief and/or OoP shall continue to collect GPS data for an additional 20 minutes after the ABGPS flight for a post-flight static initialization.

13D-13 Deliverable data to OoP

District Surveys/Region shall deliver the following data to OoP through the DPC:

- ABGPS Receiver Data
- Base-station Receiver Data
- Ground Control Data
- Mapping Epoch Coordinates
- Mission Epoch Coordinates

13D-14 Post-mission GPS Processing and Data Analysis

The Aerotriangulation will post process the kinematic data and confer with the DPC the results of the GPS processing.