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Aerial photography has become a valuable method of acquiring information on estuarine current circulation patterns. The method provides a comprehensive picture of nearly simultaneous surface water movements. It represents a significant improvement over conventional surface float and current meter methods because large areas may be covered in great detail with limited personnel and equipment.

The goals of this study include the development and documentation of methodology for evaluating and displaying surface current velocities and two dimensional diffusion coefficients using dye tracers, oblique aerial photography and digital computers. Field procedures and data reduction techniques have been tested and modified in an attempt to provide a maximum amount of useful data with a minimum expenditure of manpower and materials.

The study has demonstrated that fluorescent dye tracers, placed

in articulated streaks, are conveniently deployed, easily interpreted photographically, conservative with respect to dye wastage and useful for diffusion studies as well as current studies. Individual oblique aerial photographs have been utilized in preference to stereo or vertical photogrammetric methods to eliminate reflected light problems and to allow the use of available aircraft and photographic equipment. Greater course variation and low altitude flights are permissible under some cloud covers that could otherwise preclude the use of other aerial photo methods.

Digital computer procedures are described which analyze aerial photo data by (1) determining the six parameters of the camera and photograph orientation based on initial approximations of position and angular rotation and (2) calculating magnitudes and directions of currents and approximate diffusion rates. Computer graphic techniques are presented which are used to display estuary boundaries, velocity vectors and dye patch outlines.

This report is intended to become a user's manual for the application of the Oregon State University photogrammetric equipment. However, the principles involved and the methodology described are general and can be readily applied by the reader in designing his own system for determining estuarine circulation patterns through the use of air photo imagery.

Airphoto Analysis of Estuarine Circulation

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AIRPHOTO ANALYSIS OF ESTUARINE CIRCULATION

I. INTRODUCTION

Quantitative information about tidal and wind induced circulation patterns is necessary for wise utilization of an estuarine resource. The information is needed for water quality analysis, navigational assistance, biological research, shoaling and erosion pattern prediction, selection of outfall sites for industrial operations and public works projects, planning harbor developments, etc.

To determine the magnitude and direction of current velocities it has been common practice to measure the velocity at a point or section with a current meter or to track an object moving with the water mass. Both techniques are surface based activities and often require shore based triangulation surveys for horizontal positioning. Adequate coverage can be restricted either by accessibility to certain areas or by limited personnel and equipment.

Photogrammetric methods overcome these limitations by providing the observer with a broad field of view and relatively high powers of resolution. Aerial photography surveys with dye tracers permit detailed studies of circulation patterns over wide areas with few surface vessels. Resulting photos can be used to identify regions of intense shear, rotation, and/or stagnation zones which may go unnoticed with a current meter survey. Photo records may be scanned at a later date and specific areas of interest can be analyzed for current velocities.

Other photogrammetric methods have been developed which require vertical photography. The parallax method relies on analysis of pairs of stereophotos (Cameron, 1952). This method requires higher flight altitudes than other methods and exceptional atmospheric conditions, as well as a specially trained photogrammetrist and stereoscopic plotting equipment. In the present study, these shortcomings are avoided through the combined use of oblique aerial photography and computer analysis.

The methodology for obtaining satisfactory airphoto imagery and some data processing methods have been developed by previous researchers (James, 1970). In this study, operational procedures for optimum coverage of an estuary are finalized. More important, computer programs are written specifically for current studies in estuaries using oblique aerial photography.

Scope of the Investigation

Air photo analysis requires a large format camera for wide angular coverage of the area. Additional small cameras with different film combinations aid in photo interpretation. Typically, the camera unit is mounted in the baggage compartment of a small high wing aircraft with the baggage door removed. The cameras are mounted obliquely thus reducing direct sunlight reflection from the water surface. Diluted rhodamine WT dye is seeded from small boats under direction of the photographer. As the dye mixes and moves with the water mass, time lapse aerial photographs are taken. Determination of ground coordinates of the dye segments being analyzed is dependent only upon identification of three or more ground points, therefore the photos can be taken from any elevation, bearing and plane orientation.

Digital data for computer analysis is taken from the photographic film using an X-Y coordinatograph connected to a digitizer and standard card punch. The computer program (1) computes the orientation of each photograph from composite station coordinates of points identifiable as ground control points in the photo, (2) computes the X, Y ground coordinates of photo points measured in the photographic X-Y plane, and (3) computes and stores coordinates and velocity information of dye patches and surface floats in a format compatible with the plotting routines.

The final result is tabulated as velocities at the appropriate times and coordinates and is graphically displayed either on a CRT terminal or a computer controlled pen plotter. The plot record outlines a portion of the estuary under study and identifies the position of each float and of each dye segment centroid. The outline of each dye patch can also be plotted. A velocity vector shows the direction and relative magnitude of the water motion. A number for each vector is printed at the head of that vector and refers to tabulated velocity information.

Only a few man hours are required to process data for one dye patch consisting of five to ten photographs, each photo yielding three to seven velocity vectors.

Correlation of velocities obtained by aerial photography and by current meters shows that the velocity of the surface and near surface waters as found from the air can be expected to be 15 percent larger than those velocities measured at six-tenths the depth. The standard error of the velocity computations for such measurements is less than 0.03 feet per second.

II. BACKGROUND

Conventional Methods of Resolving Currents

The traditional approach to circulation studies involves either tracking an object moving with the water mass or constructing velocity profiles at fixed stations.

An assortment of objects has been used to trace current systems (Waldichuk, 1966). For the measurement of surface water movements, floating drift cards, buoys, dyes, drift bottles, and floats made of styrofoam, wood and polyethylene have been used. Drift poles and drogues are used to indicate subsurface water movements.

A large number of floats is required to give a comprehensive picture of the water circulation. Several vessels and shore observers are necessary in order to monitor many floats. This inhibits many studies since if boats are limited, then so is the area which can be covered in a single survey. Also, some areas of interest may be unapproachable, either by land or water, making a comprehensive study difficult.

Occasionally, a vantage point is available from which a major portion of the estuary is visible. Floats and/or drogues can then be monitored by triangulation techniques using conventional land surveying equipment. Waldichuk (1966) pin-pointed float positions by theodolites set on a bluff. The floats were equipped with lights for tracking throughout the night.

Current meter information alone is inadequate for describing estuarine circulation unless many observations at many positions are possible.

Remote Sensing Techniques

Aerial photography has been used by a number of investigators in determining surface currents. Work by the Coast and Geodetic Survey in tidal current surveys has been the groundwork for present techniques in computer analysis (Keller, 1963; Keller and Tewinkel, 1966).

In general, the approach for aerial methods has been to mark the water surface with a target and note the movement of that target. Targets have included anything that floats with the water mass and is easily distinguishable in photographs taken at elevations of several thousand feet. The positions of the objects in successive photographs are determined and the average velocity for the time interval is simply the distance traveled divided by the time of travel.

The parallax method (Cameron, 1962), one of the early techniques for determining travel distance, depends on orientations of stereoscopic models on photogrammetric plotting equipment. With proper orientation, any target movement perpendicular to the line of flight of the photographing aircraft manifests itself as a y-parallax (an elevation change) measurement, which can be converted into an x-parallax measurement. These computations are simple enough to carry out by hand. The criteria for adequate stereophotos are a predetermined aircraft elevation and flight pattern, because the direction of flight should be either parallel to or perpendicular to the current to be measured (Forrester, 1960). Since a completely uniform direction of flow is unlikely, it becomes necessary to measure the differential parallax in both the X and Y directions. The resultant current velocity is the combined velocity components in both directions.

Cameron (1962) claims the parallax method can be used to measure water current speeds of any magnitude over one m.p.h. Velocities below one m.p.h. down to 1/16 m.p.h. are considered measurable if floats are employed along with compatible flying speed and scale.

Successful use of the parallax method demands a vertically mounted camera and a level flight. Furthermore, a relatively slow aircraft (Cameron, 1952; Forrester, 1960) flying at a high altitude (Keller, 1963) is required. This provides better land detail, reduces the volume of photogrammetric data reduction, and allows maximum displacement between exposures yielding more exaggeration of the stereoscopic illusion. This requirement is a drawback, since longer intervals produce average velocities rather than the more instantaneous results of shorter interval photos. Also, aircraft selection becomes a major concern in planning an aerial survey.

Other limitations (Cameron, 1962) include the appearance of "blank areas" on the water surface where some currents are present. Standing waves can also provide difficulties. Wind action causes false parallax along the wind direction even though no water current exists. Data reduction, involving orientation of a pair of photographs by a highly skilled instrument operator and measurement of target movements, takes approximately one day per stereoscopic model (Keller, 1963; Waugh, 1964).

James (1970) used aerial photographs and photogrammetry to measure waste concentration and determine dispersion patterns and diffusion coefficients in nearshore ocean waters. Dye markers were seeded at selected locations in the study area. The change in position and size of the dye patches between photographic flights determined the velocity and diffusion coefficients. The resection technique used by James to calculate photo orientation and the rotation matrix was developed by the U.S. Coast and Geodetic Survey (Keller and Tewinkel, 1966). Two dimensional diffusion coefficients are calculated using a non-convective, depth independent, mass conservation relationship. These methods, particularly the use of oblique photography, are expanded in the present study for application to estuarine circulation studies.

Tracers and Targets for Aerial Photography

Aerial photo analysis of water currents is dependent upon the use of suitable targets moving with the water mass. A target should be large enough to be within the resolving powers of the observer and the photographic equipment; it should contrast in color with the surrounding water under various conditions of turbidity and lighting; and, it should have approximately the same density as the surrounding water so that it will neither be dominated by surface winds nor be slow to respond to advective current changes. A variety of tracers and targets have been tried in an attempt to optimize these features and still observe the constraints imposed by economy, availability of materials, and ease of deployment.

River Silt

Naturally available silt in turbid river water can be used as a target. River silt moves on the surface of seawater and is subject to drifting with both tidal and wind currents. No expense is involved in initiating or recovering the target. It is often clearly visible in aerial photographs.

Investigators who have capitalized on the presence of silt (Waldichuk, 1966) have reported that the cloud-like appearance makes identification of discrete silt patches difficult for quantitative measurements of currents.

Paper

In a surface current study of Cordova Bay, British Columbia (Waldichuk, 1966), 40 foot long strips of 54-1/2 pound paper proved suitable as target material, primarily because of "good buoyancy, comparatively good endurance." Paper was found to be less expensive than other tracer materials and responds to currents down to one meter per second.

To be clearly identifiable in aerial photographs, large sheets had to be used. This required special equipment for dispensing the paper. Also, the paper needed strength when wet, as well as buoyancy, to resist buckling and twisting by "choppy sea surface" conditions.

In a 1965 study of the Juan de Fuca Strait, Waldichuk's paper targets were broken up by wave action, even though a heavier (90 lb), stronger and more buoyant bond paper was selected (Waldichuk, 1966). Observations of the paper fragments revealed a wind-driven onshore movement.

Unless the paper is recovered after the study, it can become a litter nuisance in confined waters and on the shoreline.

Foam

In a study of Tampa Bay, Florida, mechanically produced fire foam became the surface target (Wauch, 1964). A special spray pump mixed the protein base liquid with sea water. "Streaks" of foam were laid on the water surface from small boats. Waugh claimed that the foam was not disturbed by the wind, but formed a thin even layer on the water.

In April, 1959, a Canadian research team took advantage of foam generated by turbulent rapids in the Rideau River in Ottawa (Forrester, 1960). The natural foam proved acceptable as a target from 3000-foot elevations.

Aluminum Powder

Waldichuk (1966) found aluminum powder patches "comparatively inexpensive" targets for determination of surface water (a thin surface film of water) movements. Patches were created 50 feet in diameter using approximately one-half pound of aluminum powder per patch. The major disadvantage reported was the frequent powder seedings required due to rapid disintegration of patches in choppy water.

Oil Film

Oil on water reflects light such that a slick is clearly visible in an aerial photograph. Because a small quantity produces a large patch and distribution is simple, the cost of producing an adequate target is minimal. An oil film is seldom used due to drawbacks of (1) pollution of water and beaches, (2) rapid dispersion in choppy or turbulent waters, and (3) application only to studies of the surface waters (Waldichuk, 1966).

Drogues and Plywood Panel Floats

The Coast and Geodetic survey found that 4 ft-by-4 ft painted plywood panels made satisfactory targets for photography down to a scale of 1:35,000 (Waugh, 1964). Much larger targets were determined impractical because of bulkiness and so were not used for smaller scale photographs.

Burgess and James (1970) set four foot square floats adrift in studying waste dispersion near shore. Several floats were set with drogues. Photography was carried out from 4000 to 11,000 feet elevations. Floats were reported to have become trapped in ocean kelp beds, occasionally.

Dye Solutions and Dye Packages

The U.S. Geological Survey determined the circulation of water in Bolinas Lagoon, California, using rhodamine B (Ritter, 1970). The bright red dye was seeded from a helicopter, forming lines of dye spots across the lagoon channel. Color aerial photographs were taken from 6,000 feet, from which the dye movement was measured.

III. FIELD PROCEDURES

Successful field operations are dependent upon properly functioning aerial photography equipment, readily distinguishable targets on the water surface, and coordination of the air and surface activities. The equipment and techniques discussed in the following are representative of those required for a satisfactory circulation study.

Photographic Equipment

Two or more cameras are desirable for convenient airphoto analysis. A large format camera provides wide angular coverage for photo and target orientation, while a smaller format camera with color or infrared film is useful for supplementary photo interpretation. Specifically, a large format camera is often used with black and white aerographic film. Surface dye streaks on the black and white negatives may be difficult to distinguish from foam lines or bottom features in shallow water. To aid in photo interpretation, a smaller photo of the same region on color film will often make the dye streak readily apparent. If necessary, measurements can be made on the smaller photographs with very little procedural change in the photo data reduction process. Thus the multiple camera system provides a supplementary record as well as added information.

The particular camera package used in this study, shown in Figure 1, consists of a K-17 mapping camera and two 70 mm Hasselblad cameras. By using different film and/or filter combinations on the multiple cameras, the aerial photographic information is optimized. The K-17 camera gives larger angular coverage than the two smaller cameras and is used for photographic orientation and measurements. The two 70 mm cameras allow additional identification of various surface and subsurface features.

Table 1. Aerial photography equipment and film.

Camera	Film Type	Film and Filter Combination	f-Stop	Shutter Speed	Remarks
Hasselblad	2448	Regular color and polarizing filter	f/4	1/250	Bright day
	2448	"	"	1/125	Broken clouds
	8443	IR color film and #12 filter and yellow filter	f/6.3	1/250	
K-17	2402	Black and white aerographic film; Tiffen dark red II filter	f/6.3	"C"	

The cameras are mounted obliquely to reduce direct sunlight reflections from the water surface. The two 70 mm cameras are oriented at about 35 degrees from the vertical, while the mapping camera is aimed at about 45 degrees from the vertical. The camera package is secured in the baggage compartment of a small high wing aircraft, the cargo hatch being removed to provide a port for photographing.

The cameras are triggered simultaneously with the aid of an electronic timing device and electronic shutters. The timing is adjusted to 1/100 second.

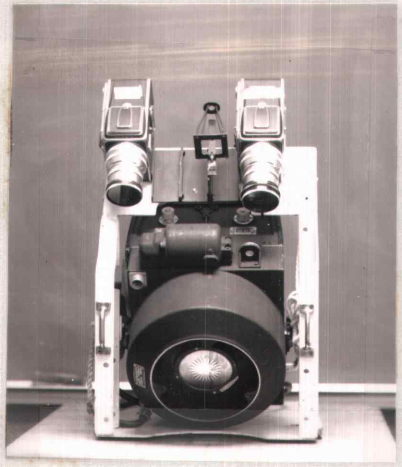


Figure 1. Multiple camera package for aerial photography.

Black and white aerographic film is used in the K-17 mapping camera. The 9-1/2 inch square black and white photographs produce a sharp contrast between land and water, aid in discerning sand bars and other bottom features, and are readily processed using the available photogrammetry laboratory equipment.

It has been found that color film is particularly useful for photo interpretation. As an example, one 70 mm camera is loaded with normal color film, type 2448, and the other is loaded with infrared color film, type 8443. The addition of color to the photograph furthers discrimination and helps distinguish dye in the water. Color infrared film provides exceptional contrast between dye and water under partly cloudy conditions.

Targets

The rhodamine WT dye has been used by previous research groups, mainly because of its low absorption and low decay rate (Burgess and James, 1971). Fluorescein, (light green in water) is an acceptable substitute under certain conditions, but is difficult to distinguish visually in dark Pacific Northwest estuary waters. Also, fluorescein dye has a high photochemical decay rate.

The problem of achieving the most efficient dye release is approached in several ways.

1. Dye plumes, where the dye is injected into the estuary at a single point. This technique is well suited to outfall diffusion studies.
2. Dye streaks, where the diluted dye is poured continuously from the stern of boat moving across the channel, leaving a ribbon of brightly colored water three feet to ten feet wide strung from bank to bank. This technique is useful for location of zones of intense shear, rip currents, and other

non-uniform flow conditions.

3. Dye segments or articulated streaks, where the premixed dye solution is released intermittently in the boat wake as the boat travels across the estuary. This technique tends to conserve dye and provides readily discernible water masses for subsequent time lapse photo analysis. The size and spacing of segments is a function of the detail required. As an example, segments on the order of 100 feet in length spaced at 100 foot intervals provide satisfactory detail for large estuaries and usually assure that adjacent segments will not diffuse together too quickly.

Ordinarily, the research team dilutes the dye concentrate to less than a 50 percent solution in preparation for a release. Thorough mixing with estuary water insures that the dye solution will not remain solely on the surface of the estuarine waters because of low specific gravity. Further mixing is accomplished by releasing the dye in the prop wash of the boat wake.

Large surface floats may be substituted in lieu of tracer dye. The floats are reusable if recovered, however they are cumbersome to deploy and do not yield any diffusion information. Dimensions on the order of four feet by four feet are required for rapid photo identification. The floats may be fabricated from polyurethane sandwiched between two plywood sheets or from a single plywood sheet with diagonal six inch deep keels. The latter assures that the floats motion will not be dominated by wind drag. The floats may be further identified by marking large black numerals on a bright orange background, although the numerals are usually visible from the air only at lower altitudes. Floats have been found to move uniformly with dye streaks in this study.

One advantage of dye, as opposed to a floating target, is that there is no danger of presenting a navigational hazard. Large floats may drift into the paths of commercial and sport fishermen cruising the estuary channels. Floats, and especially drogues, tend to become lodged on sand bars, thus presenting a recovery problem. Dye, on the other hand, will disperse and flush away during subsequent tidal cycles.

Field Coordination

In planning a survey of an estuary, points of interest are isolated and designated as dye release spots. The time of arrival of the aircraft is arranged to coincide with the time of slack water at either high or low tide, thereby providing an opportunity to study one-half of a tidal cycle. Sun altitude, a function of latitude and time of year, is also given consideration when planning a flight.

Each boat contains two personnel. One man serves as operator and one man dispenses dye and floats. Each boat is assigned a portion of the estuary to cover. Citizens band radio contact is maintained between each craft on the water and in the air.

As soon as the aircraft is overhead, one boat commences seeding dye. Additional dye releases are executed as directed from the plane in accordance with estimated ability to cover and photograph the area. The plane circles one area of interest after another, photographing visible dye traces and coordinating further dye drops with the surface crews. The frequency of photographs is controlled by the current speeds. A clearly obvious travel distance, such as 50 to 100 feet, should be allowed between photos, necessitating photo intervals ranging from ten minutes to less than 30 seconds for swifter currents.

On estuaries where points of interest are more than a few miles apart, only one location can be seeded (with two or three simultaneous dye releases) and photographed at a time. As soon as the dye has diffused extensively, the plane radios the next area with instructions to lay dye. In this manner, work progresses from one end of the estuary to the other.

Records of the activities are kept by both surface personnel and the plane crew. The time and location of each dye release is noted by the person responsible. For each photograph taken, the time, bearing of the plane, altitude of flight, tilt of the craft, and approximate location of the plane are logged by the radio operator or camera operator aboard the aircraft. The data analysis techniques discussed in the following chapter make use of this information in identification of photographs and targets, in determining the photo orientation, and in the velocity calculations.

IV. DATA REDUCTION PROCEDURES

Analysis of the aerial photographs is a detailed process, but not overly complex. A computer program, PROGRAM STREAK, has been written to calculate velocities of identifiable photo objects by determining the distance traveled between successive photographs. For each photograph, the photo orientation and ground coordinates of points of interest must be found. The data reduction procedure is accomplished in several phases (Figure 2).

The initial phase involves identifying and labeling individual photographs, then sorting and grouping the film according to time of the dye release.

Next the ground control points required for subsequent photo resection are selected and their ground coordinates are recorded along with the coordinates of the outline points of the estuary. Ground control points are specific points which are identifiable on a large scale map, vertical aerial photograph of known scale, or whose state-plane coordinates are determined by a land survey. At least three noncolinear ground control points must be located on each photograph in order to allow computation of state-plane coordinates for photo points. An outline of the estuary, accenting prominent features such as marinas, jetties, sand bars and bridges, may be digitized, using the same coordinate system as is used for the ground control. The

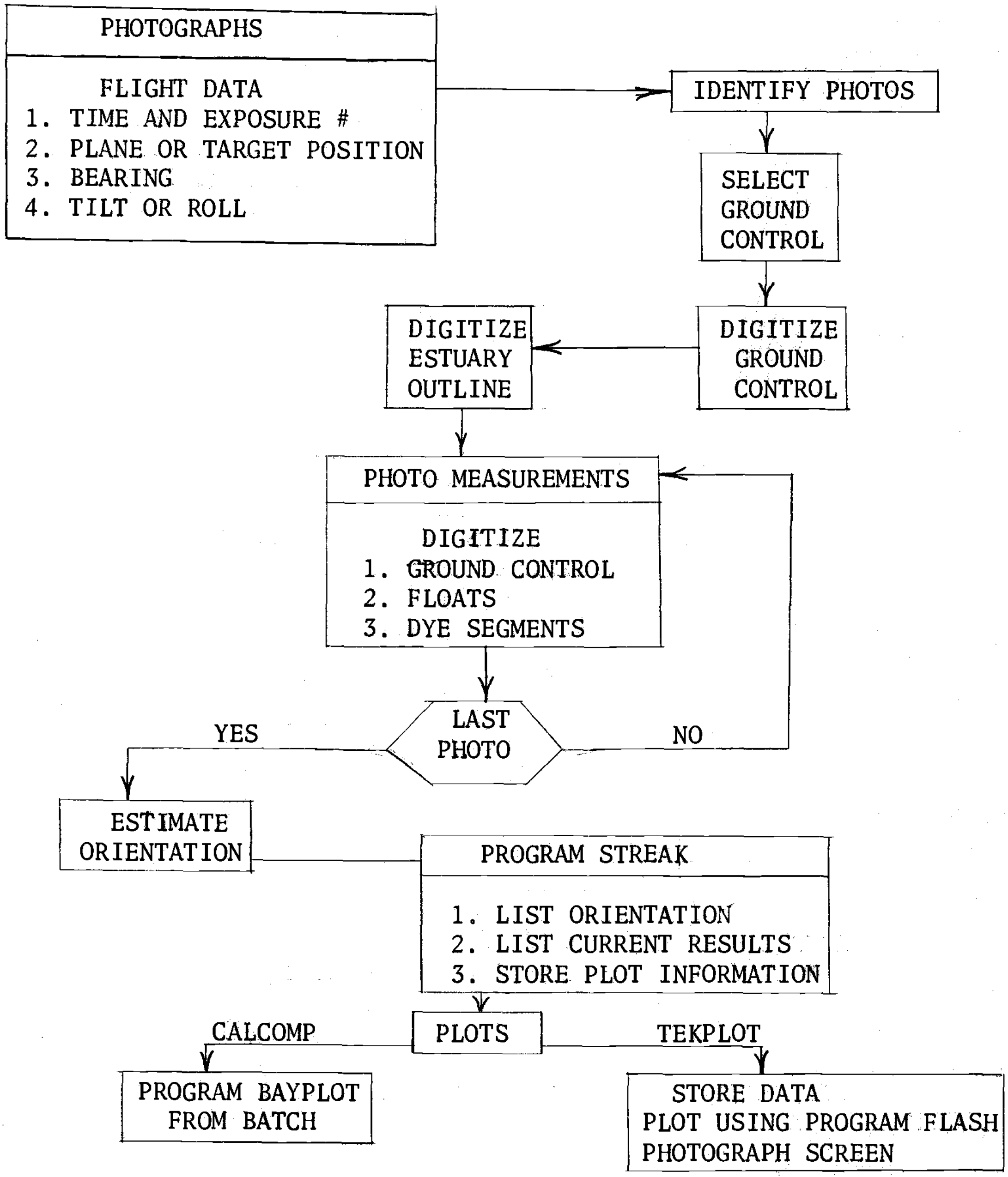


Figure 2. Data reduction flow diagram.

purpose of the outline is to provide more meaningful representation of the velocity vectors on graphical output by plotting velocities within the channels. The outline is not used by PROGRAM STREAK.

For each batch of photographs, photo measurements of ground control points, float position, and dye segment outline points are made. All data is digitized using an X-Y coordinatograph connected to a digitizer and standard card punch, although successful use of PROGRAM STREAK is possible if photo measurements are made using ordinary drafting tools and/or plotting table. The coordinatograph, however, is advantageous in that it can measure linear distances to within 1/1000 inch. Resolution of this magnitude is difficult to attain using manual methods.

The approximate orientation of each photograph is determined and a trial teletype run is initiated for calculation of precise orientation values.

The punched card deck consists of the file of ground control point coordinates, a file of photo coordinates for each photograph, and a file of photo orientation parameter initial approximations plus the necessary control cards. The deck is assembled and loaded with the program from batch to produce the desired circulation and diffusion information and data for plotting. The direct output is on the line printer; however, the user may load a plot program and send the plotting information directly to the CALCOMP plotter files. Otherwise, the final step is a graphical display of the velocity vectors within the estuary outline produced on the plotter or CRT.

Photo Interpretation

Before any useful information can be taken from the aerial photos, the film must be identified, labeled, sorted, and inspected.

The film strip is not cut into individual shots until each frame is identified from the flight notes. The direction of flight (bearing), the location of the aircraft, and the relative perspective of the photograph are all used to identify the time and target of each exposure.

Next the photos are grouped according to targets. That is, all the photographs of a particular dye release are placed in the same packet, their data digitized and run as one batch.

After all the photos for a flight are sorted, labeled and the unpaired and poorer photos which will not be processed are set aside, the ground control is selected. Each photograph is scanned and the operator selects a number of ground points which are recognizable on the reference photo or map. Some typical ground control points are corners of buildings, road intersections, bridge piers, and small stream junctures. Not only are three non-colinear points required for resection of a single photo, but faster and better results are obtained if points are evenly distributed about the principle point. Photographs that can not be resolved because of insufficient ground control must be discarded.

The remaining discussion will deal solely with the processing of one group of photographs as a batch.

The final step in preparation for digitization is locating and marking the ground control and the targets. Each photo point of interest is given an identification number. The following scheme has been useful in the present study:

000 - principal point of the photograph (exact center of exposure).

001 through 099 - ground control points.

100 through 199 - floats.

200 through 299, 300 through 399, . . ., 900 through 999 - dye patch outlines.

Floats that can be identified are circled and numbered. Floats can be given any identifying number from 100 through 199, as long as the last float observed is labeled 199. For instance, if there are three floats being tracked, they can be designated 101, 141, and 199. If in another batch, where only one float is present, it must be numbered 199.

The more segregative the dye is, the greater is the amount of information derivable from the set of photos. As described in Chapter III, dye can be laid in segments to provide more targets. If segmental releases are not utilized, each dye streak is visually broken into sections. Each section represents a distinct portion of dye, showing a definite trend in the water movement. Up to eight dye segments can be accommodated per photograph according to the above coding, each segment being carried on throughout the batch. Since the computer program is only sensitive to the existence of the 99, the number of dye segments can be as many as proper dimensioning of variables provides for. The user simply ignores the value of the first digit of the code and insures that the last point of each segment is numbered X99.

Ground Control

Ground control is stored in a data file composed entirely of digitized coordinates of control points. The scale factor is also input with the ground control. The scale factor is the conversion from coordinatograph units used on the ground control map to units of feet. The coordinatograph digitizes 1000 units to the inchand if the "map" scale were one inch equals 1320 feet, then the scale factor is 1.32 feet per unit.

The format used by PROGRAM STREAK for the coordinates taken from a vertical photograph is (5X, 3(I4, 3F6.0)). The first five characters (5X) of each card (or line) may be arbitrarily chosen since these are not read by the resection subroutine. The user might use some code to identify which estuary or series of photographs is being studied. The remaining format specifications are the identification number and X, Y, and Z coordinates of three ground control points.

During the photo interpretation phase of data reduction, the user chooses his ground control points. These should be numbered and marked on the vertical photograph or control map.

Next, the ground control reference system is established. It is suggested that a right-hand coordinate system be used with South-North taken as the Y-axis and East as the abscissa. Next, either an origin or reference point is established in the southwestern corner of the vertical photo, using arbitrary or survey determined coordinates.

The coordinates of each successive ground control point to be used in the study are punched according to the format specification. The X and Y coordinates may be found by land survey if accuracy is desired, by measuring manually, or by available coordinatograph equipment. The elevation is recorded to the nearest ten feet.

Estuary Outline

An outline of the estuary should be digitized for future use from the vertical photograph at the same time the ground control file is constructed. This permits extraction of all the pertinent information from the vertical photo at one time and assures direct correspondence of coordinates. The outline file is not utilized by PROGRAM STREAK, but adds a meaningful dimension to plots produced by PROGRAM BAYPLOT and PROGRAM FLASH.

The Fortran format (5X, 3(4X, 3F6.0)) is similar to that of the ground control file. For convenience, all the elevations may be assumed zero.

If the coordinates are not measured in units of feet, correction is necessary. A simple Fortran program is easily devised which can convert measured units to feet (PROGRAM RESCALE in Appendix D).

Photo Measurements

For each photograph, the tabulated photo coordinate points include (1) the principle point, (2) the ground control points visible in the photo, (3) floats, and (4) points describing the outlines of dye segments. Also to be determined for each photograph are the trial values of the orientation parameters $(X_o, Y_o, Z_o, \omega, \phi, \kappa)$.

Each frame is identified by the time at which the photograph was taken. The time code is an integer representation of the time in tenths of a minute based on a 24-hour clock. For example, 9:40:06 a.m. is 09401 and 3:50:30 p.m. is 15505.

The Fortran format used for input to PROGRAM STREAK is (I5, 3(I4, 2F6.0, 6X)). For each card (or each line, if input is from terminal or paper tape), has the time (photo identification) in the "I5" position. The remainder of the information consists of the identification numbers and X and Y photo coordinates for three points. The Z coordinate is zero for all photo points, since the photo is a two-dimensional representation.

The first step in the measurement process is orientation of the flim on a light table. The positive X-axis is in the direction of flight. Y is positive at 90° clockwise from the X-axis, rather than 90° counter-clockwise as in the normal Cartesian system used for ground control. A photo taken while flying north would have south-to-north as the X-axis and west-to-east as the Y-axis (east-to-west is negative).

The principal point serves as a reference. It is usually given the arbitrary photo coordinates (5000, 5000, 0), although any value will do, provided no negative values appear in the other measurements.

With the film positioned and referenced, the photo data file is filled (See Appendices B and D). For each point of interest, the point identification number (I4) and the X and Y photo coordinates 2F6.0) are recorded. The points are taken in sequential order, i.e., principal point, ground control, floats and dye points. The only stipulation is that ground control points do not appear on the same card or line with floats or dye points. Floats and dye points may be listed together.

As described earlier, dye streaks may necessarily be broken into segments to provide more detailed velocity information. The outline of each segment is traced clockwise. The points describing that outline are digitized, each point given an identifying number. The first segment is numbered from 200 to 299, 299 being the closing point of the trace. The second segment is numbered 300 to 399, etc. The last point recorded for each segment must be X99.

After completing the dye measurements, the orientation parameters are estimated and set into a separate data file. These parameters are used as the first step in an iterative solution to the plane (or camera) location and photo orientation. Each line or card of the file contains the time (photo identification), the three position parameters, and three angular orientation parameters of the aircraft. Input is free-form.

It should be understood that the orientation parameter estimates are not direct photo measurements. X_o and Y_o are input as coordinates in the ground control frame of reference whose state-plane coordinates differ by the scale factor. Omega is the rotation of the photo plate about the positive X-axis (ground control frame of reference) in the Y-Z plane. Phi is the rotation in the X-Z plane about the Y-axis and kappa is the final rotation about the Z-axis in the X-Y plane.

There are five steps in orienting an individual plate.

1. Locate the principle point of the photo on the ground control vertical photograph or map.
2. By comparing the film image with the map, determine the direction of flight (azimuth) relative to the Y-axis of the

ground control. The bearing given in the flight notes will be a good indication. Also, the direction of the camera aim in the X-Y plane is readily found in the same operation.

3. Assuming the cameras were aimed at 45° from the vertical, locate back along the line-of-aim in the X-Y plane at a distance from the principle point equal to the altitude of the aircraft (found in the flight notes) to find the aircraft position.
4. Record X_o and Y_o. Record Z_o as the altitude in feet as taken from the flight notes (no correction is necessary).
5. Record omega, phi, and kappa using Figure 3. These approximations have been empirically verified in the present study. An easy estimate of kappa is 180° - AZI, where AZI is the angle clockwise from the ground control positive Y-axis to the direction of flight.

All photo measurements are repeated for each photograph of the batch.

PROGRAM STREAK

PROGRAM STREAK is run with two subroutines. Subroutine RESECT determines the orientation of each photograph and the rotation (or transformation) matrix using photo coordinates of the principle point and ground control points, the ground coordinates of the control points, and the estimated orientation parameters. The main program,

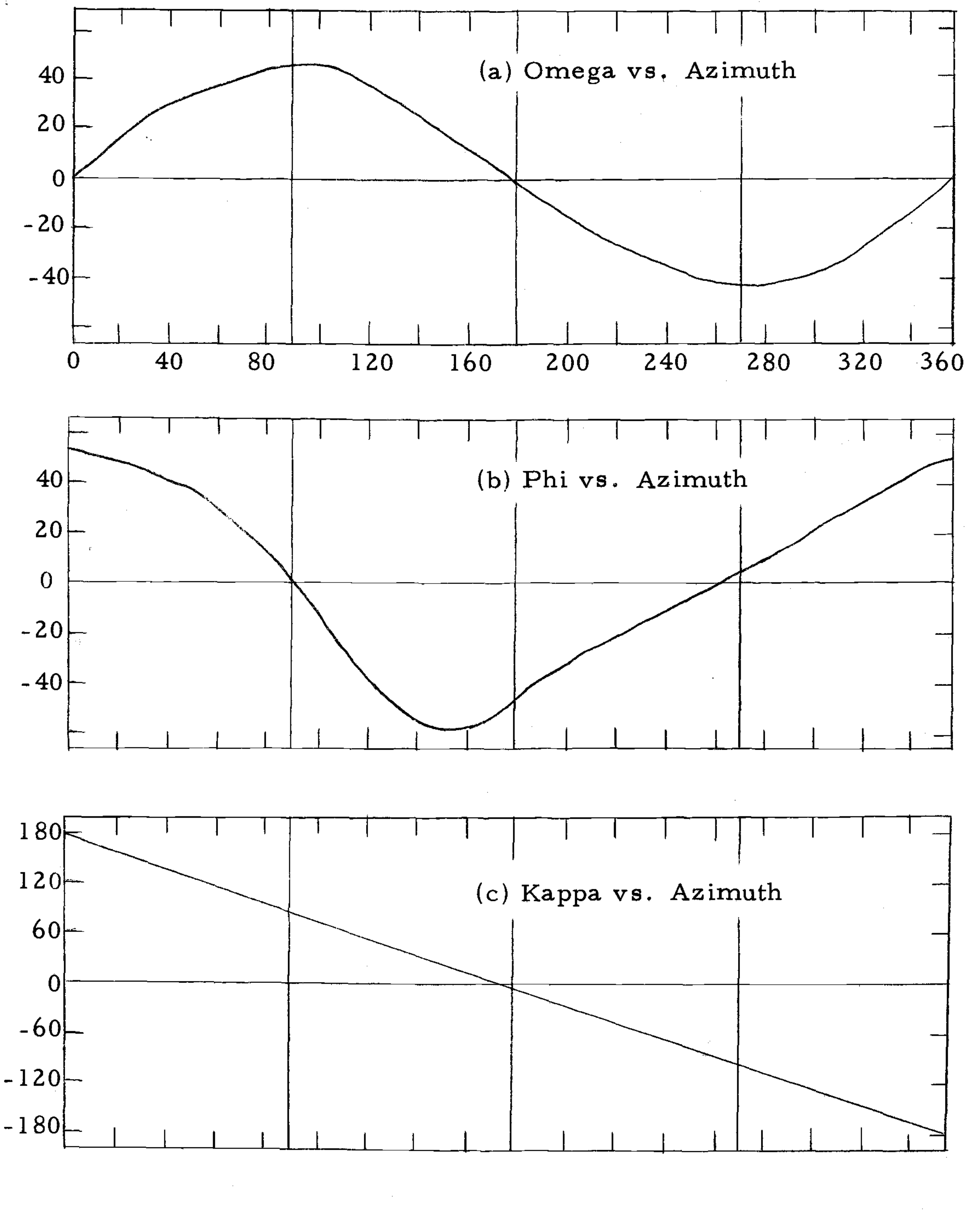


Figure 3. Angular orientation parameters vs. azimuth.

using the results of RESECT, then converts photo coordinates of points of interest (floats or dye outlines) to ground coordinates. If dye segment outline points are input, subroutine SECPROP (Burgess and James, 1971) is called to compute the area, centroidal coordinates, and moments of inertia for each dye segment. The main program calculates the magnitude and direction of the currents indicated by the dye segment centroid's position and float positions. The information is stored in two data files, one for immediate interpretation and one for subsequent plotting routines.

Subroutine RESECT performs individual photo resection and calculates the rotation matrix ($\underline{C}$) which relates photo coordinates of a point to the ground coordinate system. Resection in photogrammetry is defined as the determination of the six fundamental parameters, ($X_o, Y_o, Z_o, \omega, \phi$, and κ) of the single photograph from the given positions and elevations of at least three noncolinear point images on the photograph. X_o, Y_o, and Z_o are the initially unknown coordinates of the camera in the ground system. The three angular parameters constitute rotations about the coordinate axes as described in the previous section and in Appendix A.

The general relationship used in both RESECT and the main program is

$$\begin{bmatrix} X-X_o \\ Y-Y_o \\ Z-Z_o \end{bmatrix} = \lambda \underline{C}^T \begin{bmatrix} y-Yp \\ x-Xp \\ -f \end{bmatrix}$$

where X, Y, Z are the ground coordinates, x and y are photo coordinates of the point, f is the calibrated focal length of the camera, and lambda is a scaling factor or ratio of direction cosines. Resection and determination of $\underline{C}$ is initiated by inputting the photo coordinates of ground control points and their coordinates on the ground, along with the estimated orientation parameters, (X_o, Y_o, Z_o, ω, ϕ, and κ).

Subroutine SECPROP performs areal property calculations given the ground coordinates of dye patch outline points. The area of the dye segment (A) is given by

$$A = \frac{1}{2} \sum_{i=1}^{n} X_i (Y_{i-1} - Y_{i+1})$$

The coordinates of the centroid ($\overline{X}$ and $\overline{Y}$) are found using the expressions

$$\overline{X} = \frac{1}{6A} \sum_{i=1}^{n} Y_i [X_{i+1}(X_i + X_{i+1}) - X_{i-1}(X_i + X_{i-1})]$$

$$\overline{Y} = \frac{1}{6A} \sum_{i=1}^{n} X_i[Y_{i-1}(Y_i+Y_{i-1})-Y_{i+1}(Y_i+Y_{i+1})]$$

The basis for diffusion coefficient calculations is a two-dimensional Fickian model (Burgess and James, 1971). First, the irregular shaped dye patch is represented by "an equivalent ellipse" that has the same area, the same ratio of principle moments of inertia, and is fitted to a line of equal concentration about the dye patch. The major and minor semi axes of the ellipse are found by calculating the moments of inertia about the centroidal axes and computing the principle moments of inertia using Mohr's circle equations. Next, it is assumed that the dye concentration at the visible edge of the patch is one-half the concentration at the centroid. D_x and D_y, the longitudinal and lateral diffusion coefficients, are proportional to the change in size of the equivalent ellipse between photographs.

The remaining calculations are performed in the main program. The velocity of the dye is simply the distance between the centroids of the dye segments in two photographs divided by the time between the photographs. The magnitude is reported as an absolute value, while the direction is given by an azimuth. The azimuth is the clockwise rotation from the y-axis in the ground control system of a line extending from the centroid of the dye segment in the first photo to its centroid in the second photo.

The program may be run from batch or teletype, whichever is more convenient (see Appendix B). To be run from teletype, the majority of the data must be stored and called from file, as it is quite tedious to type in all the photo coordinates for a series of photographs.

File input is in three units (Table 2). A title or label and the value of "MARGIN" are read from standard input, photocoordinates are read from logical unit number (LUN) 8, ground control is on LUN 9, and photo orientation is read from LUN 10.

One user option is to have the outline of each dye patch or dye segment plotted by PROGRAM BAYPLOT or FLASH. If outlines are desired, the variable "MARGIN" is set equal to 2. If not, "MARGIN=1" and the state-plane coordinates of dye points are not stored for plotting.

The output from PROGRAM STREAK is on two separate scratch files. LUN 20 contains corrected orientation for each photograph and velocity and diffusion information for each dye streak segment. LUN 2 provides all information for plotting, including ground coordinates of dye outline points, ground coordinates of dye centroids, and velocity magnitudes. Line printer records should be made of both files.

Table 2. Scratch file (logical unit number) assignment.

Program	Input/output	LUN	Description
STREAK	IN	8	photo coordinates of principle point, ground control points, floats, and dye outline points
	IN	9	ground control ground coordinates
	IN	10	orientation parameter approximations
	IN	60	value of "MARGIN"; title card
	OUT	2	data for plotting
	OUT	20	tabulated orientation, velocity, and diffusion calculations
BAYPLOT	IN	2	data for plotting
	IN	30	coordinates of estuary outline points
	IN	60	values of "VS", "IGS", and magnification
	OUT	1	CALCOMP plot
FLASH	IN	2	data for plotting
	IN	30	coordinates of estuary outline points
	IN	60	values of "VS" and "IGS"
	OUT	61	tekplot

Graphical Display

To display graphically the results of the current studies, two computer programs have been written. PROGRAM BAYPLOT is designed to display the velocity vectors within the outline of the estuary on a labeled grid system. Thus, a synoptic current picture can be produced for any time of the tidal cycle. An adaptation of PROGRAM BAYPLOT, PROGRAM FLASH has been designed exclusively for display on the Tektronix T-4002 cathode ray tube terminal. The graphic output is identical to the Calcomp plots produced with PROGRAM BAYPLOT. The program is initiated and run from the T-4002.

Each plot program:

1. Constructs and labels a grid of the area of interest, the labels being ground coordinates.
2. Plots the outline of that portion of the estuary found in the area of interest.
3. Draws the outlines of dye patches if that information is available.
4. Plots the centroid of each dye segment or float in the data file.
5. Constructs and labels velocity vectors for each dye segment or float. The direction of the vector is that of the centroids motion and the vector length is proportional to the average speed of the object.

Float and dye data is read by the programs from LUN 2. If the program is run in conjunction with STREAK, the output of STREAK can be used immediately by simply rewinding LUN 2 and proceeding without any alteration.

In creating the file, strict attention should be paid to the Fortran format specification. Dye outline points should be listed first, followed by dye vector and finally float vector data.

The coordinates of points defining the outline of the estuary are loaded into LUN 30. It is recommended that the outline deck be loaded with the PROGRAM BAYPLOT from batch, thus eliminating the need for storage of the large number of points.

The velocity vector scale factor and the size of the grid divisions, standard input (LUN 60), is necessary to both programs. The velocity scale factor (VS) is the number of scaled feet equal to one foot-per-second. For example, if VS=100, then a vector of magnitude one F.P.S. will be 100 feet long. The grid scale factor (IGS) determines the number and interval of grid divisions. One thousand must be nearly evenly divisible by IGS. Recommended grid sizes are 50, 100, 125, 200, 250, 333 and 500 feet.

The user may magnify the CALCOMP plotted output up to 2.75 times. The normal BAYPLOT will be 6.90 by 6.90 inches, with resolvable points 0.01 inches apart. The X and Y magnification desired are input in the format (2F4.2). If no magnification is desired, XMAG and YMAG are both read in equal to 1.00.

Since PROGRAM BAYPLOT will not write the identification, a special label control card must be included with the card deck.

Use of the graphical display routines is explained in more detail in Appendix C.

V. CONCURRENT FIELD DATA

Lint Slough Study

On August 8 and 9, 1972, the current circulation system at Lint Slough on Alsea Bay, Oregon was investigated. The study was made in anticipation of a new outfall for the City of Waldport's sewage treatment facilities. Concern was expressed that on flood tide, effluent released into the Alsea River might find its way into Lint Slough. Also, the circulation patterns within the slough, which determine the fate of effluent from the present outfall, were of interest. Integration of the results permitted a determination of the relative flow rates of the slough and the river channel.

Three current measuring stations were established in the main channel of the Alsea River upstream of the Lint Slough juncture and one current measuring station was established at the mouth of Lint Slough. Bathymetry at both sections was taken. Current measurements were made at regular intervals with Price Current Meters during flood tide. Readings were at six-tenths depth (four-tenths distance from the bottom), the theoretical depth of average velocity (Webber, 1965).

A number of dye releases were made a few hundred yards downstream of the stations. The first two releases each consisted of a line of dye extending across the entire river channel. A dye plume was later initiated near the same release point. Shallow draft drogues were set adrift with each dye release.

Photographs of the study area were taken at approximately two minute intervals from an altitude of two thousand feet. The black and white film processing was handled entirely by the O.S.U. photo service. The color film was processed by Kodak process E-3 by the Ocean Engineering research personnel.

The photograph in Figure 4 shows one of the dye streaks moving up the Alsea river (right to left, or eastward) at the mouth of Lint Slough. As evidenced by the angular shape of the streak, the current at the center of the channel is much stronger than nearer the banks. This streak was broken visually by the technician into three segments during the photo measurement stage of data reduction. The computer representation (Figure 5) indicates the movement of these three segments from their initiation past the study area.

One dye streak became two, as the jetty separated the flow of the dye. Figures 6 and 7 not only show the dye pattern, but provide resolution of bottom features. The deeper portions and channels of Lint Slough are darkly colored and the shallower mud flats, the kelp beds, and rocks are clearly visible, even though covered with silt ladden water. Figure 8 is a computer controlled plot of the results from this series of photographs, Tek-Plot above, Cal-Comp below.

Correlation of the velocities obtained by aerial photography and

Figure 4. Dye streak No. 4, Lint Slough, Aug. 8, 1972.

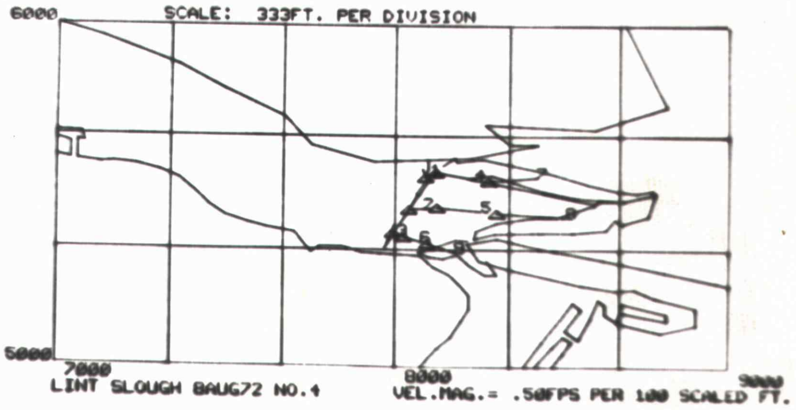


Figure 5. Computer representation of dye streak No. 4.

Figure 6. Dye streak No. 2, Lint Slough.

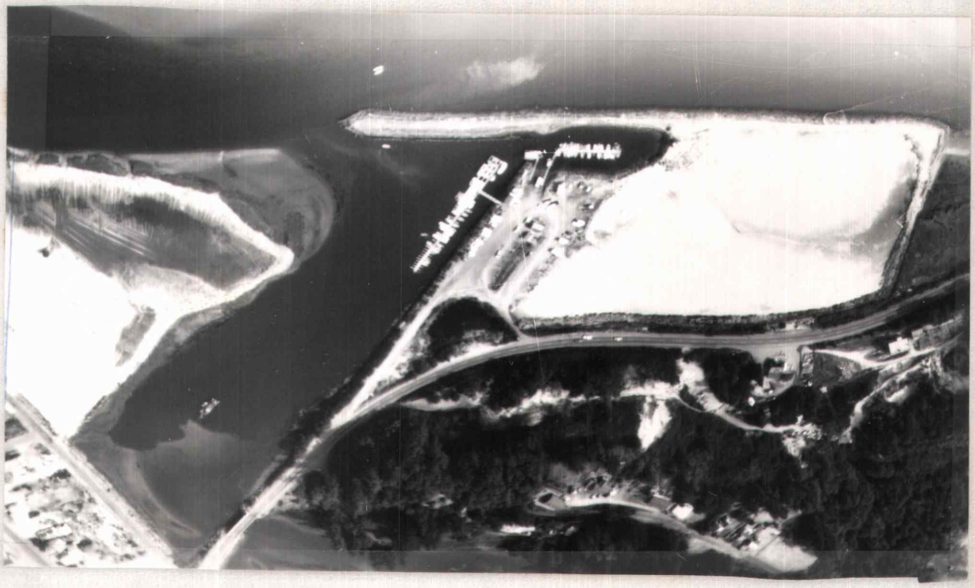
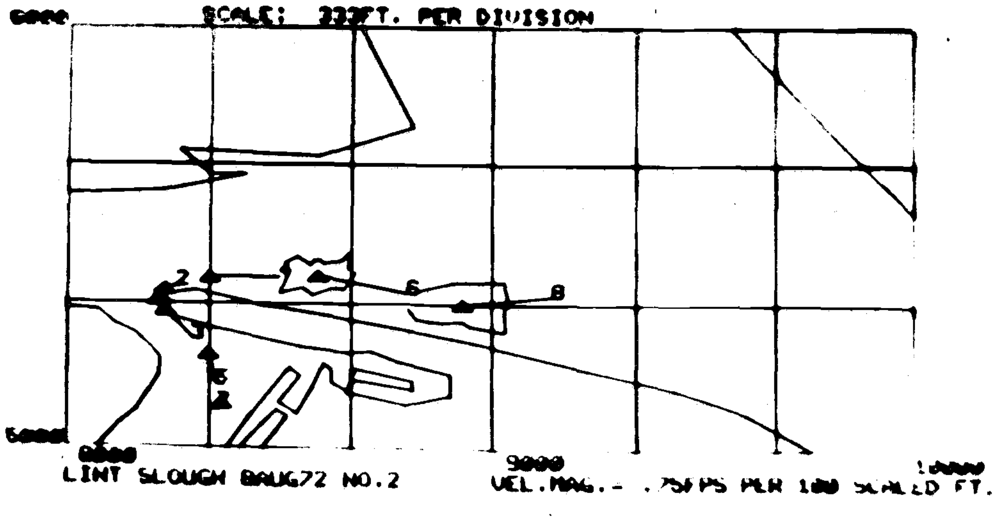
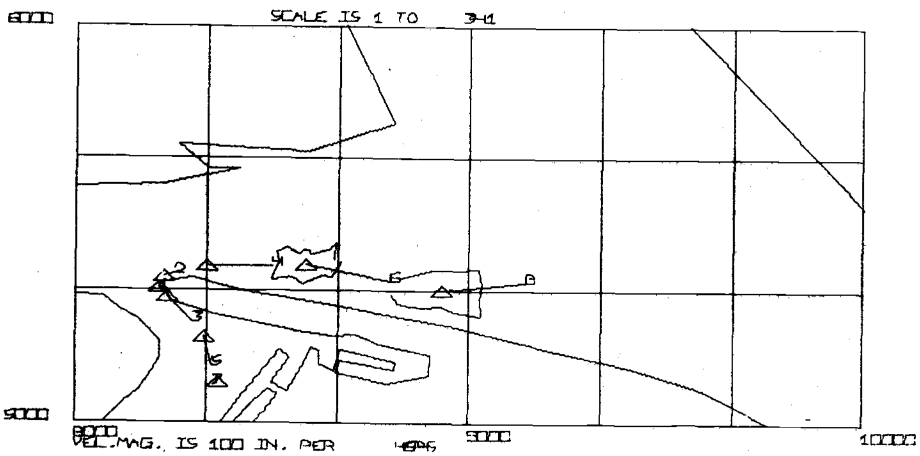


Figure 7. Dye streak No. 2 after 100 seconds.



a. Tek-Plot



b. Cal-Comp

Figure 8. Computer representation of dye streak No. 2.

by current meters is shown in Figure 9. Three photographs which showed dye in the vicinity of a current measuring station were utilized in this comparison. Those velocities obtained were compared to the velocity measured at approximately the same time at that station. The least-squares-fit yielded a slope of 1.15, which indicates that the velocity of the surface and near surface waters as found from aerial photographs can be expected to be 15 percent larger than those velocities measured at six-tenths the depth for a well mixed estuary. This result tends to agree with the empirical law: the mean velocity is approximately 85 percent of the surface velocity (Vennard, 1940).

The dye movement proved to be indicative of the movement of the water mass to a depth of about one foot, as the drogues traveled consistently with the dye marked waters.

The ebb tide study provided no opportunity to compare the aerial method with current meters. Dye streaks were released at three sections of the upper (southern) portion of Lint Slough and a dye patch was placed at the present outfall site (Figure 10). Current meter data was taken at a known cross section in an effort to measure the flow rate. Tide records at each end of the study area provided tidal height and phase lag information.

The aerial photographs confirmed earlier drogue study results. Computer plots established the predominent flushing pattern as following the main channel of the slough and passing under the docks at the

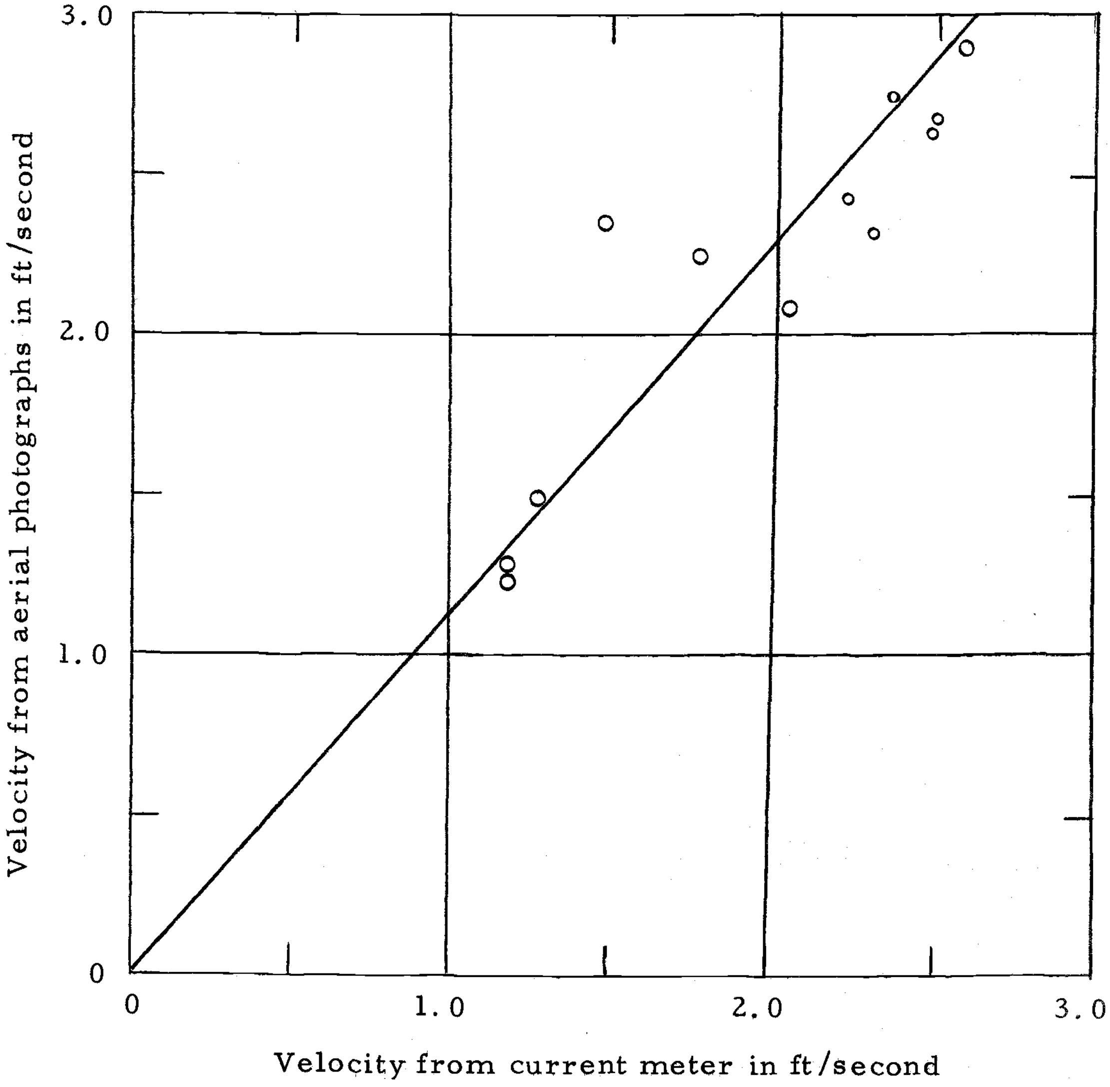


Figure 9. Comparison of velocities obtained from current meters and aerial photographs.

marina before entering the Alsea River.

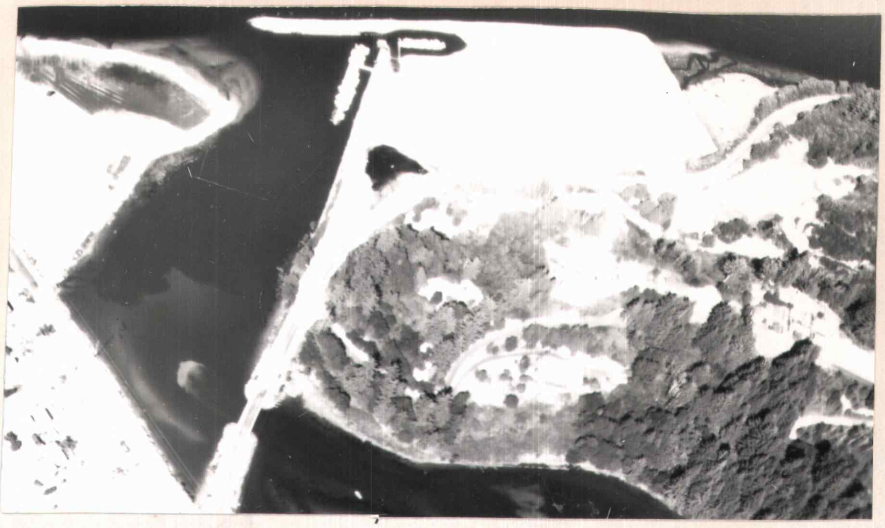


Figure 10. Dye patch at Lint Slough, Aug. 9, 1972.

The research team found that on the flooding tide the flow into the slough is approximately one-tenth the flow upriver, as a comparison of the relative sizes of the two tidal prisms would predict. The ebb tide currents are well defined and well over 90 percent of the region above the existing outfall is flushed out each tidal cycle.

Siletz Estuary Study

A study of a more complicated circulation pattern was performed under winter runoff and spring tide conditions. The Siletz estuary, located approximately 95 miles south of the Columbia River mouth (Percy, 1973), had received much attention because of extensive erosion on both the ocean side and bay side of the sand spit and because of environmentalist's concern for the future of the estuary and its drainage basin. Aerial photographs of dye releases on February 17, 1973, along with water quality data, sediment samples, and continuous seasonal tide records have been collected to aid in creating a more complete hydraulic description of Siletz.

Important to the effort of this project was the extensive use of articulated dye streaks as targets for aerial photography. Figure 11 shows the northern portion of the Siletz Bay with a segmented dye release extending from the spit toward Cutler City. Each segment takes on a characteristic shape which readily distinguishes it in later photos. Thus, large numbers of individual dye segments not only provide more targets, but alleviate much confusion in photo interpretation.

The successful use of articulated streaks over the entire estuary led to the formation of Figure 12. Shown in Figure 12 is the computer representation of Siletz Bay and a fraction of the velocity information produced between 2:12 and 3:30 p.m. during ebb tide.

Figure 11. Dye release on Siletz Bay.

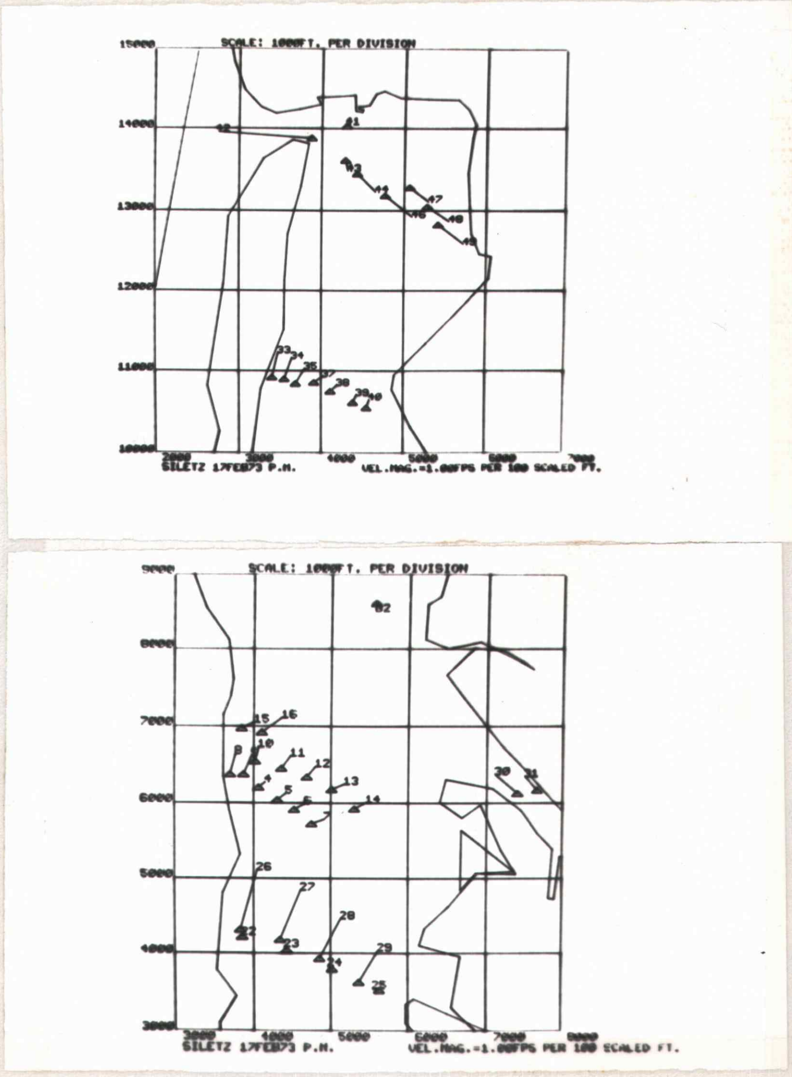


Figure 12. Partial results of Siletz study.

VI. DISCUSSION OF METHODS AND RESULTS

Precision of a Single Measurement from an Aerial Photograph

In an effort to determine the precision attainable with the existing operators and techniques, a trial was devised. A single photograph was selected as being representative of the quality of photography and the aircraft orientation of the majority of photographs. The ground coordinates of several points chosen at random across the entire photograph were found repeatedly using PROGRAM STREAK.

For each of the 40 trial runs, the photo coordinates of each of the five ground control points and the eight points of interest were digitized. Thus, each run represented a solitary group of measurements and calculations, yielding its own set of photo orientation parameters, orientation matrix, and X and Y coordinates of the points of interest.

Each coordinate of the eight points was considered a variable and each calculation result was considered an observation on that variable. This resulted in 40 observations on each of 16 variables. Calculations of the mean, median, standard deviation, and skewness provided a statistical description of each variable.

The mean, or sample average of variable X is given by

$$\overline{X}_i = \frac{1}{n_i} \sum_{j=1}^{n_i} X_{ij}$$

The variance:

$$s_i^2 = \frac{1}{n_i - 1} \sum_{j=1}^{n_i} (X_{ij} - \overline{X}_i)^2$$

The standard deviation:

$$s_i = \pm\sqrt{s_i^2}$$

The skewness:

$$m_i = \frac{1}{n_i - s_i^3} \sum_{j=1}^{n_i} (X_{ij} - \overline{X}_i)^3$$

It was found that for those points which fell within an area bounded by the ground control points, the standard deviations (or standard errors) were lowest and nearly the same in magnitude. For this "area of confidence," it was assumed that a single standard error could be calculated on the basis that the standard deviation of a population is the mean of the standard deviations of the individual random samples.

$$\sigma_s = \frac{1}{n} \sum_{i=1}^{n} s_i$$

It was determined that within the region of confidence of a single photograph, the ground coordinates of a point have a standard error of ±3.411 feet.

Error in Velocity Measurements

If each individual measurement has a standard error σ_s, then the distance between two points will have a standard error $\sqrt{\sigma_s^2 + \sigma_s^2}$, or $\sqrt{2}\,\sigma_s$. Subsequently, the time lapse distance traveled between successive photographs will have a standard error of ±4.823 feet.

For each velocity measurement, the standard error would be $\pm \frac{4.823}{t}$ ft/sec where t is the time interval in seconds. In the Lint Slough study, the average time interval was 230 seconds for the 30 photographs. Ordinarily, times of two to three minutes are expected, as the plane can usually make a pass over the dye in this amount of time.

Using 165 seconds as a mean time interval, the mean standard error computation from this set of photos becomes ±0.029 ft/sec, which is quite small compared to the velocities measured (Figure 9).

Accuracy of Drogue Monitoring Methods

Whenever the research team conducted drogue studies, drogues were tracked exclusively from small boats. The boats are not equipped with position finding instruments, so all position records are from visual observations. Two methods of reference were employed:

1. a grid scored chart or high altitude vertical photograph from which the coordinates of each drogue could be approximated

by orienting the observer and drogue with respect to discernable shoreline sitings,

2. range poles placed at near even intervals along the estuary.

The grid system is most applicable to large areas and deep water, whereas the range pole system is useful for narrow bodies of water. It is difficult to determine the precise location of drogues on the water a great distance from land marks. As a result, the grid system method can yield large errors for small drogue displacements.

The range pole method is subject to similar shortcomings. Range poles were set for the ebb tide study of Lint Slough on August 9, 1972. Twenty-nine poles were placed at approximately 100 foot intervals along the west side of the channel. The pole positions were determined by triangulation with a transit.

Determination of drogue positions relative to the range poles proved to be highly uncertain, due to parallax problems. A drogue might be as far as 200 feet from the line of range poles, in which case the boat orientation determined where the observer located the drogue. It is conceivable that some travel lengths were in error as much as 100 feet. This would indicate a percent uncertainty of velocities ranging from ten to 40 percent. This method can be improved by placing range poles on both sides of the channel. Parallax problems are minimized by siting across pairs of range poles.

VII. CONCLUSION

Qualitative information about tidal and wind induced circulation patterns has been obtained from aerial photographs in studies of shore erosion on the Siletz estuary, in an outfall site selection study in Alsea Bay, and in dredge spoil distribution studies on other Oregon estuaries. The aerial photographs provide permanent visual records which show directions and magnitudes of flow and often locate stagnation zones and regions of intense shear.

The oblique aerial photography method, which relies upon digital computer computation for final data reduction, has proven workable and preferable to other methods, including surface based surveys and the parallax method of photogrammetric current measurement.

Limitations of Aerial Photography

Good flying conditions are essential for the successful use of aerial photographic methods. The sky should be clear. Broken clouds can be tolerated if they are well above the flight elevation. The water surface brightness is increased by skylight reflection from the cloud cover. Polarizing filters can be used to reduce this reflection, however, scattered clouds will cast shadows which result in uneven lighting. Fog, common along the West Coast during the summer, renders aerial photography ineffective.

The time of day is also significant. Experiences in the field have shown that adequate photography is usually possible during the summer months between 0930 and 1630 hours daylight time. During these hours, the sun altitude is high enough to provide sufficient lighting. Since the photographing plane is always positioned between the sun and the subject, at low sun altitudes the sunlight will not reflect back sufficiently for satisfactory exposures.

Wind can cause complications, more so for the ground crew than the aircraft. Severe winds can produce hazardous operating conditions for small boats and the dye must be seeded from the aircraft. The effectiveness of dye patches is sharply reduced in choppy waters; the dye disperses quite rapidly and is difficult to distinguish visually from the air. Furthermore, the effect of wind driven currents is difficult to separate from tidal currents.

Summary of Present Techniques

The methodology developed has proven the most satisfactory in terms of cost and amount of data generated of any circulation analysis technique evaluated.

Oblique aerial photographs taken with a large format aerial camera provide opportunity for adequate ground control and reduce direct sunlight reflection from the water surface. A camera package which also contains smaller cameras with different film combinations optimizes information and aids in photo identification. A unit with the cameras mounted at an inclination to the vertical is easily secured in a light aircraft with a removable baggage door.

The most suitable target is rhodamine WT tracer dye. The diluted dye is best seeded from small boats in articulated streaks across the estuary. To gain maximum utilization of dye and facilitate reduction of photographic data, dye segments of equal length and spacing are laid in each run. As the dye mixes and moves with the water mass, photographs are taken at two to three minute intervals. The photos can be taken from any elevation, bearing, or plane orientation as long as sufficient ground control and minimal sunlight reflection exists.

An X-Y coordinatograph connected to a digitizer and standard card punch is used to digitize coordinates of photo images on the photographic film. The data is input to a computer program which (1) computes the orientation and rotation matrix for each photograph from the composite station coordinates of points identifiable as ground control points in the photo, (2) computes the X and Y ground coordinates of photo points measured in the photographic X-Y plane, and (3) computes and stores coordinates and velocities of dye segments in a format compatible with the plotting routines.

The resulting current patterns are represented pictorially on available plotting equipment, either a cathode ray tube terminal or computer controlled pen plotter. The graphical display outlines a portion of the estuary under study and identifies the position of each dye segment centroid at the time of each photograph. The outline of each dye patch can also be plotted and the direction and magnitude of the water movement is indicated with a velocity vector.

The reliability of velocities determined by this method has been established by correlation with concurrent current meter measurements. It has been found that the velocity of the surface and near surface waters as determined from the air is 15 percent larger than those velocities measured at six-tenths the depth. The standard error for a representative group of aerial velocity computations is less than 0.03 feet per second.

The techniques developed are adaptable to current studies in lakes, rivers, and the ocean nearshore. The data reduction progresses swiftly and a technician can process the data for one dye release in a little more than one hours time. Since one dye release may consist of eight dye segments appearing on five to ten photographs, 30 to 70 velocity vectors can be derived. The ability to economically analyze large volumes of data, combined with concise methods of graphical display leads to an expected increase in future use of aerial photography techniques in hydraulic studies.

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APPENDICES

APPENDIX A

DEVELOPMENT OF RESECTION SUBROUTINE

Resection in photogrammetry is defined as the determination of the six fundamental parameters ($X_o, Y_o, Z_o, \omega, \phi, \kappa$) of a single photograph from the given positions of three or more objects and their corresponding images on the photograph. Once these parameters are known determination of positions on the ground of any object having a photo image is possible.

The development of the subroutine by the U.S. Coast and Geodetic Survey (Keller and Tewinkel, 1966) followed earlier work on analytic aerotriangulation (Harris, Tewinkel, and Whitten, 1962). James (1970) adapted the subroutine for computer processing photographs in his ocean outfall studies.

Rotation Formulas

The relative orientation is based on a classic geometric rotation of coordinate axes in three dimensions. Three sequential rotations, rather than the three angles between respective axes, are used (Harris, *et al.*, 1962).

The x, y, z-coordinate system is used to identify the position of the image on the photograph. The X, Y, Z-coordinate system is a rectangular ground coordinate system in which Z is positive upward and X and Y form a right handed sequence (i.e., if +X is eastward, +Y is northward).

The x^*, y^*, z^*-coordinate system is introduced. It has the same origin as the x, y, z-system, but varies in angular orientation. Also, the x^*, y^*, z^*-axes are parallel to the X, Y, Z axes, respectively. The sequence of rotations allows expression of x, y, z-values in terms of x^*, y^*, z^* coordinates. A rotation matrix $\underline{C}$ will be derived such that

$$\underline{X} = \underline{C}\,\underline{X^*} \tag{1}$$

and

$$\underline{X^*} = \underline{C}^{-1}\underline{X} \tag{2}$$

Omega is the x-tilt counterclockwise positive about the x^* axis. The x', y', z'-coordinate system is introduced to identify the coordinates of the image point P in terms of x^*, y^*, z^* for the "ω" rotation.

The second rotation (ϕ) is the y-tilt about the inclined y'-axis counterclockwise positive.

The third rotation (κ) is the counterclockwise angle from the reference x-axis to the corresponding photo x'-axis. This is actually the swing about the twice rotated z^*-axis.

The resulting rotation matrix (Harris et al., 1962) is as follows:

$$\underline{C} = \begin{bmatrix} c11 & c12 & c13 \\ c21 & c22 & c23 \\ c31 & c32 & c33 \end{bmatrix} \quad (3)$$

where

$c11 = \cos\phi \cos\kappa$

$c12 = \cos\omega \sin\kappa + \sin\kappa \sin\phi \cos\kappa$

$c13 = \sin\omega \sin\kappa - \cos\omega \sin\phi \cos\kappa$

$c21 = -\cos\phi \sin\kappa$

$c22 = \cos\omega \cos\kappa - \sin\omega \sin\phi \sin\kappa$

$c23 = \sin\omega \cos\kappa + \cos\omega \sin\phi \sin\kappa$

$c31 = \sin\phi$

$c32 = -\sin\omega \cos\phi$

$c33 = \cos\omega \cos\phi$

Since the transformation matrix is orthogonal, the inverse equals its transpose and Equation (2) becomes

$$\begin{bmatrix} x^* \\ y^* \\ z^* \end{bmatrix} = \begin{bmatrix} c11 & c21 & c31 \\ c12 & c22 & c32 \\ c13 & c23 & c33 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} \quad (4)$$

Projection Transformation

The relation between the x^*, y^*, z^* image coordinates on the photograph and the X, Y, Z coordinates of the object on the ground is shown in Figure A-1.

X_o, Y_o, Z_o are the initially unknown coordinates of the camera in the ground system. By similar triangles,

$$\frac{X-X_o}{Z-Z_o} = \frac{x^*}{z^*} \tag{5}$$

Thus,

$$\begin{aligned} x^* &= (X-X_o)z^*/(Z-Z_o) \\ y^* &= (Y-Y_o)z^*/(Z-Z_o) \\ z^* &= (Z-Z_o)z^*/(Z-Z_o) \end{aligned} \tag{6}$$

Substituting these expressions into Equation (1) yields

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \underline{C} \begin{bmatrix} X-X_o \\ Y-Y_o \\ Z-Z_o \end{bmatrix} \left(\frac{z}{Z-Z_o}\right) \tag{7}$$

Expanding and dividing $\underline{x}$ and $\underline{y}$ by $\underline{z}$ gives the projection transformation equations,

$$\frac{x}{z} = \frac{(X-X_o)c11 + (Y-Y_o)c12 + (Z-Z_o)c13}{(X-X_o)c31 + (Y-Y_o)c32 + (Z-Z_o)c33} \tag{8a}$$

$$\frac{y}{z} = \frac{(X-X_o)c21 + (Y-Y_o)c22 + (Z-Z_o)c23}{(X-X_o)c31 + (Y-Y_o)c32 + (Z-Z_o)c33} \tag{8b}$$

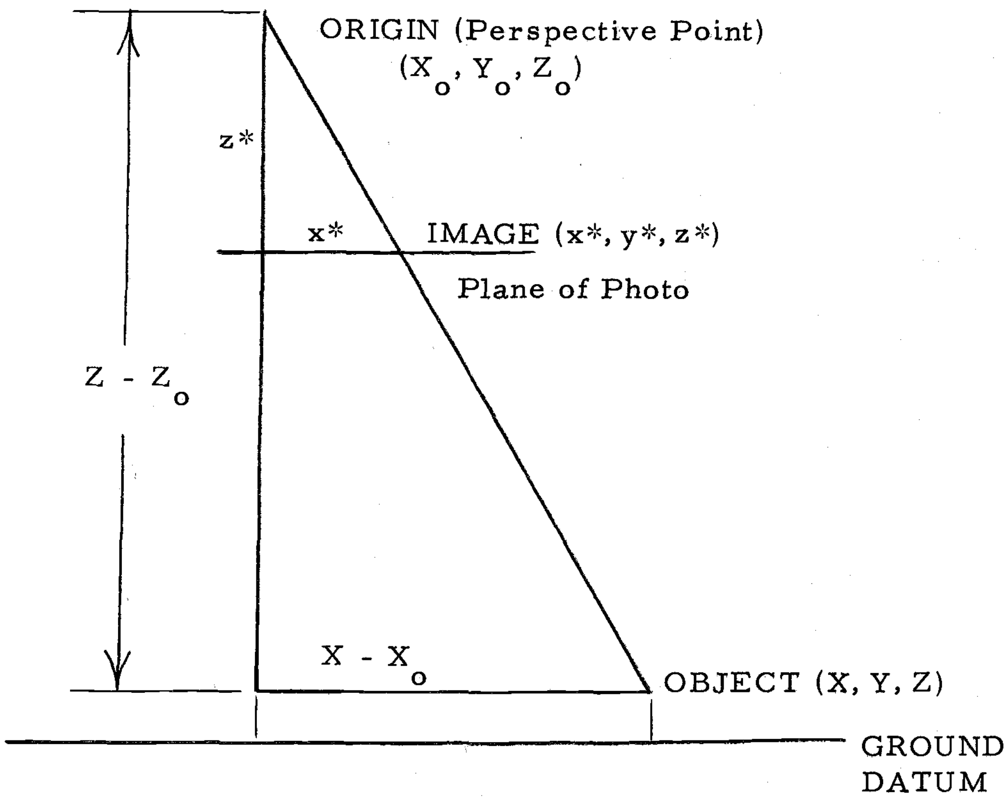

Figure A-1. Relation of rotated photo coordinates to ground coordinates.

The values for x and y for a set of images are measured. z is a constant equal to the calibrated focal length of the camera and is considered to have a negative sign. X, Y, Z are known for each image point of the set. The six parameters are given initial approximations and are adjusted iteratively until the adjustment is small (less than 0.00001 radians). A form of Newton's Method is used.

A pair of projective transformation equations (Equations (8a) and (8b)) is generated by each image-object of the set. Six equations (three images) are required to solve for the six unknowns.

Adjustments $(dX_o, dY_o, dZ_o, d\omega, d\phi, d\kappa)$ are obtained by simultaneous set of observations equations derived by applying partial differentiation to Equation (6) and rearranging terms. The 14 coefficients of the observation equations are the p-terms of the subroutine.

Initial Approximations

The angular parameters can be approximated by using Figure 3, given the direction of flight. The mounting angle of the camera axis is 45° and the camera is mounted on the port side of the aircraft.

Solution by Computer

The observation equations previously described are reduced to six normal equations and solved by gaussian elimination, as described by Harris _et al_. (1962) and Keller (1966).

The output of subroutine RESECT consists of corrected values for the six parameters of the photograph plus the corresponding C-matrix.

Coordinate Transformation

Once the resection is complete, each image point of the photograph can be subjected to a coordinate transformation to determine the ground coordinates of the object. Again,

$$\underline{X} = \underline{C}\ \underline{X}^* \tag{9a}$$

$$\underline{X}^* = \underline{C}^T \underline{X} \tag{9b}$$

Referring to Figure A-1 and Equation (5), the following Fortran expressions are generated, using z equal to -focal length and Z equal to zero.

XT = C(1,1)*XI+C(2, 1)*YI - C(3, 1)*FL (11a)

YT = C(1, 2)*XI+C(2, 2)*YI - C(3, 2)*FL (11b)

ZT = C(1, 3)*XI+C(2, 3)*YI - C(3, 3)*FL (11c)

and

$$X = X_o - Z_o{*}XT/ZT \tag{12a}$$

$$Y = Y_o - Z_o{*}YT/ZT \tag{12b}$$

APPENDIX B

USE OF PROGRAM STREAK

PROGRAM STREAK was designed to calculate photo orientations and velocities of identifiable photo objects. The program is written in Fortran IV for use on the CDC 3300 of the OS3 operating system.

Digital data is taken from the photographic film using an X-Y coordinatograph connected to a Model 3700 Autotrol digitizer and a standard card punch. The computer program (1) computes the orientation matrix of each photograph from composite station coordinates of three or more non-colinear points identifiable as ground control points in the photo, (2) computes the X and Y ground coordinates of photo points measured in the photographic X-Y plane, and (3) computes and stores coordinates and velocity information of dye patches and surface floats in a format compatible with the plotting routines.

Flight Information

As each photograph is taken, the following should be recorded:

1. Exposure number.
2. Time to nearest five seconds.
3. Bearing (azimuth from magnetic north) of aircraft.
4. Altitude.
5. Approximate roll (tilt of wings from level).

6. Approximate position of either the aircraft or the target.

Equipment

1. A light table for the 9 1/2 x 9 1/2 K-17 aerographic film.
2. X-Y coordinatograph connected to the Autotrol Digitizer.
3. Standard card punch - IBM 026.
4. Large scale vertical photograph or a detailed map of the estuary.

Identifying Numbers

Each frame is given an identification number which corresponds to the time at which the photograph was taken. The time code is the time in tenths of a minute based on a 24-hour clock. For example, 9:40:06 a.m. is 09401 and 3:50:30 p.m. is 15505.

Each point of interest is given a three digit identification number.

000 - Principle point of photograph (exact center of the exposure).

001 through 099 - Ground control points. These are specific points which are identifiable in the oblique photograph and on a large scale map or a vertical aerial photograph of known scale, or whose state-plane coordinates are determined by a land survey. At least three non-colinear ground control points must be located on each photograph in order to allow computation of the state-plane coordinates

for photopoints.

100 through 199 - Floats. The last float observed in a batch is labeled 199. For instance, if there are three floats being tracked in one photo batch, they can be designated 101, 141, and 199. In another batch, where only one float is present, it must be numbered 199.

200 through 299, 300 through 399, . . . , 900 through 999 - Dye patch outline points. The first segment is numbered 200 to 299, 299 being the closing point of the clockwise traced outline. The second segment is numbered 300 to 399, etc. The last point recorded for each segment must be X99.

Coordinate Systems

The ground control coordinate system may be totally arbitrary, or it may be referenced to another system, as Range and Township lines of a public land survey. It is suggested that south-to-north be taken as the Y-axis and east as the abscissa. An origin or reference point is established on the "map" and given the arbitrary or survey determined coordinates. Coordinates of all ground control points and estuary outline points are in this system, and all photo points coordinates are converted by PROGRAM STREAK to coordinates in this system.

The photographic coordinate system is quite different. The positive X-axis is in the direction of flight. Y is positive at 90°

clockwise from the X-axis, rather than 90° counter-clockwise as in the normal Cartesian system used for ground control. A photo taken while flying north would have south-to-north as the X-axis and west-to-east as the Y-axis (east-to-west is negative).

Photo Interpretation

1. Identifying individual photographs. Referring to the flight notes, label each photograph.

2. Group photos according to targets. For example, all the photographs of a dye release at 10 a.m. are placed in the same packet. Their data is digitized and run as one batch.

3. Select ground control points. Scan all of the photos to be processed and select a number of ground points whose images are recognizable in several of the photos and on the reference photo or map. Some typical ground control points are corners of buildings, road intersections, bridge piers, and small stream junctures. Not only are three non-colinear points required for resection of a single photograph, but faster converging solutions and better results are obtained if the points are evenly dispersed about the principle point. Photographs that can not be resolved because of insufficient ground control must be discarded.

Ground Control - LUN 9

1. Format Specification. (a) The Fortran format used by PROGRAM STREAK for the coordinates taken from the vertical photograph is (5X, 3(I4, 3F6.0)). Check to be sure that the correct Removable Patch Panel is installed in the digitizer.

(b) The first five characters of each card (or line) in LUN 9 may be arbitrarily chosen, since these are not read by subroutine RESECT. The user might use some code to identify which estuary or series of photographs is being studied. Set the Autotrol CONSTANT DATA switches 1-5 with the code chosen. Set all other CONSTANT DATA switches to zero.

(c) The remaining format specifications are the identification numbers and X, Y, and Z coordinates of three ground control points.

2. Reference Point. (a) Position the "map" or vertical photo graph on the table so that the intended X and Y axes correspond to the direction of motion of the X and Y arms of the coordinatograph. Set the coordinatograph direction switches for a right hand coordinate system.

(b) Mark the origin or reference point.

(c) Fill the card hopper of the card punch.

(d) Turn card punch main switch to ON and the mode switch to AUTO.

(e) Turn on card punch switches for AUTO, PRINT, SKIP, DUP.

(f) Press release key twice.

(g) Turn on digitizer.

(h) Hold the cross-hair of the coordinatograph over the reference point, clear the X, Y, Z counters and increment the X and Y axes counters to the reference coordinate values. Insure the signs are not negative.

3. Construction of Data File. (a) Reset EVENT counter and increment to event 01.

(b) Increment Z to nearest ten foot elevation of the point.

(c) Hold cross-hair of coordinatograph arm over ground control point 01 and press RECORD.

(d) Taking each ground control point in order, check correct event number, increment Z, place cross-hair over the point and push the SET RECORD button. Continue until file is complete.

Estuary Outline

1. Format Specification. The Fortran format specification is identical to that used in LUN 9. Set the code on the CONSTANT DATA switches as described earlier. Event numbers can be ignored.

2. Coordinate Reference System. The estuary outline is digitized using the same setup (map, reference point, and coordinate

axes) as the ground control.

3. Data File Construction. (a) Establish reference as described for ground control.

(b) Following the high water line of the estuary with the cross-hair, push the RECORD button on the control unit of the coordinatograph at intervals spaced closely enough to provide sufficient resolution. Elevations are assumed zero.

(c) The outline is not utilized by PROGRAM STREAK, but compliments the resulting computer generated plots. If the coordinate units are not in feet, PROGRAM RESCALE can be employed to convert to appropriate units. (See Appendix D for listing of PROGRAM RESCALE.)

Photo Measurements for a Single Photo

1. Format Specification. The Fortran format used for LUN 8 data (photo measurements) is (I5, 3(I4, 2F6.0, 6X)). Each card or each line has the time (photo identification) in the I5 position. The remaining information consists of identification numbers and X and Y photo coordinates for three points. Use the same Patch Panel as for ground control.

2. Coordinate System. (a) Place the film on the light table. The direction of flight should be to the right (positive X-direction). Y is positive at 90° clockwise from the X-axis. Set the Y -DIR

switch to NEG on the coordinatograph.

(b) Mark the principle point of the photograph and all ground control points recognizable in the photo.

3. Measuring Ground Control. (a) Set the time on CONSTANT DATA switches 1-5.

(b) Set the event switch (CONSTANT DATA switch 6) on zero. Set all other CONSTANT DATA to zero.

(c) Set the EVENT COUNTER RESET switch located on the back of the Auto-trol so that pushing the RESET button zeros the event counter. Zero all counters.

(d) Set crosshairs over the Principle Point., increment X and Y counters to (5000, 5000), and press RECORD SET button.

(e) For each ground control point, set crosshair over point, check that the event corresponds to the ground control point identification number, and press SET on the "finger-tip control."

4. Measuring Float Positions. (a) If floats appear in the batch of photographs, set the event counter switch to 1. This provides the first digit in the identification number. The tens and units digits are incremented by event counter buttons.

(b) Push RELEASE on the card bunch so that a new card is up.

(c) Increment the Event counter button to the correct identification number.

(d) Center cross-hair over float and push the RECORD SET button.

(e) Repeat for additional floats, being sure that the last float digitized is labeled 199.

5. Measuring Dye Segments. (a) Break the dye releases into segments. Up to eight segments can be handled per photograph, using the described coding. Each segment or section of dye represents a distinct portion of dye showing a definite trend in the water movement. Mark each segment with a grease pencil.

(b) Set the even counter switch on 2. Trace the outline of the first dye segment clockwise, recording point coordinates frequently enough to describe the boundary. The event counter increments with each record. The tracing need not close physically. The last point digitized must be 299.

(c) Set the event counter switch to 3. Trace the outline of the next segment clockwise. The last point is 399. Continue the process for the remaining segments.

6. Photo Orientation. (a) Locate the principle point of the photo on the ground control vertical photograph or map.

(b) By comparing the film image with the map, determine the direction of flight (azimuth) relative to the Y-axis of the ground control. The bearing given in the flight notes will be a good indication. Also, the direction of the camera aim in the X-Y plane is readily found in the same operation.

(c) Assuming the cameras were aimed at 45° from the vertical, scale back along the line-of-aim in the X-Y plane at a distance from the principle point equal to the altitude of the aircraft (found in the flight notes) to find the aircraft position.

(d) Measure and record X and Y as measured in the ground control reference system. Record Z as the altitude in feet (no conversion is required).

(e) Omega is the rotation of the photo plate about the positive X-axis (ground control frame of reference) in the Y-Z plane. The sign of omega is that of kappa.

Phi is the rotation in the X-Z plane about the Y-axis. Use Figure 3 to estimate ω and ϕ.

(f) Kappa is the rotation about the Z-axis in the X-Y plane through which the photograph must go to align the positive X-axis of the photo with the negative Y-axis of the ground control reference system. For a photo looking north, i.e., flying east, and using north as the positive direction of Y in the ground control, kappa is 90°. For a photo looking south, then, kappa would be -90°. An easy estimate is $\kappa = 180° - AZI$, where AZI is the angle clockwise between the ground control positive Y-axis and the direction of flight.

Organization of Data

1. Photo Measurements - LUN 8. Assemble all cards produced in digitization of photos and order according to time.

2. Ground Control - LUN 9. The first card of this file contains the scale of the vertical photograph in feet per digitized unit. Following that are all the ground control points as digitized.

3. Photo Orientation - LUN 10. Include one card for each photograph. Punch the time, X_o, Y_o, Z_o, ω, ϕ, and κ, leaving a space between each number (free form input).

4. Standard Input - LUN 60. The first card contains the code for saving corrected dye outline points for plotting. Insert "MARGIN=1" if no outline is desired, and "MARGIN=2" to provide an outline. Next, include a label card for the data being run. The label may be up to 24 characters.

APPENDIX C

COMPUTER PROGRAMS FOR GRAPHICAL DISPLAY

The two plotter programs were written to display graphically the results to the current studies. Each program (1) constructs and labels a grid of the area of interest (labels are state-plane coordinates), (2) plots the outline of that portion of the estuary found in the area of interest, (3) draws the outline of the dye patches provided that information is available, (4) plots the centroid of each dye segment or float in the data file, and (5) constructs and labels velocity vectors for each dye segment or float. The direction of the vector is that of the centroids motion and the vector length is proportional to the average speed over the time between photographs.

PROGRAM BAYPLOT

1. PROGRAM BAYPLOT is for use on the Calcomp plotter only. The program can be run from batch or teletype. Velocity input is the data stored on LUN 2 by STREAK. If the program is run from batch in conjunction with STREAK, the output of STREAK can be used immediately by simply rewinding LUN2 and proceeding with the remaining control mode commands.

2. LUN 30 is the file of coordinates of points defining the outline of the estuary. The card deck produced by digitizing can be

loaded directly, provided the scale is one foot equals one digitized unit. If not, PROGRAM RESCALE is employed and that output loaded into LUN 30.

3. Standard input. (a) The velocity scale factor (VS) is the number of scaled feet equal to one foot-per-second. For example, if VS=100, then a vector of magnitude one F.P.S. will be 100 feet long. The format is (3X, F3.0).

(b) The grid scale factor (IGS) determines the number and interval of grid divisions. One thousand must be nearly evenly divisible by IGS. Recommended grid sizes are 50, 100, 125, 200, 250, 333, and 500. The format is (4X, I4).

(c) The user may magnify the Calcomp plotter output up to 2.75 times. The normal plot will be 6.90 x 6.90 inches, with resolvable points .01 inches apart. The X and Y magnifications desired are input in the format (2F4.2). If no magnification is desired, XMAG and YMAG are both read in equal to 1.00.

PROGRAM FLASH

1. PROGRAM FLASH is exclusively for output on the Tektronix T-4002 graphics display terminal, a direct view cathode ray storage tube terminal. The program is run from the terminal and output is direct. Either a 35 mm photograph or a hard copy can be made of the screen output for permanent record.

2. Input on LUN 2 and LUN 30 is identical with that used for BAYPLOT. Standard input includes VS and IGS only. Teletype instructions appear for proper input.

3. Operation of Tektronix T-4002.

(a) Turn power OFF/ON key to ON position.

(b) Push ON-LINE/LOCAL key to ON-LINE for communication with the operating system.

(c) Set ASCII/TTY to TTY.

(d) Set KEYBOARD/AUX to KEYBOARD.

(e) Set DISPLAY/AUX to DISPLAY.

(f) Depress PAGE FULL and DATA RECEIVED indicators.

(g) Set DIRECT/COMPOSE on DIRECT.

(h) Depress FULL/CLEAR, HOME, and ERASE.

(i) Depress SOH to enter control mode. The # sign will appear in the home position.

(j) The teletype commands are:

```
# job number, job user code
#EQUIP, 2= (velocity file name)
#EQUIP, 30= (outline file name)
#REWIND, 2, 30
#FORTRAN, I=FLASH, X, E
#LOAD, 56
RUN
RUN
```

The teletype response is:

```
TYPE IN VELOCITY VECTOR SCALE FACTOR
VS= (type in value)
TYPE IN GRID SIZE
IGS= (type in grid size)
```

The screen then erases. Hold the PAGE FULL indicator down until the plot is finished. Depress VIEW/HOLD periodically to maintain image intensity.

APPENDIX D

COMPUTER LISTINGS

Listing of Card Deck for Batch Run

```
'COPY,O=8
10111 000 04999 05006 0000   001 08635 05515 0000   002 03173 04593 0000
10111 004 04544 05361 0000   005 05347 02637 0000
10111 201 05493 05766 0000   202 05522 05740 0000   203 05530 05751 0000
10111 299 05497 05777 0000   301 05488 05775 0000   302 05499 05786 0000
10111 303 05459 05832 0000   399 05448 05818 0000
10158 000 04995 05009 0000   001 08796 05636 0000   002 03200 04749 0000
10158 004 04621 05537 0000   005 05349 02729 0000
10158 201 05613 05957 0000   202 05491 05843 0000   203 05459 05752 0000
10158 204 05502 05772 0000   205 05501 05785 0000   206 05606 05856 0000
10158 207 05733 05941 0000   299 05676 05965 0000   301 05614 05965 0000
10158 302 05510 06029 0000   303 05452 06037 0000   304 05303 06044 0000
10158 305 05180 06039 0000   306 05095 06037 0000   307 05122 05981 0000
10158 308 05176 05996 0000   309 05192 05981 0000   310 05204 05987 0000
10158 311 05221 05977 0000   312 05253 06000 0000   313 05273 05984 0000
10158 314 05468 05981 0000   399 05541 05982 0000
10177 000 04999 05005 0000   001 08869 05248 0000   002 03074 05000 0000
10177 004 04749 05642 0000   005 04936 02688 0000
10177 201 05632 05781 0000   202 05545 05700 0000   203 05481 05665 0000
10177 204 05413 05633 0000   205 05438 05613 0000   206 05493 05634 0000
10177 207 05533 05630 0000   208 05509 05578 0000   209 05603 05672 0000
10177 210 05666 05729 0000   211 05667 05764 0000   212 05650 05781 0000
10177 299 05627 05785 0000   300 04735 06081 0000   301 04802 06001 0000
10177 302 04863 06005 0000   303 04983 05964 0000   304 05041 06001 0000
10177 305 05171 05979 0000   306 05125 06077 0000   307 05145 06125 0000
10177 308 05075 06161 0000   309 05000 06118 0000   310 04976 06141 0000
10177 311 04940 06141 0000   312 04919 06125 0000   313 04816 06142 0000
10177 314 04772 06180 0000   399 04781 06097 0000
10197 000 04996 04993 0000   001 02098 05818 0000   002 07195 06242 0000
10197 003 05049 02428 0000   004 05537 05687 0000
10197 201 04944 05660 0000   202 05040 05717 0000   203 05078 05794 0000
10197 204 05074 05845 0000   205 05011 05876 0000   206 04922 05870 0000
10197 207 04892 05816 0000   208 04883 05723 0000   299 04884 05666 0000
10197 300 05771 05481 0000   301 05913 05462 0000   302 06012 05466 0000
10197 303 06110 05465 0000   304 06135 05507 0000   305 06133 05548 0000
10197 306 06148 05596 0000   307 06136 05600 0000   308 06062 05592 0000
10197 309 06000 05583 0000   310 05961 05569 0000   311 05885 05570 0000
10197 312 05828 05565 0000   313 05773 05555 0000   399 05740 05527 0000
10207 000 04997 04997 0000   001 08745 05515 0000   002 03077 05143 0000
10207 004 04659 05822 0000   005 05001 02660 0000
10207 201 05411 05455 0000   202 05489 05566 0000   203 05493 05668 0000
10207 204 05485 05802 0000   205 05369 05837 0000   206 05275 05749 0000
10207 207 05260 05654 0000   299 05306 05535 0000   300 03444 05958 0000
10207 301 03511 05956 0000   302 03757 06056 0000   303 03906 06113 0000
10207 304 03906 06200 0000   305 03824 06242 0000   306 03702 06250 0000
10207 307 03607 06253 0000   308 03497 06212 0000   309 03475 06146 0000
10207 310 03447 06108 0000   311 03438 06081 0000   312 03499 06019 0000
10207 399 03456 05992 0000
''
'COPY,O=9
0.553
22222 001 12377 09049 0000   002 17170 08688 0000   003 15225 22448 0000
22222 004 15683 09376 0000   005 15565 04745 0000
''
'COPY,O=10
10111 15160 18400 2000 -40 -4 -90
10158 15000 19000 2000 -41 -3 -90
10177 15520 18830 1950 -41 2 -95
10197 14750 12955 2000 45 -10 90
10207 15200 18500 2000 -45 -20 -90
10382 15000 20000 2134 -38 -5 -85
10397 13100 13500 2000 36 -30 45
10408 16320 18459 2000 -45 10 -75
10418 15900 18400 2000 -45 0 -75
''
'EQUIP,2=FILE
'EQUIP,20=FILE
'REWIND,8,9,10
'REWIND,2,20
'FORTRAN,I=STREAK,X,L,E
'LOAD,56
RUN
      MARGIN=2
LINT SLOUGH 8AUG72 NO.2
'REWIND,2,20
'COPY,I=20
'COPY,I=2
'REWIND,2,8
'EQUIP,62=PUN
'LABEL,62/WEISE
'COPY,I=2,O=62
'COPY,I=8
'UNEQUIP,62
'COPY,O=8
10382 000 05000 05000 0000   001 08060 05490 0000   002 02396 04457 0000
10382 004 03721 05297 0000   005 04922 02341 0000
10382 201 04848 06329 0000   202 04855 06295 0000   203 04856 06268 0000
10382 204 04876 06252 0000   205 04852 06207 0000   206 04960 06107 0000
10382 207 04975 06117 0000   208 04881 06201 0000   299 04903 06279 0000
10382 301 04963 06109 0000   302 05136 05938 0000   303 05147 05935 0000
10382 399 04974 06109 0000   401 05151 05935 0000   402 05277 05807 0000
10382 499 05175 05942 0000
10397 000 05000 04997 0000   001 03655 07404 0000   002 07416 04820 0000
10397 003 01155 02130 0000   004 06111 05089 0000
10397 400 05120 05203 0000   401 05091 05187 0000   402 05008 05191 0000
10397 403 04927 05207 0000   404 04848 05241 0000   405 04876 05261 0000
10397 406 04947 05244 0000   407 04988 05239 0000   408 05041 05211 0000
10397 499 05082 05219 0000
10397 302 05111 05407 0000   303 05112 05368 0000   304 05126 05331 0000
10397 305 05136 05209 0000   306 05106 05236 0000   307 05105 05345 0000
10397 309 05088 05353 0000   310 05083 05388 0000   399 05086 05411 0000
10397 201 05076 05575 0000   202 05102 05479 0000   203 05107 05405 0000
10397 205 05082 05439 0000   206 05082 05505 0000   299 05068 05575 0000
10408 000 05000 05008 0000   001 07985 04970 0000   002 02315 05773 0000
10408 004 04244 06115 0000   005 03796 03015 0000
10408 200 05828 06654 0000   201 05700 06634 0000   202 05397 06662 0000
10408 203 05165 06680 0000   204 04999 06623 0000   205 05102 06600 0000
10408 206 05195 06625 0000   207 05655 06585 0000   208 05717 06614 0000
10408 299 05792 06615 0000   301 05010 06611 0000   302 05081 06515 0000
10408 303 05231 06443 0000   304 05355 06378 0000   305 05456 06256 0000
10408 306 05521 06264 0000   307 05451 06356 0000   308 05366 06436 0000
10408 309 05245 06478 0000   310 05168 06515 0000   311 05136 06552 0000
10408 399 05139 06589 0000   401 05470 06255 0000   402 05728 06088 0000
10408 403 05807 06054 0000   404 05959 06025 0000   405 05957 06053 0000
10408 406 05847 06070 0000   407 05764 06102 0000   408 05685 06145 0000
10408 409 05698 06162 0000   410 05639 06204 0000   411 05583 06210 0000
10408 412 05568 06264 0000   499 05511 06264 0000
10418 000 05006 05002 0000   001 07941 04962 0000   002 02428 05513 0000
```

```
10418 004 04293 05902 0000   005 03943 02965 0000
10418 201 05745 06466 0000   202 05675 06536 0000   203 05647 06510 0000
10418 204 05484 06564 0000   205 05016 06566 0000   206 04671 06542 0000
10418 207 04429 06541 0000   208 04280 06559 0000   20  04163 06599 0000
10418 210 04164 06567 0000   211 04369 06490 0000   212 04759 06435 0000
10418 213 04983 06436 0000   214 05382 06471 0000   215 05547 06419 0000
10418 215 04591 06431 0000   216 04552 06462 0000   29  04374 06489 0000
10418 300 04138 06582 0000   300 04138 06582 0000   301 04172 06424 0000
10418 302 04369 06336 0000   303 04425 06358 0000   304 04479 06278 0000
10418 305 04734 06214 0000   306 04973 06170 0000   307 05263 06115 0000
10418 308 05392 06060 0000   309 05388 06105 0000   310 05267 06181 0000
10418 311 05020 06260 0000   312 04865 06287 0000   313 04784 06331 0000
10418 314 04600 06419 0000   315 04563 06455 0000   399 04389 06486 0000
10418 401 05275 05954 0000   402 05187 05890 0000   403 05263 05878 0000
10418 404 05377 05906 0000   405 05472 05951 0000   406 05565 05913 0000
10418 407 05668 05905 0000   408 05735 05917 0000   409 05509 06031 0000
10418 499 05428 06042 0000
''
'REWIND,8,9,10
'REWIND,2,20
'LOAD,56
RUN
      MARGIN=2
LINT SLOUGH 8AUG72 NO.4
'REWIND,2,20
'COPY,I=20
'COPY,I=2
'REWIND,2,8
'EQUIP,62=PUN
'LABEL,62/WEISE
'COPY,I=2,O=62
'UNEQUIP,62
'COPY,I=8
'COPY,O=30
22222   6   5611   5463        7   5670   5480         8   5728   5503
22222   9   5776   5533       10   5870   5575        11   5965   5592
22222  12   6030   5614       13   6103   5630        14   6173   5636
22222  15   6176   5654       16   6230   5654        17   6233   5677
22222  18   6278   5669       19   6278   5643        20   6289   5636
       *
       *
       *
     ETC.
''
'REWIND,2
'EQUIP,1=PLOT
'LABEL,1/WEISE
'LABEL,1/LINT SLOUGH 8AUG72 NO.4
'FORTRAN,I=BAYPLOT,X,L
'LOAD,56,L=*CALTEK
RUN
VS=100
IGS=1000
2.752.75
'LOGOFF
```

Listing of Computer PROGRAM STREAK

```
      PROGRAM STREAK
C***********************************************************************
C      PROGRAM CALCULATES VELOCITIES OF FLOATS AND DYE PATCHES FROM
C               DIGITIZED COORDINATES ON AERIAL PHOTOGRAPHS.
C      FIRST,THE CORRECTION MATRIX FOR A PHOTOGRAPH IS FOUND BY
C               CALLING RESECT2.  THE CORRECTED POSITIONS OF PHOTO
C               POINTS ARE COMPUTED.  IF DYE, THE PLANE GEOMETRIC
C               PROPERTIES ARE FOUND USING SECPROP.   THEN, FROM
C               POSITIONS WITH TIME, VELOCITIES ARE COMPUTED.
C      POINT IDENTIFICATION -
C               000 - PRINCIPLE POINT OF PHOTOGRAPH
C               001 THRU 099 - GROUND CONTROL POINTS
C               100 THRU 199 - FLOATS
C               200 THRU 999 - DYE POINTS
C      FOR FLOATS AND DYE, THE LAST FLOAT AND LAST POINT OF DYE
C               PATCH MUST BE NUMBERED X99.
C      ALL OUTPUT ON LUN 20, PLUS  PLOTTING DATA ON LUN 2
C***********************************************************************
      COMMON C(20,3), IP(3), XF(3), YF(3),ZF(3),CK1,CK2
      DIMENSION XFL(10,5),YFL(10,5), VF(10),XD(100,2),XT(3),DYE(10,10,6)
      DIMENSION VEL(12),AZI(12),IT(10),AX(3)
      NF=0.
      READ(60,54) MARGIN
   54 FORMAT (13X,I1)
      LFLT=1
      READ(60,55)(AX(I),I=1,3)
   55 FORMAT(3A8)
      WRITE(20,56)(AX(I),I=1,3)
   56 FORMAT(9X,3A8)
      WRITE(2,56)(AX(I),I=1,3)
      INO=1
      IFLAG=1
      ITD=0
      IA=1
  100 CALL RESECT2(FL,XP,YP)
      IF(CK1.LT.0.) GO TO 401
      IF (CK2.GT.1.) GO TO 401
      ICHECK=1
  110 READ(8,1)ITM,        (IP(J),XF(J),YF(J),J=1,3)
    1 FORMAT(I5,3(I4,2F6.3,6X))
      IF(EOF(8)) GO TO 1000
      IF(IP(1).GT.99) GO TO 10
      IF(XF(1).LT.0.001) GO TO 110
      BACKSPACE 8
      IA=IA+1
      GO TO 100
   10 DO 200 J=1,3
      IT(IA)=ITM
      IF(IP(J).EQ.0.AND.XF(J).EQ.0.) GO TO 110
      X1=YP-YF(J)
      Y1=XP-XF(J)
      DO 210 K=1,3
  210 XT(K)=C(4,K)*X1+C(5,K)*Y1+C(6,K)*(-FL)
      XDIS=SQRT(XT(1)*XT(1)+XT(2)*XT(2)+XT(3)*XT(3))
      DO 220 K=1,3
  220 XT(K)=XT(K)/XDIS
      XPG1=C(1,1)-XT(1)*C(1,3)/XT(3)
      XPG2=C(1,2)-XT(2)*C(1,3)/XT(3)
      IGO=IP(J)/100
      GO TO (20,50,50,50,50,50,50,50,50,50) IGO
   20 XFL(INO,IA)=    XPG1
      YFL(INO,IA)=XPG2
      INO=INO+1
      IF(IP(J).NE.199) GO TO 200
      NF=INO-1
      INO=1
      GO TO 200
   50 XD(IFLAG,1)=XPG1
      XD(IFLAG,2)=XPG2
      GO TO (52,51) MARGIN
   51 WRITE(2,53)IFLAG,XPG1,XPG2
   53 FORMAT('MARGIN',1X,I2,6X,2F6.0)
   52 IFLAG=IFLAG+1
      ITEST=IP(J)/100
      ITEST=ITEST*100+99
      IF (IP(J).NE.ITEST) GO TO 200
      N=IFLAG-1
      CALL SECPROP (XD,N,ICHECK,IA,DYE)
      IFLAG=1
      ICHECK=ICHECK+1
  200 CONTINUE
      GO TO 110
 1000 ICOUNT=ICHECK-1
      IF(IA.EQ. 1) GO TO 401
      LV=0
      WRITE(2,5)
    5 FORMAT('VECTOR',2X,' PHOTOS',14X,'INITIAL COORDS',
     13X,'FINAL COORDS',3X,'VELOCITY')
      DO400 J=2,IA
      SUMVE=0.0
      VELNO=0.0
      K=J-1
C.....TIME CONVERSION ROUTINE
      JT1=IT(J)/1000
      JT2=IT(K)/1000
      JT3=ABS(JT1-JT2)
      TIME=(IT(J)-IT(K)-JT3*400)*6.
C.....DYE PATCH VELOCITIES
      WRITE(20,9) IT(K),IT(J)
    9 FORMAT(//'DYE PATCH DATA, PHOTO',I5,' PHOTO',I5)
      IF(TIME.EQ.0.) GO TO 401
      DO 391 I=1,ICOUNT
      XDIST=(DYE(I,J,1)-DYE(I,K,1))
      YDIST=(DYE(I,J,2)-DYE(I,K,2))
      AZI(I)=ATAN(XDIST/YDIST)
      IF(YDIST.LT.0.) AZI(I)=AZI(I)+3.14159
      IF(AZI(I).LT.0.) AZI(I)=AZI(I)+6.28318
      XDIST=SQRT(XDIST*XDIST+YDIST*YDIST)
      IF(XDIST.LT. 5.0) XDIST=0.0
      VEL(I)=XDIST/TIME
      SUMVE=SUMVE+VEL(I)
      VELNO=VELNO+1.
      LV=LV+1
      WRITE(2,4)LV,IT(K),IT(J),I,DYE(I,K,1),DYE(I,K,2),
     1DYE(I,J,1),DYE(I,J,2),VEL(I)
    4 FORMAT(2X,I2,3X,I5,X,I5,2X,'DYE',I3,4X,2(F6.0),
     12X,2(F6.0),2X,F8.4)
      WRITE(20,12) I,(DYE(I,K,L),L=1,3),(DYE(I,J,L),L=1,3),VEL(I),AZI(I)
```

```
12 FORMAT(/'NO',I2,/' XCENTROID-1',F10.0,/' YCENTROID-1',F10.0,/
  C' AREA-1',F15.2,/' XCENTROID-2',F10.0,/' YCENTROID-2',F10.0,/
  C' AREA-2',F15.2,/' VELOCITY',F13.2,'FPS',/'AZIMUTH'
  C'FROM NORTH',F8.5,'RADIANS')
   RATIO=SQRT(DYE(I,K,4)/DYE(I,K,5))
   RAT2=DYE(I,K,3)/3.14159
   ASQ1=RAT2*RATIO
   BSQ1=RAT2/RATIO
   RATIO=SQRT(DYE(I,J,4)/DYE(I,J,5))
   RAT2=DYE(I,J,3)/3.14159
   ASQ2=RAT2*RATIO
   BSQ2=RAT2/RATIO
   RTA1=SQRT(ASQ1)
   RTA2=SQRT(ASQ2)
   RTB1=SQRT(BSQ1)
   RTB2=SQRT(BSQ2)
   DIV=1.386*TIME*2.
   DX=(ASQ2-ASQ1)/DIV
   DY=(BSQ2-BSQ1)/DIV
   WRITE(20,15) DX,DY,RTA1,RTA2,RTB1,RTB2
15 FORMAT('DIFFUSION STUDY'/' DX=',F10.2,'FT.SQ/SEC',5X,'DY=',F10.2,
  1'FT.SQ/SEC'/' A1=',F6.0,'  A2=',F6.0,',  B1=',F6.0,',  B2=',
  2F6.0)
391 CONTINUE
C.....FLOAT VELOCITIES
   IF(NF.EQ.0.) GO TO 400
   WRITE (20,17)
17 FORMAT(/' FLOAT DATA'/,30X,'INITIAL COORDS.',4X,'FINAL COORDS.',
  14X,'VELOCITY')
   DO 392 I=1,NF
   XDIST=XFL(I,J)-XFL(I,K)
   YDIST=YFL(I,J)-YFL(I,K)
   ZDIST=SQRT(XDIST**2+YDIST**2)
   IF(ZDIST.LT. 5.0) ZDIST=0.0
   VF(I)=ZDIST/TIME
   LV=LV+1
   WRITE(20,18)LV,IT(K),IT(J),I,XFL(I,K),YFL(I,K),XFL(I,J),YFL(I,J),
  2VF(I)
18 FORMAT(2X,I2,3X,I5,X,I5,X,'FLOAT',I2,4X,2(F6.0),
  12X,2(F6.0),2X,F8.4)
   WRITE(2,18)LV,IT(K),IT(J),I,XFL(I,K),YFL(I,K),XFL(I,J),YFL(I,J),
  3VF(I)
   VELNO=VELNO + 1.
   SUMVE = SUMVE + VF(I)
392 CONTINUE
   VELM=0.0
   IF(VELNO.GT.0.1) VELM=SUMVE/VELNO
   WRITE(20,13) TIME,VELM
13 FORMAT(/'TIME FOR VEL.',F8.3,/' MEAN VEL. =',F5.2)
400 CONTINUE
   GO TO 402
401 WRITE(20,16)
16 FORMAT(' TIME IS ZERO')
402 WRITE(20,19)
19 FORMAT(' LAST PHOTO')
   REWIND 8
   END FILE 2
   END FILE 20
   STOP
```

```
      SUBROUTINE SECPROP(X,N,NO,IFLT,DYE)
C.....X AND Y=COORDS OF POINTS DEFINING CLOCKWISE PATH AROUND
C.....BOUNDARY, N=NUMBER OF POINTS, CLOSURE FROM PT N TO PT 1
C.....IS AUTOMATIC (POINT 1 IS READ IN ONLY ONCE).
C..... NO=DYE PATCH NUMBER,IFLT=PHOTOGRAPH NUMBER
C.....IGX,IGY,IGXY ARE ABOUT CENTROIDAL AXES PARALLEL TO X AND Y
C.....THETA IS CLOCKWISE ANGLE FROM X AXIS TO MAJOR PRINC AXIS.
      REAL IX,IY,IXY,IGX,IGY,IGXY,IMAX,IMIN
      DIMENSION X(100,2), DYE(10,10,6)
      XLOW=X(1,1)
      YLOW=X(1,2)
      DO 10 I=1,N
      X(I,1)=X(I,1)-XLOW
      X(I,2)=X(I,2)-YLOW
   10 CONTINUE
      XI=X(N,I)
      XM=X(1,1)
      XMSQ=XM*XM
      T2X=XI+XM
      YI=X(N,2)
      YM=X(1,2)
      YMSQ=YM*YM
      T2Y=YI+YM
      A=AXBAR=AYBAR=IX=IY=IXY=0.
      DO 3 I=1,N
      IF(I.NE.N) GO TO 1
      M=1
      GO TO 2
    1 M=I+1
    2 XL=XI
      XI=XM
      XM=X(M,1)
C.....XL=X(I-1), XI=X(I), XM=X(I+1), Y AND S SIMILAR
      T1X=T2X
      T2X=XI+XM
      T3X=XM-XI
      XISQ=XMSQ
      XMSQ=XM*XM
      YL=YI
      YI=YM
      YM=X(M,2)
      T1Y=T2Y
      T2Y=YI+YM
      T3Y=YM-YI
      YISQ=YMSQ
      YMSQ=YM*YM
      A=A+XI*(YL-YM)
C.....ACCUMULATE 2*A, 6*A*XBAR, 12*IX, 72*IXY, ETC.
      AXBAR=AXBAR-YI*(XL*T1X-XM*T2X)
      AYBAR=AYBAR+XI*(YL*T1Y-YM*T2Y)
      IX=IX+T3X*(YISQ+YMSQ)*T2Y
      IY=IY-T3Y*(XISQ+XMSQ)*T2X
    3 IXY=IXY-T3Y*(18.*XISQ*T2Y+T3X*(T3X*T3Y+4.*(2.*XI+XM)*(YI+2.*YM)))
      A=A*.5
      AXBAR=AXBAR/6.
      AYBAR=AYBAR/6.
      XBAR=AXBAR/A
      YBAR=AYBAR/A
      IX=IX/12.
```

```
      IY=IY/12.
      IXY=IXY/72.
C....TRANSFER TO CENTROIDAL AXES
      IGX=IX-AYBAR*YBAR
      IGY=IY-AXBAR*XBAR
      IGXY=IXY-AXBAR*YBAR
      T1=(IGX-IGY)*.5
      T2=(IGX+IGY)*.5
      T3=SQRT(T1*T1+IGXY*IGXY)
C.....COMPUTE PRINC MOMENTS OF INERTIA AND ORIENTATION
C.....PRINC AXES.
      IF(T2.LT.1.) T3=-T3
      IMAX=T2+T3
      IMIN=T2-T3
      THETA=28.6479*ATAN(IGXY/T1)
      IF(T1.LT.0.) THETA=THETA+90.
      DYE(NO,IFLT,1)=XBAR+XLOW
      DYE(NO,IFLT,2)=YBAR+YLOW
      DYE(NO,IFLT,3)=ABS(A)
      DYE(NO,IFLT,4)=ABS(IMAX)
      DYE(NO,IFLT,5)=ABS(IMIN)
      DYE(NO,IFLT,6)=THETA
      RETURN
      END


      SUBROUTINE RESECT2 (FL,XP,YP)
      COMMON C(20,3), IP(3), XF(3), YF(3),ZF(3),CK1,CK2
      DIMENSION B(15,6),P(2,8),D(6,7)
C     INPUT LUNS ARE9
C        8  PHOTO COORDINATES - TIME IN TENTHS OF MINUTES, POINT IDENT.,
C                     X-PHOTO COORD.,Y-PHOTO COORD.
C        9  GROUND CONTROL - RIVER IDENTIFICATION(OPTIONAL - FIRST FIVE
C                     SPACES), X Y Z GROUND COORDS.
C       10  INITIAL ORIENTATION PARAMETERS - TIME,X Y Z COORDS. OF PLANE,
C                     ORIENTAION, SCALE OF GROUND CONTROL
C     OUTPUT DATA ON LUN 20
      FL=6.0
      IGO=0
      I=1
C     READ PHOTO CONTROL COORDINATED
   10 READ(8,1)ITM,       (IP(J),XF(J),YF(J),J=1,3)
    1 FORMAT(I5,3(I4,2F6.3,6X))
      IF (IP(1) .LT.100) GO TO 25
      BACKSPACE 8
      GO TO 40
   25 DO 38 J=1,3
      IF(IP(J) .EQ. 0 .AND. XF(J) .GT. 0.001) GO TO 26
      IF(IP(J) .EQ. 0) GO TO 38
      GO TO 28
   26 XP=XF(J)
      YP=YF(J)
      GO TO 38
   28 B(I,1)=IP(J)
      B(I,2)=YF(J)
      B(I,3)=XF(J)
      I=I+1
   38 CONTINUE
      GO TO 10
   40 IMAGE=I-1
      IF(IMAGE.LT.3) GO TO 1002
      DO 57 I=1,IMAGE
      B(I,2)=YP-B(I,2)
      B(I,3)=XP-B(I,3)
   57 CONTINUE
C     READ GROUND CONTROL
      REWIND 9
      K=0
      SCL=FFIN(9)
   60 READ(09,2)(IP(J),XF(J),YF(J),ZF(J),J=1,3)
    2 FORMAT(5X,3(I4,3F6.0))
      IF(EOF(9)) GO TO 101
      DO 70 J=1,3
      DO 100 I=1,IMAGE
      K=B(I,1)
      L=IP(J)
      IF (K-L) 100,80,70
   80 B(I,4)=XF(J)
      B(I,5)=YF(J)
      B(I,6)=ZF(J)
  100 CONTINUE
   70 CONTINUE
      GO TO 60
C     READ INITIAL PARAMETERS FOR CAMERA PHOTO NO.,X,Y,Z IN FT
C     AND OMEGA,PHI, KAPPA IN DEGREES
  101 REWIND 10
  110 IPLT=FFIN(10)
      IF(IPLT-ITM)111,119,111
  111 DO 112 I=1,6
      TRASH=FFIN(10)
  112 CONTINUE
      GO TO 110
  119 DO 120 J=1,3
      C(1,J)=FFIN(10)
  120 CONTINUE
      AO=FFIN(10)
      AP=FFIN(10)
      OK=FFIN(10)
      C(2,1)=AO/57.2958
      C(2,2)=AP/57.2958
      C(2,3)=OK/57.2958
      DO 121 I=1,2
  121 C(1,I)=C(1,I)*SCL
      DO 122 I=1,IMAGE
      DO 122 K=4,5
  122 B(I,K)=B(I,K)*SCL
      DO 130 I=1,3
      C(3,I)=COSF(C(2,I))
      C(2,I)=SINF(C(2,I))
  130 CONTINUE
C     ORIENTATION FACTORS IN C ARRAY
  610 C(4,1)=C(3,2)*C(3,3)
      C(5,1)=-C(3,2)*C(2,3)
      C(6,1)=C(2,2)
      C(10,1)=-C(2,2)*C(3,3)
```

```
      C(11,1)=C(2,2)*C(2,3)
      C(12,1)=C(3,2)
      C(10,2)=C(4,1)*C(2,1)
      C(11,2)=C(5,1)*C(2,1)
      C(12,2)=C(2,1)*C(2,2)
      C(10,3)=-C(4,1)*C(3,1)
      C(11,3)=-C(5,1)*C(3,1)
      C(12,3)=-C(3,1)*C(2,2)
      C(4,2)=C(3,1)*C(2,3)+C(12,2)*C(3,3)
      C(5,2)=C(3,1)*C(3,3)-C(12,2)*C(2,3)
      C(6,2)=-C(2,1)*C(3,2)
      C(4,3)=C(2,1)*C(2,3)+C(10,1)*C(3,1)
      C(5,3)=C(2,1)*C(3,3)+C(11,1)*C(3,1)
      C(6,3)=C(3,1)*C(3,2)
      DO 612 I=7,9
      C(I,1)=0.
      C(I,2)=-C(I-3,3)
      C(I,3)=C(I-3,2)
      C(13,I-6)=C(5,I-6)
      C(14,I-6)=-C(4,I-6)
  612 C(15,I-6)=0.
      GO TO (613,763),IGO
C     CLEAR NORMAL EQUATION D ARRAY
  613 DO 614 I=1,6
      DO 614 J=I,7
  614 D(I,J)=0.
C     COMPUTE P TERMS FOR RESECTION PASS POINTS
      DO 618 NU=1,IMAGE
      DO 619 K=1,3
  619 C(16,K)=B(NU,K+3)-C(1,K)
      K=4
      DO 620 L=17,20
      DO 620 I=1,3
      C(L,I)=C(K,1)*C(16,1)+C(K,2)*C(16,2)+C(K,3)*C(16,3)
  620 K=K+1
      DO 621 I=1,2
      DO 622 L=1,4
  622 P(I,L)=(B(NU,I+1)*C(L+16,3)-(-FL)*C(L+16,I))/C(17,3)
      DO 623 L=5,7
  623 P(I,L)=(-B(NU,I+1)*C(6,L-4)+(-FL)*C(I+3,L-4))*C(1,3)/C(17,3)
  621 P(I,8)=-P(I,1)
C     CONTRIBUTION TO NORMAL EQUATIONS
      DO 618 I=1,6
      DO 618 J=I,7
      DO 618 K=1,2
  618 D(I,J)=D(I,J)+P(K,I+1)*P(K,J+1)
C     FORWARD SOLUTION
      DO 699 I=1,6
      CK1=D(I,I)
      IF(D(I,I).LT.0.0) GO TO 1008
      SQR=SQRT(D(I,I))
      DO 698 J=I,7
  698 D(I,J)=D(I,J)/SQR
      IF (I-6)697,696,696
  697 IP1=I+1
      DO 699 L=IP1,6
      DO 699 J=L,7
  699 D(L,J)=D(L,J)-D(I,L)*D(I,J)
C     BACK SOLUTION
  696 D(6,7)=D(6,7)/D(6,6)
      DO 691 I=1,5
      NMI=6-I
      NMIP1=NMI+1
      DO 690 J=NMIP1,6
  690 D(NMI,7)=D(NMI,7)-D(J,7)*D(NMI,J)
  691 D(NMI,7)=D(NMI,7)/D(NMI,NMI)
      DO 625 I=4,6
  625 D(I,7)=D(I,7)*C(1,3)
C     ADD LEAST SQUARES RESULTS TO CAMERA PARAMETERS IN C ARRAY
      DO 626 J=1,3
      C(1,J)=C(1,J)+D(J+3,7)
      C(4,J)=D(J,7)
      CK2=ABS(C(4,J))
      IF (ABS(C(4,J)).GT.1.0) GO TO 1010
      C(5,J)=SQRT(1.-C(4,J)*C(4,J))
      C(6,J)=C(2,J)*C(5,J)+C(3,J)*C(4,J)
      C(7,J)=C(3,J)*C(5,J)-C(2,J)*C(4,J)
      C(2,J)=C(6,J)
  626 C(3,J)=C(7,J)
C     TEST MAGNITUDE OF CORRECTIONS FOR ORIENTATION PARAMETERS
      DO 628 I=1,3
      IF (ABS(D(I,7))-.00001)628,628,610
  628 CONTINUE
      IGO=2
      GO TO 610
C     CAMERA PARAMETERS OUTPUT
  763 WRITE(20,532)
      WRITE(20,527)
      WRITE(20,528) ITM   ,(C(1,J),J=1,3)
      WRITE (20,529)
      WRITE(20,528) ITM   ,(C(2,J),J=1,3)
      WRITE(20,528) ITM   ,(C(3,J),J=1,3)
      WRITE(20,530) ITM
      WRITE(20,533) ((C(I,J),J=1,3),I=4,6)
  527 FORMAT(' TIME               XO                  YO                  ZO')
  528 FORMAT(I7,3(2X,E14.7))
  529 FORMAT(' TIME            OMEGA               PHI                 KAPPA')
  530 FORMAT(/30H ORIENTATION MATRIX AT TIME   ,I7)
  532 FORMAT(/50H ORIENTATION PARAMETER CORRECTION LIMIT IS 0.00001)
  533 FORMAT(1X,3(2X,E14.7))
      GO TO 1100
 1002 WRITE(20,1003)ITM
 1003 FORMAT(' INSUFFICIENT CONTROL, PLT',I6)
      GO TO 1100
 1008 WRITE(20,1009)I,I,CK1
 1009 FORMAT(' D(',I3,I3,')  ',F8.4)
      GO TO 1100
 1010 WRITE(20,1011)J,C(4,J)
 1011 FORMAT(' C(4,',I2,')=',F8.4 )
 1100 RETURN
      END
```

Computer Programs for Plotting

```
      PROGRAM BAYPLOT
C.....FOR USE ON CALCOMP PLOTTER
      DIMENSION XE(3),YE(3)
C.....SCALING
C.....READ VELOCITY VECTOR SCALE FACTOR,FEET PER F.P.S.
      READ(60,6)VS
    6 FORMAT(3X,F3.0)
C.....READ GRID DIVISION SIZE,FEET
      READ(60,18)IGS
   18 FORMAT(4X,I4)
C     SIZE WINDOW
      XMIN=90000.
      YMIN=90000.
      XMAX=1000.
      YMAX=1000.
      READ(2,102) WASTE
  102 FORMAT(I5)
    4 READ(2,3) IST
    3 FORMAT(7X,I2)
      IF(IST.NE. 0) GO TO  4
   10 READ(2,1) XA,YA,XB,YB
    1 FORMAT(30X, 2F6.0,2X,2F6.0)
      IF(EOF(2)) GO TO 20
      XS=XA
      YS=YA
      GO TO 12
   13 XS=XB
      YS=YB
   12 IF(XMIN.GT.XS) XMIN=XS
      IF(YMIN.GT.YS) YMIN=YS
      IF(YMAX.LT.YS) YMAX=YS
      IF(XMAX.LT.XS) XMAX=XS
      IF(XS.EQ.XA) GO TO 13
      GO TO 10
   20 IPEN=0
C     SCALE GRID
      IXN=XMIN/1000
      IXX=XMAX/1000+1
      IYN=YMIN/1000
      IYX=YMAX/1000+1
      XMIN=IXN*1000
      XMAX=IXX*1000
      YMAX=IYX*1000
      YMIN=IYN*1000
      XRNG=XMAX-XMIN
      YRNG=YMAX-YMIN
      XSCA=690./XRNG
      YSCA=690./YRNG
      IF(XSCA.GT.YSCA) XSCA=YSCA
      YSCA=XSCA
      XW=XMAX+50./XSCA
      YW=YMAX+25./YSCA
      XL=0.-60./XSCA
      YL=0.-14./YSCA
      CALL ERASE
      CALL FSCALE(XSCA,YSCA,250.,30.)
      READ(60,5) XMAG,YMAG
    5 FORMAT(2F4.2)
      CALL SIZE(XMAG,YMAG)
C     LABEL SCALE
      CALL ALPHAS
      XSI=XSCA/100.
      ISC=1.0/(XSI*XMAG)
      CALL XLATE(ISC,BCDCON)
      X=144./(XSCA*XMAG)
      Y=YRNG-YL/3.
      CALL PLOT(X,Y ,0,0)
      CALL WRITEY(1.,0.,8HSCALE IS,6H 1 TO )
      CALL DELTA(X,0.,0,0)
      CALL WRITEY(1.,0.,2H0),BCDCON)
      IVS=100*ISC/VS
      CALL XLATE(IVS,BCDCON)
      XV=240./(XSCA*XMAG)
      YLL=0.-24./YSCA
      CALL PLOT(0.,YLL,0,0)
      CALL WRITEY(1.,0.,8HVEL.MAG.,8H IS 100 ,8HIN. PER ,8H      FPS)
      CALL DELTA(XV,0.,0,0)
      CALL WRITEY(1.,0.,2H0),BCDCON)
C     DRAW GRID
      CALL VECTORS
      NOX=XRNG/IGS+1.
      NOY=YRNG/IGS
      X=0.0
      IPEN=0
      KPEN=1
C     VERTICAL LINES
      DO 30 I=1,NOX
      Y=0.0
      CALL PLOT(X,Y,IPEN,0)
      DO 29 J=1,NOY
      Y=Y+IGS
   29 CALL PLOT(X,Y,KPEN,0)
   30 X=X+IGS
C     HORIZONTAL LINES
      Y=0.0
      NOX=NOX-1.
      NOY=NOY+1.
      DO 32 I=1,NOY
      X=0.0
      CALL PLOT(X,Y,IPEN,0)
      DO 31 J=1,NOX
      X=X+IGS
   31 CALL PLOT(X,Y,KPEN,0)
   32 Y=Y+IGS
C     LABEL X AXIS
      CALL ALPHAS
      NX=XRNG/1000.+1
      ICON=XMIN-1000.
      CALL PLOT(0.,0.,0,0)
      CALL DELTA(0.,YL,0,0)
      DO 33 I=1,NX
      ICON=ICON+1000
      CALL XLATE(ICON,BCDCON)
      CALL WRITEY(1.,0.,2H0),BCDCON)
   33 CALL DELTA(1000.,0.,0,0)
C     LABEL Y AXIS
      NY=YRNG/1000+1
      CALL PLOT(0.,0.,0,0)
```

```
      CALL DELTA(XL,0.,0,0)
      ICON=YMIN-1000.
      DO 35 I=1,NY
      ICON=ICON+1000
      CALL XLATE(ICON,BCDCON)
      CALL WRITEY(1.,0.,2H0),BCDCON)
   35 CALL DELTA(0.,1000.,0,0)
C.....PLOTTING
C     ESTUARY OUTLINE
      CALL VECTORS
      CALL PLOT(0.,0.,0,0)
      CALL WINDOW(0.,0.,XRNG,YRNG,0)
   40 READ(30,2)(XE(J),YE(J),J=1,3)
    2 FORMAT(5X,3(4X,2F6.0,6X))
      IPEN=1
      DO 41 I=1,3
      IF(XE(I).EQ.0.) GO TO 50
      X=XE(I) -XMIN
      Y=YE(I) -YMIN
   41 CALL PLOT(X,Y,IPEN,0)
      GO TO 40
   50 REWIND 2
C     OUTLINE OF DYE PATCHES
      READ(2,102) WASTE
  101 READ(2,100)J1 ,XD,YD
  100 FORMAT(7X,I2,6X,2F6.0)
      IF (EOF(2)) GO TO 72
      IF(J1.EQ. 0) GO TO 71
   71 IF(XD.EQ. 0.) GO TO 61
      IPEN=0
      XD=XD-XMIN
      YD=YD-YMIN
      IF(J1.GT.1) IPEN=1
      CALL PLOT(XD,YD,IPEN,0)
      GO TO 101
C     DYE PATCH PLOTS
   61 READ(2,62)IL,I,X1,Y1,X2,Y2,VI
   62 FORMAT(2X,I2,21X,I1,4X,2(F6.0),2X,2(F6.0),2X,F8.4)
      IF (EOF(2)) GO TO 72
      IPEN=0
      KPEN=1
      X=X1-XMIN
      Y=Y1-YMIN
      CALL PLOT(X,Y,IPEN,5)
      CALL PLOT(X,Y,KPEN,5)
      DX=X2-X1
      DY=Y2-Y1
      DZ=SQRT(DX**2+DY**2)
      DELX=VS*VI*DX/DZ
      DELY=VS*DY*VI/DZ
      CALL DELTA(DELX,DELY,KPEN,0)
      CALL ALPHAS
      CALL XLATE(IL,BCDCON)
      CALL WRITEY(1.,0.,2H0),BCDCON)
      CALL VECTORS
      X=X2-XMIN
      Y=Y2-YMIN
      CALL PLOT(X,Y,IPEN,5)
      GO TO 61
```

```
   72 END FILE 1
      CALL BYENOW
      END
''
```

```
      PROGRAM FLASH
      DIMENSION XE(3),YE(3)
      DIMENSION AX(3)
C.....SCALING
      WRITE(61,6)
    6 FORMAT(' TYPE IN VELOCITY VECTOR SCALE FACTOR ')
      VS=TTYIN(4HVS= )
      READ(2,7)(AX(I),I=1,3)
    7 FORMAT(9X,3A8)
      WRITE(61,18)
   18 FORMAT(' TYPE IN GRID SIZE ')
      IGS=TTYIN(4HIGS=)
C     SIZE WINDOW
      XMIN=90000.
      YMIN=90000.
      XMAX=1000.
      YMAX=1000.
    4 READ(2,3) IST
    3 FORMAT(7X,I2)
      IF(IST.NE.0.) GO TO 4
   10 READ(2,1) XA,YA,XB,YB
    1 FORMAT(30X,2F6.0,2X,2F6.0)
      IF(EOF(2)) GO TO 20
      XS=XA
      YS=YA
      GO TO 12
   13 XS=XB
      YS=YB
   12 IF(XMIN.GT.XS) XMIN=XS
      IF(YMIN.GT.YS) YMIN=YS
      IF(YMAX.LT.YS) YMAX=YS
      IF(XMAX.LT.XS) XMAX=XS
      IF(XS.EQ.XA) GO TO 13
      GO TO 10
   20 IPEN=0
C     SCALE GRID
      IXN=XMIN/1000
      IXX=XMAX/1000+1
      IYN=YMIN/1000
      IYX=YMAX/1000+1
      XMIN=IXN*1000
      XMAX=IXX*1000
      YMAX=IYX*1000
      YMIN=IYN*1000
      XRNG=XMAX-XMIN
      YRNG=YMAX-YMIN
```

```
      XSCA=700./XRNG
      YSCA=695./YRNG
      IF(XSCA.GT.YSCA) XSCA=YSCA
      YSCA=XSCA
      XW=XMAX+50./XSCA
      YW=YMAX+25./YSCA
      XL=0.-60./XSCA
      YL=0.-14./YSCA
      CALL ERASE
      CALL FSCALE(XSCA,YSCA,250.,30.)
C     LABEL SCALE
      CALL VECTORS
      XSI=XSCA*.008
      ISC=1.0/XSI
      Y=YRNG-YL/3.0
       CALL PLOT(0.,Y,0,0)
      CALL ALPHAS
      WRITE(61,21)IGS
   21 FORMAT(10X,'SCALE9 ',I4,'FT. PER DIVISION')
      YLL=0.-30./YSCA
      CALL PLOT(0.,YLL,0,0)
      WRITE(61,9)(AX(I),I=1,3)
    9 FORMAT(1X,3A8)
      XMID=350./XSCA
      CALL PLOT(XMID,YLL,0,0)
      VSS=VS/100.
      WRITE(61,8) VSS
    8 FORMAT(' VEL.MAG.=',F4.2,'FPS PER 100 SCALED FT.')
C     DRAW GRID
      CALL VECTORS
      NOX=XRNG/IGS+1.
      NOY=YRNG/IGS
      X=0.0
      IPEN=0
      KPEN=1
C     VERTICAL LINES
      DO 30 I=1,NOX
      Y=0.0
      CALL PLOT(X,Y,IPEN,0)
      DO 29 J=1,NOY
      Y=Y+IGS
   29 CALL PLOT(X,Y,KPEN,0)
   30 X=X+IGS
C     HORIZONTAL LINES
      Y=0.0
      NOX=NOX-1.
      NOY=NOY+1.
      DO 32 I=1,NOY
      X=0.0
      CALL PLOT(X,Y,IPEN,0)
      DO 31 J=1,NOX
      X=X+IGS
   31 CALL PLOT(X,Y,KPEN,0)
   32 Y=Y+IGS
C     LABEL X AXIS
      CALL ALPHAS
      NX=XRNG/1000.+1
      ICON=XMIN-1000.
      CALL PLOT(0.,0.,0,0)
      CALL DELTA(0.,YL,0,0)
      DO 33 I=1,NX
      ICON=ICON+1000
      WRITE(61,34) ICON
   34 FORMAT(1X,I5)
   33 CALL DELTA(1000.,0.,0,0)
C     LABEL Y AXIS
      NY=YRNG/1000+1
      CALL PLOT(0.,0.,0,0)
      YNOW=0.
      CALL DELTA(XL,YNOW,0,0)
      ICON=YMIN-1000.
      DO 35 I=1,NY
      ICON=ICON+1000
      WRITE(61,34) ICON
   35 CALL DELTA(0.,1000.,0,0)
C.....PLOTTING
C     ESTUARY OUTLINE
      CALL VECTORS
      CALL WINDOW(0.,0.,XRNG,YRNG,0)
      CALL PLOT(0.,0.,0,0)
   40 READ(30,2)(XE(J),YE(J),J=1,3)
    2 FORMAT(5X,3(4X,2F6.0,6X))
      IF(EOF(30)) GO TO 50
      IPEN=1
      DO 41 I=1,3
      X=XE(I) -XMIN
      Y=YE(I) -YMIN
   41 CALL PLOT(X,Y,1,0)
      GO TO 40
   50 REWIND 2
C     OUTLINE OF DYE PATCHES
      CALL NORMAL
      READ(2,102)WASTE
  102 FORMAT(I5)
  101 READ(2,100) J1,XD,YD
  100 FORMAT(7X,I2,6X,2F6.0)
      IF (EOF(2)) GO TO 72
      IF(JI.EQ.0) GO TO 71
   71 IF(XD.EQ.0.) GO TO 61
      IPEN=0
      XD=XD-XMIN
      YD=YD-YMIN
      IF(J1.GT.1) IPEN=1
      CALL PLOT(XD,YD,IPEN,0)
      GO TO 101
C     DYE PATCH PLOTS
   61 READ(2,62) IL,I,X1,Y1,X2,Y2,VI
   62 FORMAT(2X,I2,21X,I1,4X,2(F6.0),2X,2F6.0,2X,F8.4)
      IF (EOF(2)) GO TO 72
      IPEN=0
      KPEN=1
      X=X1-XMIN
      Y=Y1-YMIN
      CALL PLOT(X,Y,IPEN,5)
      CALL PLOT(X,Y,KPEN,5)
      DX=X2-X1
      DY=Y2-Y1
      DZ=SQRT(DX**2+DY**2)
```

```
      DELX=VS*VI*DX/DZ
      DELY=VS*DY*VI/DZ
      CALL DELTA(DELX,DELY,KPEN,0)
      CALL ALPHAS
      CALL NORMAL
      IF(IL.LT.10.)GO TO 64
      WRITE(61,63) IL
   63 FORMAT(I3)
      GO TO 66
   64 WPITE(61,65) IL
   65 FORMAT(I2)
   66 CALL VECTORS
      X=X2-XMIN
      Y=Y2-YMIN
      CALL PLOT(X,Y,IPEN,5)
      GO TO 61
   72 CONTINUE
      CALL PAGE
      CALL BYENOW
      END
''
```

```
      PROGRAM RESCALE
      DIMENSION IP(3),XP(3), YP(3)
      SCALE=FFIN(60)
C     OUTLINE
  100 READ(60,2) JN,(IP(J),XP(J),YP(J),J=1,3)
    2 FORMAT(I5,3(I4,2F6.0,6X))
      IF(XP(1).EQ.0) GO TO 400
      DO 10 I=1,3
      XP(I)=XP(I)*SCALE
   10 YP(I)=YP(I)*SCALE
      WRITE(62,4) JN,(IP(J),XP(J),YP(J),J=1,3)
    4 FORMAT(I5,3(I4,2F6.0,6X))
      GO TO 100
  400 CONTINUE
      END
''
```

Output from PROGRAM STREAK

LINT SLOUGH 8AUG72 NO.2

```
ORIENTATION PARAMETER CORRECTION LIMIT IS 0.00001
TIME            XO               YO               ZO
 10111    8.1616155E 03    6.8221710E 03    2.2089589E 03
TIME            OMEGA            PHI              KAPPA
 10111   -6.4807842E-01   -1.1665522E-01   -9.9394679E-01
 10111    7.6157361E-01    9.9317247E-01    1.0986254E-01

ORIENTATION MATRIX AT TIME      10111
    1.0911245E-01   -7.4865785E-01    6.5391582E-01
    9.8716059E-01    1.5881251E-01    1.7104222E-02
   -1.1665522E-01    6.4365365E-01    7.5637394E-01

ORIENTATION PARAMETER CORRECTION LIMIT IS 0.00001
TIME            XO               YO               ZO
 10158    8.2370093E 03    6.7589797E 03    2.1952411E 03
TIME            OMEGA            PHI              KAPPA
 10158   -6.5545985E-01   -1.0863374E-01   -9.9536353E-01
 10158    7.5523002E-01    9.9408184E-01    9.6184420E-02

ORIENTATION MATRIX AT TIME      10158
    9.5615185E-02   -7.4487961E-01    6.6031213E-01
    9.8947281E-01    1.4351628E-01    1.8618044E-02
   -1.0863374E-01    6.5158073E-01    7.5076045E-01

ORIENTATION PARAMETER CORRECTION LIMIT IS 0.00001
TIME            XO               YO               ZO
 10177    8.5099011E 03    6.6886672E 03    2.1295433E 03
TIME            OMEGA            PHI              KAPPA
 10177   -6.5892253E-01   -2.0954339E-02   -9.9985913E-01
 10177    7.5221081E-01    9.9978043E-01   -1.6784650E-02

ORIENTATION MATRIX AT TIME      10177
   -1.6780965E-02   -7.5233659E-01    6.5856515E-01
    9.9963959E-01    1.1797456E-03    2.6819644E-02
   -2.0954339E-02    6.5877785E-01    7.5204565E-01

ORIENTATION PARAMETER CORRECTION LIMIT IS 0.00001
TIME            XO               YO               ZO
 10197    8.3040545E 03    2.7216421E 03    2.2828952E 03
TIME            OMEGA            PHI              KAPPA
 10197    8.0485499E-01   -1.7194715E-02    9.9951578E-01
 10197    5.9347152E-01    9.9985216E-01   -3.1116114E-02

ORIENTATION MATRIX AT TIME      10197
   -3.1115513E-02    5.9361477E-01    8.0414774E-01
   -9.9936801E-01   -4.6339761E-03   -3.5243592E-02
   -1.7194715E-02   -8.0473600E-01    5.9328378E-01

ORIENTATION PARAMETER CORRECTION LIMIT IS 0.00001
TIME            XO               YO               ZO
 10207    8.3891788E 03    6.6743455E 03    2.2374240E 03
TIME            OMEGA            PHI              KAPPA
 10207   -6.6190773E-01   -5.1327112E-02   -9.9999710E-01
 10207    7.4958532E-01    9.9868190E-01    2.4080225E-03
```

```
ORIENTATION MATRIX AT TIME      10207
    2.4048484E-03   -7.4950134E-01    6.6199846E-01
    9.9867900E-01    3.5778732E-02    3.6880049E-02
   -5.1327112E-02    6.6103527E-01    7.4859729E-01

DYE PATCH DATA, PHOTO10111 PHOTO10158

NO 1
 XCENTROID-1          8211
 YCENTROID-1          5340
 AREA-1             113.73
 XCENTROID-2          8230
 YCENTROID-2          5316
 AREA-2            3931.06
 VELOCITY              .11FPS
AZIMUTHFROM NORTH 2.48498RADIANS
DIFFUSION STUDY
 DX=        5.78FT.SQ/SEC        DY=           .42FT.SQ/SEC
 A1=     11  A2=      68,  B1=       3,  B2=     18

NO 2
 XCENTROID-1          8225
 YCENTROID-1          5366
 AREA-1             222.59
 XCENTROID-2          8332
 YCENTROID-2          5396
 AREA-2            5069.41
 VELOCITY              .39FPS
AZIMUTHFROM NORTH 1.30080RADIANS
DIFFUSION STUDY
 DX=       13.75FT.SQ/SEC        DY=           .28FT.SQ/SEC
 A1=     17  A2=     105,  B1=       4,  B2=     15

DYE PATCH DATA, PHOTO10158 PHOTO10177

NO 1
 XCENTROID-1          8230
 YCENTROID-1          5316
 AREA-1            3931.06
 XCENTROID-2          8328
 YCENTROID-2          5215
 AREA-2            3354.42
 VELOCITY             1.23FPS
AZIMUTHFROM NORTH 2.36846RADIANS
DIFFUSION STUDY
 DX=       -4.19FT.SQ/SEC        DY=           .02FT.SQ/SEC
 A1=     68  A2=      58,  B1=      18,  B2=     19

NO 2
 XCENTROID-1          8332
 YCENTROID-1          5396
 AREA-1            5069.41
 XCENTROID-2          8585
 YCENTROID-2          5398
 AREA-2           10713.86
 VELOCITY             2.22FPS
```

AZIMUTHFROM NORTH 1.56065RADIANS
DIFFUSION STUDY
DX= -11.90FT.SQ/SEC DY= 4.32FT.SQ/SEC
A1= 105 A2= 85, B1= 15, B2= 40
DYE PATCH DATA, PHOTO10177 PHOTO10197

NO 1
XCENTROID-1 8328
YCENTROID-1 5215
AREA-1 3354.42
XCENTROID-2 8360
YCENTROID-2 5102
AREA-2 13670.72
VELOCITY .98FPS
AZIMUTHFROM NORTH 2.86416RADIANS
DIFFUSION STUDY
DX= 12.61FT.SQ/SEC DY= 6.55FT.SQ/SEC
A1= 58 A2= 87, B1= 19, B2= 50

NO 2
XCENTROID-1 8585
YCENTROID-1 5398
AREA-1 10713.86
XCENTROID-2 8930
YCENTROID-2 5332
AREA-2 20580.50
VELOCITY 2.93FPS
AZIMUTHFROM NORTH 1.76158RADIANS
DIFFUSION STUDY
DX= 21.20FT.SQ/SEC DY= 4.20FT.SQ/SEC
A1= 85 A2= 120, B1= 40, B2= 55

DYE PATCH DATA, PHOTO10197 PHOTO10207

NO 1
XCENTROID-1 8360
YCENTROID-1 5102
AREA-1 13670.72
XCENTROID-2 8352
YCENTROID-2 5095
AREA-2 16022.75
VELOCITY .18FPS
AZIMUTHFROM NORTH 4.00589RADIANS
DIFFUSION STUDY
DX= 12.85FT.SQ/SEC DY= 1.05FT.SQ/SEC
A1= 87 A2= 98, B1= 50, B2= 52

NO 2
XCENTROID-1 8930
YCENTROID-1 5332
AREA-1 20580.50
XCENTROID-2 9099
YCENTROID-2 5348
AREA-2 19709.41
VELOCITY 2.82FPS
AZIMUTHFROM NORTH 1.47110RADIANS
DIFFUSION STUDY
DX= -9.46FT.SQ/SEC DY= .55FT.SQ/SEC

A1= 120 A2= 113, B1= 55, B2= 56
LAST PHOTO
''

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MARGIN 1	8218	5346
MARGIN 2	8207	5330
MARGIN 3	8203	5335
MARGIN 4	8216	5351
MARGIN 1	8220	5351
MARGIN 2	8215	5356
MARGIN 3	8229	5382
MARGIN 4	8235	5375
MARGIN 1	8216	5354
MARGIN 2	8272	5303
MARGIN 3	8290	5257
MARGIN 4	8271	5265
MARGIN 5	8271	5272
MARGIN 6	8222	5303
MARGIN 7	8165	5339
MARGIN 8	8189	5354
MARGIN 1	8215	5357
MARGIN 2	8256	5395
MARGIN 3	8280	5402
MARGIN 4	8342	5414
MARGIN 5	8394	5418
MARGIN 6	8429	5422
MARGIN 7	8422	5393
MARGIN 8	8398	5397
MARGIN 9	8392	5389
MARGIN 10	8387	5391
MARGIN 11	8380	5386
MARGIN 12	8365	5395
MARGIN 13	8358	5386
MARGIN 14	8276	5374
MARGIN 15	8245	5370
MARGIN 1	8301	5265
MARGIN 2	8335	5223
MARGIN 3	8362	5205
MARGIN 4	8390	5187
MARGIN 5	8379	5177
MARGIN 6	8356	5188
MARGIN 7	8338	5187
MARGIN 8	8347	5159
MARGIN 9	8310	5209
MARGIN 10	8285	5239
MARGIN 11	8286	5257
MARGIN 12	8294	5265
MARGIN 13	8303	5267
MARGIN 1	8676	5405

MARGIN	2	8650	5367
MARGIN	3	8625	5370
MARGIN	4	8575	5351
MARGIN	5	8551	5369
MARGIN	6	8498	5359
MARGIN	7	8517	5406
MARGIN	8	8509	5428
MARGIN	9	8538	5444
MARGIN	10	8568	5424
MARGIN	11	8578	5434
MARGIN	12	8592	5434
MARGIN	13	8601	5427
MARGIN	14	8643	5434
MARGIN	15	8660	5451
MARGIN	16	8657	5413
MARGIN	1	8344	5190
MARGIN	2	8398	5147
MARGIN	3	8418	5087
MARGIN	4	8416	5048
MARGIN	5	8382	5023
MARGIN	6	8334	5026
MARGIN	7	8317	5066
MARGIN	8	8311	5138
MARGIN	9	8311	5184
MARGIN	1	8823	5363
MARGIN	2	8909	5384
MARGIN	3	8967	5383
MARGIN	4	9025	5387
MARGIN	5	9034	5350
MARGIN	6	9027	5314
MARGIN	7	9030	5273
MARGIN	8	9022	5269
MARGIN	9	8981	5274
MARGIN	10	8946	5281
MARGIN	11	8925	5292
MARGIN	12	8881	5289
MARGIN	13	8849	5292
MARGIN	14	8818	5299
MARGIN	15	8801	5322
MARGIN	1	8340	4982
MARGIN	2	8305	5045
MARGIN	3	8304	5102
MARGIN	4	8309	5174
MARGIN	5	8360	5193
MARGIN	6	8402	5147
MARGIN	7	8409	5096
MARGIN	8	8388	5029
MARGIN	1	9208	5267
MARGIN	2	9179	5265
MARGIN	3	9060	5315
MARGIN	4	8990	5342
MARGIN	5	8984	5384
MARGIN	6	9016	5405
MARGIN	7	9067	5410
MARGIN	8	9108	5412
MARGIN	9	9159	5393
MARGIN	10	9175	5361
MARGIN	11	9191	5342
MARGIN	12	9198	5329
MARGIN	13	9178	5297
MARGIN	14	9199	5284

VECTOR	PHOTOS				INITIAL COORDS		FINAL COORDS		VELOCITY
1	10111	10158	DYE	1	8211	5340	8230	5316	.1099
2	10111	10158	DYE	2	8225	5366	8332	5396	.3931
3	10158	10177	DYE	1	8230	5316	8328	5215	1.2322
4	10158	10177	DYE	2	8332	5396	8585	5398	2.2225
5	10177	10197	DYE	1	8328	5215	8360	5102	.9827
6	10177	10197	DYE	2	8585	5398	8930	5332	2.9327
7	10197	10207	DYE	1	8360	5102	8352	5095	.1767
8	10197	10207	DYE	2	8930	5332	9099	5348	2.8221

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