3-03.1 PURPOSE. Photogrammetric surveys achieve the same results as conventional surveys by methods which require a minimum of field work. Photogrammetric surveys are performed by making measurements from aerial photographs properly oriented to a few field measurements to form, in proper equipment, a small scale three-dimensional model of a part of the earth's surface. Through the use of stereoplotters the location and elevation of man-made features are obtained from the model. Conventional surveys require numerous field measurements to obtain the same data and information.

3-03.2 THEORY OF FLIGHT PLANNING. There is a direct relationship between the flight height, photo-coverage, focal length of the camera, and the size of the negative which is taken into consideration when planning a photographic mission. As the flight height increases, the photo-coverage increases and the scale of the negative becomes smaller. Where the photogrammetric mapping is to be performed to a predetermined scale, the flight height, and consequently the photo-coverage on any one negative is predetermined by the camera and stereoplotter being used. On low level photographic missions and/or where mapping of relatively large areas is desired, it is sometimes necessary to plan extra flights to obtain coverage of entire areas. Photographic missions cannot be properly planned without knowledge of the intended use of the photography and/or the scale desired for the mapping. The focal length of the department's camera is 150 millimeters, the negative is 230 millimeters square, and the magnification of the stereoplotter is six times. These constants allow the relationships to be expressed by the following three simple formulas:

Photo-coverage (m) = 1.5 x Flight Height (m)
Photo-coverage (ft.) = 1.5 x Flight Height (ft.)

Photo-scale (ratio) = Photo-coverage m / 0.23m
Photo-scale (ratio) = Photo-coverage ft. / 0.9in.

Mapping scale (m/m) = Photo-scale coverage / 6
Mapping scale (ft./in.) = Photo-scale coverage (ft./in.) / 6

A summary of the results of the formulas based on common flight heights is tabulated in Table 3-03.1. The accuracy of the mapping compiled by Photogrammetry is in direct relationship to the flight height. Photography flown at an altitude of 460 m (1500 feet) above mean sea level has a mapping accuracy such that 90% of the elevations will be within 150 mm (6 in.). Photography flown at an altitude of 920 m (3000 feet) above mean sea level has a mapping accurace such that 90% of the elevations will be within 300 mm (12 in.).

TABLE 3-03.1
PHOTOGRAMMETRIC RELATIONSHIPS

Flight Height (m)	Photo Cover (m)	Photo Scale (ratio)	Map Scale (m/m)
460	690	1:3000	1:500
920	1,380	1:6000	1:1000

Flight Height (ft.)	Photo Cover (ft.)	Photo Scale (ft./in.)	Map Scale (ft./in.)	Min. Contour Interval (ft.)
1,440	2,160	240	40	1
1,800	2,700	300	50	1
3,600	5,400	600	100	2
7,200	10,800	1,200	200	5

3-03.3 SURVEYS ADAPTABLE TO PHOTOGRAMMETRY. Projects with certain physical characteristics are adaptable to economical photogrammetric surveys. The districts must make the judgement, based on their knowledge of the requirements of each project, whether a conventional or photogrammetric survey is preferable. The factors which will influence this judgement include:

3-03.3 (1) SCOPE OF THE PROJECT. Projects encompassing a large area will in almost all cases be most economically surveyed photogrammetrically. Conversely, smaller projects should be field surveyed. It is difficult to provide an absolute quantitative guideline to determine which projects fall into which category. In general, projects less than 400 meters (1300 feet) in length should be field surveyed.

3-03.3 (2) TYPE OF PROJECT. Sometimes photogrammetry can be economically applied to resurfacing and widening projects in highly developed areas to obtain planimetry (2D only). Such surveys do not require vertical control. Projects which required precise elevations should be field surveyed.

3-03.3 (3) TERRAIN. Projects with terrain which would be difficult or impossible to field survey should be surveyed by photogrammetry. These might include projects in highly developed areas, extremely rough terrain, heavily timbered areas, as well as bridge surveys for large streams.

3-03.3 (4) TIME CONSIDERATIONS. Projects that are time sensitive will almost always be field surveyed, because of the lead time necessary for photogrammetric surveys. Projects whose scheduling doesn't permit this should be field surveyed.

The table below offers guidelines to help determine whether a photogrammetric survey or a conventional survey would best suit a project:

TABLE 3-03.2
PHOTOGRAMMETRIC SURVEY VERSUS CONVENTIONAL SURVEY

PHOTOGRAMMETRIC	CONVENTIONAL
Wide Corridor Projects	Small Bridge Replacements (< 400 m)
Relocation	Resurfacing Projects
Rough Terrain	Shoulder Widening Projects
Large Bridge Replacements (>400 m)	Small Area Planimetric (2D) Surveys
Large Area Planimetric (2D) Surveys	

In addition to the guideline stated above, the district personnel requesting the mapping should discuss the project with the district survey party chief and the photogrammetry department when determining which method of survey would be best.

3-03.4 PROCEDURES. Since photogrammetry requires the use of expensive equipment which should be kept busy, the photography and plotting for photogrammetric surveys is centralized in the headquarters office. Other work is performed in the districts. This requires that eight sequential stages necessary to complete a photogrammetric survey be coordinated between the headquarters office and the districts. These stages are: (1) recommendations for flying program; (2) flight planning; (3) targeting; (4) photography; (5) establishing vertical control; (6) establishing horizontal control; (7) compiling photogrammetric survey data; and (8) furnishing electronic data to districts. Stages 1, 3, and 5 are performed by the districts on all projects. Targeting is set by the districts and must be accomplished before photography. Photogrammetric survey data will be furnished to the districts in the form of computer generated digital map models for use with CEAL.

3-03.4 (1) RECOMMENDATIONS FOR FLYING PROGRAM. The districts recommend projects for the flying program each year at the request of the headquarters office. Projects recommended for mapping are those on which a location study, if necessary, has been approved, or projects on which this requirement will be satisfied in time to obtain the photography during the flying season from approximately December 15 to approximately

April 15. Normally, projects that are in the design year of the approved construction program are considered, but other projects may be considered if conditions warrant. Other projects to be flown for aerial photo coverage only, in preparation for a location study, should also be considered at this time.

3-03.4 (2) FLIGHT PLANNING. The flight planning is performed by the headquarters office, but certain information is necessary from the districts to intelligently plan the photographic mission. The information furnished by the district includes the location indicated on a map, the desired mapping scale, or the limits of the mapping scales if more than one is desired. The extent of any areas to be mapped which might extend beyond the normal limits of the photographs is also included. In rural areas, the headquarters office is furnished with a county map on which the location is accurately shown in pencil. In urban areas, a more detailed large scale city map is used. If there is any question regarding areas to be mapped which may be beyond the normal photograph limits, the district advises the headquarters office of all such areas because the cost of additional photography is very small compared to additional flights or to extending the photogrammetric survey by field methods.

3-03.4 (3) AUTHORITY TO TARGET. The district checks with photogrammetry before targeting the location to insure that the plane is available for photographing the route after it is targeted.

3-03.4 (4) TARGETING AND PHOTOGRAPHY. When the targeting is completed the district advises the photogrammetry office and the location is photographed as soon as practical. The district is furnished with two sets of contact prints of the photographs. One set is for the district files. The second set is used by the district to mark the mapping corridor and the entire set is to be returned to photogrammetry. The district should also provide photogrammetry a description of the scope of the project (an HP-1 or location study report), to provide insight for efficient mapping. The project will then be planned for control requirements.

It is desirable to limit the photogrammetric corridor to only that area which can be foreseen to be necessary for the design of the project. This will help keep the size of the Digital Map Model to a minimum. Separate corridors, planimetric (2D), and terrain (3D), can be described for photogrammetric surveys. The district's recommendation regarding the type and extent of photogrammetric survey data coverage should consider the following:

For planimetric (2D) coverage, corridors should include all features which may affect design considerations and right of way takings. Planimetric corridors do not have to be connected but must be within the area in which horizontal controls have been established.

For terrain (3D) coverage, corridors should be limited to the area necessary for earthwork computations. This area would generally be within the limits of proposed right of way. Terrain corridors do not have to be connected but must be within the area in which horizontal and vertical control have been established. Corridor requests should generally not include areas for drainage computations.

It should be kept in mind that photogrammetric data will almost always be supplemented with conventional survey data.

3-03.4 (5) VERTICAL CONTROL. As soon as practical after completing the photography, photogrammetry furnishes the district with contact prints planned for vertical control, and the district proceeds with the survey for the vertical control. When the vertical control survey is completed, the district returns the vertical control photographs along with the vertical control field notebook to photogrammetry.

3-03.4 (6) DISTRIBUTION OF AERIAL PHOTOGRAPHS TO DISTRICTS. One set of contact prints will be furnished for retention by the district in addition to those provided for vertical control and corridor delineation. A screened film mosaic will be furnished to the district, if requested.

3-03.5 HORIZONTAL CONTROL

3-03.5 (1) GENERAL. Horizontal control for photogrammetric surveys is defined as the field control required to orient the photographs to a datum line which may be either the survey center line or a random traverse line. The preferred method is to establish a random base or traverse line which is tied to photo-identifiable objects or random targets, and from which the final survey center line is computed. The second preference is to establish the survey center line in the field and place targets on the center line prior to photography in such a manner that the targets are visible and identifiable on the photographs, thereby delineating the location on the photographs. The third preference is to establish the survey center line after the photography, and tie the center line to photo-identifiable objects or random targets. The first method is used where it is impractical to survey the center line because of obstructions such as extensively developed areas or where the best location is not apparent until after the mapping is complete. The second method is used where the location is definite and where schedules will allow the center line to be established prior to the photography. The third method is used on short projects where there is not time to establish targets prior to photography.

3-03.5 (2) TARGETING

3-03.5 (2) (a) PROCEDURE. Targets may be placed any time after the location is established. When targets are placed before the center line is staked, the targeted points are established and referenced so that the target locations can be accurately re-established and their station location determined when the center line is staked.

Targets are the preferred method of making photo identifiable points to which horizontal and vertical datum can be referenced to control the mapping project. The targeted points are to be established with care to ensure they are in useful locations which have clear fields of view on the ground to aid future reference to center line survey control. Targets should be located on level ground with the sky unobstructed 10 degrees above the horizon so satellites are visible to the global positioning system (GPS) receivers. It is preferred to locate targets out of traffic as the GPS receivers may have to occupy the target for 90 minutes. The surveyor may begin collection of horizontal and vertical control data before the area is photographed.

Aerotriangulation is a process to supplement the horizontal and vertical control normally required to control aerial photographs. Measurements of angles and distances on overlapping photographs are related into a spatial solution using the perspective principal of the photographs. Methods of aerotriangulation allow the photogrammetrist to supplement the field control data by an interpretative process to reduce the amount of field control required to properly orient the photo models. Those mapping projects which are of greater length than four photographs can have the field control requirements reduced significantly by the use of aero-triangulation. Those projects which are several kilometers (miles) in length may have the field control reduced to one third of that required by a fully controlled job. The limited field control thus becomes more critical and targeting of control points, for positive identification, is desirable.

3-03.5 (2) (b) MATERIAL FOR TARGETS. White paint is used for targets on paved surfaces. Unbleached muslin is used for grass, dirt and aggregate surfaces. Paint is available in the districts, and muslin is stocked in the central warehouse for requisition by the districts.

3-03.5 (2) (c) SPACING AND PLACEMENT OF TARGETS. Targets are to be spaced in accordance with the guidelines illustrated on Figure 3-03.1. The distances are a function of the flight height and the desired contour interval. All of the distances for target spacing may be adjusted by ten percent to allow proper placement in the field. The mapping project must begin and end with three horizontal and vertical control targets which are placed roughly in a triangular pattern. The two lateral targets should be spaced at the offset distance and the third target should be near the mapping corridor. No mapping will be done beyond the last target, so enough targets should be placed to insure adequate coverage. Position targets in locations with a good field of view to minimize the cutting of vegetation and reduce the number of required ground setups. Targets are located as required for visibility from the air in areas free of shadows. When targets are placed upon paved shoulders of the roadway, it is suggested that the northern shoulder be used to avoid obscuring the target with shadows from objects on the southern side of the road. Painted targets on pavement, located within public right of way, are preferred to cloth targets, located on private

property. When cloth targets are placed, they should be located on level areas, with all underbrush and weeds adjacent to the targets removed. Targets are located where they are least likely to be disturbed. Targets are placed so that the time lapse between placing the targets and the photography is held to a minimum. If the time lapse is of such duration as to cause doubt as to the target condition, the targets are checked immediately prior to photography. Vertical targets are set on paved roadways whenever possible.

3-03.5 (2) (d) SIZE AND SHAPE OF TARGETS. Acceptable sizes and shapes of targets for the various flight heights are illustrated on Figure 3-03.1.

3-03.5 (2) (e) TARGET NOTES. A separate notebook is used to record the target locations and descriptions. The notes include, for each target, the target numbers, shape of the target, and the target ties. A sketch should be provided in the field notes so someone who is not familiar with the location can identify each target on the photographs and easily relocate the targets in the field. Offset distances are recorded for targets which are offset. The targets are listed in numerical sequence in the field book. Acceptable examples for recording target notes are illustrated on Figure 3-03.2.

3-03.5 (3) POST-FLIGHT HORIZONTAL CONTROL. This method requires that photo- identifiable objects be tied to a traverse line. Horizontal control points are indicated by a red triangle with an 800 series number on the front of photographs furnished the district for horizontal control. A description of the points is included on the back of the photograph. Both horizontal and vertical control points may be indicated on the same photograph. Typical examples of these points are center of manholes, sidewalk intersections, pavement joint or intersections, power poles or other photo-identifiable objects. The survey party establishes the position of these points in the field, references them to the center line or to the base traverse. The position includes an accurate angle and horizontal distance to the base traverse or the state plane coordinates of the point. The horizontal control is planned before the center line or traverse line is established in the field and the survey party leaves recoverable horizontal control points near the probable center line of the roadway.

3-03.5 (4) BASE TRAVERSE SURVEYS.

3-03.5 (4) (a) PROCEDURE. A high order accuracy base traverse is established after photography for use as horizontal control and for use in computing the center line location. This traverse is established with electronic distance measuring equipment and a theodolite or a total station.

3-03.5 (4) (b) ACCURACY. At least second order survey accuracy is necessary. The acceptable accuracy tolerances for second order surveys are shown in Table 3-03.2. The accuracy of any traverse is not known until it is closed. The traverse may be closed on itself by looping or by tying the ends of the traverse to points on another traverse or triangulation network of as high or higher order. A second order traverse may be tied to a first or second order network, but not to a third order network. Most high order monuments were established by National Geodetic Survey (NGS) or the United States Geodetic Survey (USGS). However, some cities have monuments established by first or second order surveys. Descriptions, state grid coordinates, geodetic locations, and grid and geodetic azimuth are obtained for these monuments by contacting the proper governmental agency.

TABLE 3-03.3
TOLERANCES
SECOND-ORDER CLASS II SURVEY ACCURACY

MEASUREMENT	TOLERANCE
Distance	1:20,000
Angular	10 sec. x Sq. Root of n n = number of P.I.'s in the traverse

3-03.5 (4) (c) METHODS. Experiments on actual field surveys have been conducted to determine the most efficient methods for second order accuracy surveys. A computer program has been written based on these methods for the adjustment of traverses which practically eliminates all need for manual calculations. The use of the computer program requires that these methods and procedures be followed.

ESTABLISHING TRAVERSE STATIONS. After the general location of the base traverse is established, the traverse stations are selected. Traffic, parked cars, and the location of objects which might cause refraction are considered. After the location of the stations is determined, monuments are erected and referenced. The monument is of a material not subject to easy deterioration movement, such as a cross in concrete or 100d spikes driven below the ground line. The traverse stations are located in areas of easy accessibility having good fields of view, that will not be disturbed by normal operations until the center line can be staked.

TURNING ANGLES. If practical, angles are turned at the time of day best suited for this type of work. Early morning offers the advantage of lack of heat waves and little refraction. When angles are being turned under a hot sun the instrument is shaded. In urban areas the traffic load may dictate the time of day for turning angles. Range poles are used on long sights, and plumb bobs are used on short sights. A tripod is used to hold them over the station. The range pole is plumbed using a tribrach with optical plummet. The instrument is carefully leveled and centered over the station. Traverse angles are turned eight times, four direct and four reversed, and the mean angle is used. See Figure 3-03.3. Four angles are turned to sub-points, two direct and two reversed, and the mean is used. Angles to mapping targets are turned twice, once direct and once reversed, and again the mean angle is used. When a theodolite is used, vertical angles are also measured to convert the slope distance measured by the electronic distance measuring equipment to horizontal distance.

MEASURING DISTANCE. Distances are measured with an electronic distance measuring instrument (EDM) or a total station. The distances are measured to reflectors which are placed on a tripod and centered over the survey point. Each distance to a traverse station or sub-point is measured four times. Distances to a mapping target are measured twice. In each case the mean of the measured distance is used. In the case of an EDM, this is a slope distance which must then be converted to a horizontal distance.

NOTEBOOKS. Acceptable examples for traverse notes are illustrated on Figure 3-03.3, and Figure 3-03.4.

POLARIS OBSERVATIONS. To properly close some traverses it is necessary to obtain the correct bearing or azimuth of some of the lines involved by Polaris observation. Computations for second order observations of Polaris at any hour are found in any ephemeris. There are two important considerations in the field procedure of a Polaris observation: (1) The theodolite must be level. (2) the time must be correct. The first consideration depends on the theodolite being in adjustment and on good workmanship by the instrument operator. Correct time is obtained by radio from the Bureau of Standards, 2.5, 5.0, 10.0, 15.0 and 20.0 megacycles, the Naval Observatory, 113 kilocycles (five minute period every hour), or the Canadian Observatory, 7.5 megacycles. If a portable short-wave radio is available it is taken to the field. If not, the watch used is checked before and after the observation. Field procedures used to give a second order Polaris observation are as follows: The theodolite is set over the traverse station and leveled carefully. With the telescope direct a backsight is taken on the traverse station at the other end of the line being checked, and the circle reading is read and recorded. The telescope is turned to the star and the instant that the star passes behind the cross hair is noted. The time is recorded to the nearest second, along with the circle reading. This procedure is repeated four times with the telescope direct, and four times with the telescope reversed. Each angle and time is used to compute a bearing of the survey line. The mean of these eight computed bearings is then used. An acceptable example for recording a second order Polaris observation is illustrated on Figure 3-03.5.

3-03.6 VERTICAL CONTROL

3-03.6 (1) GENERAL. The elevation of three or more vertical control points are necessary on each photograph to orient the photograph vertically in the stereoplotter. Aerotriangulation permits the photogrammetrist to reduce the amount of required ground control elevations for an entire project, but proper ground elevations are still required to obtain reliable surface elevations.

3-03.6 (2) BENCH MARKS AND CENTER LINE PROFILE. Bench marks are established prior to obtaining the vertical control. An elevation is obtained at each target. The center line profile is taken from the aerial contours. Culvert sections are taken in the field following establishment of the approximate locations by the designer using the aerial contours.

3-03.6 (3) VERTICAL CONTROL ELEVATIONS. The district is furnished with photographs showing the required vertical control points. The location of these points are marked with a red circle and a 900 series number on the front of the photographs. A description of the points is placed on the back of the photographs by the headquarters office. The district is required to provide the described point elevation with the book and page number of the respective survey field book notes. Typical examples of these points are all targets, center line of road at entrance, fence corners, sidewalk intersections, top of manholes, and "ground 3 meters east of lone tree". Since it is important that the exact location be picked, a pocket stereoscope is used by the person picking the point on the photograph. The points on the front of the photograph are identified by a number. Level lines for establishing the elevations are turned through the control point. A complete set of level notes are kept in a separate notebook. Each vertical control point elevation is identified in the notebook by the point identification number, and the point description. The elevations of the points, along with the notebook page and number used for recording the elevation are recorded by the field personnel on the back of the photograph in the space provided. The district adds the names of important streets and roads appearing on the photographs. A three-person party will prove economical for obtaining vertical control.

3-03.6 (4) EXTRA ELEVATIONS. In running the levels from the established bench marks to the vertical control points, the survey party is encouraged to obtain elevations for additional photo-identifiable points that may be useful. If a point selected by the photogrammetry section cannot be identified in the field, the elevation of one additional point is obtained on each side of the unidentifiable point in direction of the line of flight. The location of the additional points is marked with a cross on the photograph, pin pricked and the elevation and description recorded in the field books and on the back of the photographs.

3-03.6 (5) DATUM. All elevations and vertical control are based on USGS or NGS datum.

3-03.6 (6) NOTEBOOKS. Vertical control field notes are recorded as illustrated on Figure 3-03.6. The field books used in obtaining the vertical control are forwarded to the headquarters office along with the vertical control photographs and the target elevations as soon as the field work is completed. All notebooks are returned to the district when the plotting is completed or at any time on request.

3-03.7 AERIAL PHOTOGRAPHY

3-03.7 (1) GENERAL. The photogrammetry section is available to perform various photographic assignments upon request. In order to properly plan the photographic mission, the headquarters office is furnished with basic information regarding the desired photography along with the request for the photography. Aerial photographs are also available for distribution within the department. It is the policy of the department to not furnish photographs or perform photography for others. Exceptions to this policy may be made for special circumstances.

3-03.7 (2) REQUISITIONING PHOTOGRAPHY AND PHOTOGRAPHS. Request for aerial photography and photographs are made on standard forms available from the headquarters office. Form D-101A is used to request aerial photography. Form D-102 is used to requisition aerial photographs. The request for photography is accompanied with a county map or a larger map, if necessary, in urban areas, showing the desired coverage so that the photography can be properly planned. Oblique photography can be furnished. When oblique

photography is requested, an arrow is placed on the map in the direction the camera is to be aimed. If a particular landmark is desired in the foreground of the photograph, it is also designated on the map. The purpose of the photography is designated on the form as legal, information, location study mapping, mosaic, etc., to aid in planning the photography. If there is more than one purpose, they are all listed. It is not necessary to submit requisitions for the photography to be performed for improvements on the approved flying program. Acceptable examples for completing forms D-101A and D-102 are illustrated on Figures 3-03.7 and 3-03.8.

3-03.7 (3) IDENTIFICATION OF AERIAL PHOTOGRAPHS. A series of numbers appear along the leading edge of all aerial photographs for identification. A photograph labeled as: 96 67 1:1000 (600) FEB 2, 1986 265 1 109; would be a photograph in St. Louis County (96), on Route 67, flown at a photo scale of 1:1000 (1" = 600'), on the specified date, located on roll 265, flight 1, exposure 109. (Prior to 1987, the label format was county, route, roll, flight, exposure, scale, and date). The flight number and exposure number is the portion of the photograph identification number used by survey parties as a reference in their field books. A duplicate print of any aerial photo may be ordered by specifying the roll number and the exposure number. In addition to these numbers, each photograph contains other marginal information such as number of camera exposures, time of exposure, and altimeter reading, which are for the use and reference of the photogrammetry section.