Morton Keller
National Ocean Survey
Rockville, MD 20852

Aerial Photography in the NOS Coastal Mapping Division*

The physical characteristics of the National Ocean Survey (NOS) photography operation are reviewed, and the photographic requirements of various photogrammetric activities are discussed.

Introduction

Aerial photography is one of the three principal components comprising the photogrammetric surveying complex, the other being supplemental field surveys and photogrammetric office measurements. This system is subject to a wide variety of applications, with a great many possible arrangements of the components to suit the requirements and the economy of a specific task. The judicious planning of an aerial photography mission is vital to the successful completion of a photogrammetric operation, because the photograph serves as the basic source of data for applying the science of photogrammetry to the making of maps.

Spectral Response

Photogrammetry is primarily a system of measuring and interpreting data recorded on aerial photography by electromagnetic energy ranging in wavelength from about 0.380 through 0.920 micrometers. The film emulsions and filters employed by the Coastal Mapping Division are the following:

- *Black-and-White Infrared* with a 740-nanometer filter to record wavelengths between 740 and 920 nanometers,
- *Natural-Color* with a 420-nanometer filter to record between 420 and 680 nanometers,
- *Black-and-White Panchromatic* with a 500-nanometer filter to record wavelengths between 500 and 680 nanometers, and
- *False-Color Infrared* with a 520-nanometer filter to record between 520 and 865 nanometers.

These emulsions have the following characteristics: *Black-and-white infrared* film is often used to determine the cutoff line between land and water, primarily when mapping the high- and low-water shorelines. Water absorbs infrared radiation and reflects the shorter wavelengths. Water appears black on the infrared emulsion because the 0.740 μm filter does not allow the visible rays to strike the film. Depths of one or two inches can be detected in this manner. Vegetation is an excellent source of reflected infrared radiation and creates a whitish color on the exposure. This characteristic is useful for the identification of species and plant vigor.

Other advantages include increased atmospheric haze penetration, a reduced reflection of the sun from water surfaces (sunspot), and sharply defined images of targets on the water surface for estuarine circulatory surveys. However, the black tone of the water surface hinders the identification of natural surface markings and precludes use of the emulsion for any water penetration studies.

Natural-color emulsion can record some 20,000 separable colors as they actually appear in nature. It is ideal for photographic interpretation of natural and manmade features and enables the photogrammetrist to see better into the shadows produced by elevated objects. Aids to navigation, such as lights and buoys, are clearly recorded against the blue-green water background thus making them readily identifiable for charting without the need for field verification.

Natural-color has the deepest water penetration ability of all the emulsions, reaching nearly 75 feet in clear waters. This penetration decreases to 5 or 10 feet in turbid waters but is still very useful for charting submerged rocks, shallow areas, and other subsurface features. Photogrammetric surveys preceding hydrography assist the hydrographer who does not have an overall view of the bottom to guide him in developing important details.

The natural-color emulsion permits the

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color coding of different painted targets that may be used in aerotriangulation or in current surveys. However, it does not record the natural water surface markings too well and yields a larger sun-spot because nearly all reflected visible light rays from the water surface are recorded on the emulsion.

Black-and-white panchromatic emulsion can record only about 200 distinguishable shades of gray. In its characteristics it falls somewhere between natural-color and black-and-white infrared emulsions. The sun-spot image is intermediate in size between that of the color and infrared emulsions. Its water penetration ability approaches that of natural-color, but the details are not quite as sharp. Black-and-white panchromatic provides a good overall result when trying to record both floating targets and water surface details on the same emulsion. Thus, this emulsion is quite adequate for routine mapping operations.

In many cases the best choice of all the emulsions is *false-color infrared.* The term "false-color" is used because the emulsion is designed so that reflected near-infrared radiation produces a red image, reflected red radiation yields a green image, and reflected green radiation creates a blue image on the developed exposure. The false rendition of familiar colors is a deterrent to the general acceptance of this material. However, more familiarity and understanding of its advantages will increase the popularity of false-color infrared emulsion. Healthy vegetation yields a brilliant red on the exposure, and an almost infinite number of tones between red and blue are available for various types of vegetation. The film thus is valuable for vegetation identification and the detection of crop disease.

Other uses include the detection of underground water resources, geological structure analysis, water pollution, and the study of soils. In fact, false-color infrared provides nearly all the benefits of the other emulsions with the exception of water penetration, which is limited to about 25 feet.

Resolution And Sharpness

Resolution is the ability to separate adjacent features so that they can be seen as individual images, and it is expressed as the maximum number of lines-per-millimeter that can just be resolved.

All of the emulsions yield a final image-resolution sufficient for photogrammetric purposes (40 lines/mm or more) when properly used. When copies are made from original exposures, each regeneration of the image can degrade the resolution by about 15 to 20 percent.

Sharpness refers to a separation of adjacent features as a function of the contrast in the tones of the images. The choice of which emulsion to use in obtaining maximum sharpness, therefore, depends primarily on the contrasts provided by the colors of objects in the photographed scene.

Sharpness of imagery is of prime concern to the photogrammetrist. Our experience has shown false-color infrared and natural-color emulsions to provide the greatest image sharpness, because of their ability to record separable colors. Black-and-white panchromatic has less image sharpness capability, while black-and-white infrared has the least. As a result, an equivalent black-and-white infrared photograph optically sliced from the original false-color infrared photograph in the laboratory often exhibits a superior image sharpness, when compared to a true black-and-white infrared photograph taken of the area. For this reason, false-color infrared photography is used instead of black-and-white infrared photography, except when the less expensive black-and-white infrared can be taken in tandem with natural-color or black-and-white panchromatic photography.

Aerial Cameras

The Coastal Mapping Division utilizes Wild RC-8, RC-9, and RC-10 cameras to secure the near-vertical aerial photography required for its photogrammetric operations. The RC-10 camera is equipped with interchangeable 6-inch and 3.5-inch focal length cones. A specially designed RC-10, 6-inch focal length cone having a *reseau* has also been acquired by the National Ocean Survey. This "geodetic" cone is to be used for the application of analytical photogrammetry for determining the location of monumented ground points with first- and second-order geodetic accuracies.

The National Ocean Survey Air Photo Mission

The National Ocean Survey operates two Air Photo Missions, one aircraft being a DeHavilland Buffalo, while the other is an Aero Commander 690A.

The Buffalo is a twin-engined turboprop craft, having a normal cruising speed between 120 and 180 knots at altitudes ranging up to 32,000 feet. Its cruising range is 10 hours. The cabin is unpressurized, requiring the four- to five-man crew to use oxygen at altitudes above 10,000 feet. The Buffalo has been modified to accommodate simultaneously three aerial cameras mounted in three hatches. All operational costs for the aircraft and crew are borne by NOS, and the plane is used on nearly all photographic missions conducted by the Coastal Mapping Division.

The Aero Commander 690A is a leased aircraft acquired in 1974 to obtain photography for airport surveys. It is a twin-engined turboprop craft, having a cruising speed between 100 and 270 knots at altitudes ranging up to 32,000 feet. Its cruising range is five hours. The pressurized cabin permits the three-man crew to operate without relying on oxygen. However, this requires the photography to be taken through an optically flat glass window which covers the single hatch. A backup oxygen supply is available that permits aerial photography to be taken without the glass window in place over the hatch.

The Coastal Mapping Division Photo Laboratory

The Photo Laboratory is equipped for handling black-and-white photography from the processing stage through to the making of emulsion-to-emulsion contact prints, ratio prints up to 4 × enlargement, and color transparencies from the developed film. The transparencies are used on the plotting instruments because glass plate diapositives are no longer manufactured.

The laboratory no longer has facilities for processing the original color film rolls, because of a change to a high-temperature and toxic chemistry processing procedure several years ago. The processing is therefore performed outside the agency on a contractual basis. The laboratory is making an effort to recapture its ability to process the original color film rolls in-house, by developing hardware for the COBRA film processing system. This is a repeatable, self-contained, automatic programmed method that will produce a metrically stable, high-quality product from either black-and-white or color aerial films.

General Land Mapping

The mapping operations of the Coastal Mapping Division are confined primarily to the coastal areas, except for Airport Obstruction Chart surveys. Natural-color is most desirable for land mapping purposes because of its photointerpretation capabilities. False-color infrared emulsion is useful when vegetation features are of concern. Black-and-white panchromatic is adequate for routine land mapping operations and is used whenever the sole purpose of the photography is the construction of a mosaic, because the black-and-white prints permit a better tonal match to be made between adjacent photographs. Black-and-white infrared emulsion is not used for mapping land features, because it has the least image-sharpness capability of all the emulsions.

Shoreline Delineation

The delineation of the mean low-water line (mean lower low-water line on the west coast), and/or the mean high-water line is necessary in coastal mapping operations.

A major tool in delineating shoreline is the use of infrared photography taken when tide gauges indicate the existence of the appropriate tide level. This tide-coordinated photography requires the stationing of radio-equipped observers at key tide stations throughout the area. The observers inform the aircraft of the approach of the water level to the prescribed value and advise the pilot when to start and when to cease photography.

SHORELINE DELINEATION ONLY

When the photogrammetrist is interested only in delineating the mean low-water (MLW) and/or mean high-water (MHW) line and is not concerned with other alongshore details, there are two basic methods which can be used, depending on whether or not the weather, sun angle, and tides cooperate.

Weather, sun angle, and tides cooperate. This requires that the desired stage of tide occurs during good weather while the sun is located over water and at an angle between 30° and 45°. Then one photo flight is made along the beach at mean low water, and a second flight may be made at mean high water. At least half of the photography coverage must be on land to facilitate office aerotriangulation. The less expensive black-and-white infrared can be used for an uncomplicated shoreline, while an intricate shoreline requires the use of false-color infrared emulsion, because the separable colors recorded by this emulsion enhance image sharpness and photointerpretation. An equivalent black-and-white infrared picture is then optically sliced from the false-color infrared photograph in the Photo Laboratory. Regardless of which infrared emulsion is employed, the sharp water-land interface lines can be traced directly onto the map manuscript from ratioed photographs.

Weather, sun angle, and tides do not cooperate. Unfortunately, an ideal cooperation between the elements does not always occur, and the photography is taken at some midstage level of the tide. It then becomes necessary to contour the MLW and/or MHW line using a stereoscoptic plotting instrument. An effort is made, therefore, to fly the photography near low water so as to minimize the amount of water that must be penetrated during the contouring process. The contouring procedure broadens the choice of film emulsion which can be used.

- If adequate vertical control can be established, then natural-color emulsion alone will suffice. The stereoscopic natural-color models are simply oriented to control, and the MLW and/or MHW line is contoured on the stereoplotter. Only a single camera and emulsion are employed, and the same natural-color emulsion can be used to map other alongshore details.
- When sufficient vertical control cannot be established, then black-and-white infrared photos are used to augment the natural-color photography. The exact tide stage recorded on the black-and-white infrared pictures can be ascertained by referencing the times of the exposures to tidal records. The water-land interface line thus becomes a line of known elevation, which can be transferred to the natural-color photography to serve as additional vertical control for aerotriangulation and/or leveling of the natural-color stereomodels. The MLW and/or MHW line is then obtained by contouring. The use of the interface line as vertical control reduces the amount of control that must be established in the field and office. In addition, the natural-color photos are ideal for mapping intricate shore-line and other features.
- False-color infrared can be used alone to delineate shoreline where the tide range is less than the water penetration afforded by the emulsion. An equivalent black-and-white picture sliced from the false-color infrared photograph will denote the water-land interface line. As before, the interface line becomes a line of known elevation which can be transferred back to the original false-color infrared photos to serve as additional vertical control for aerotriangulation and/or leveling of the false-color infrared steromodels. The MLW and/or MHW line is then contoured by the stereoplotter operator. Only a single camera and film emulsion are employed, and less vertical control must be established in the field and office.

DELINEATION OF SHORELINE AND OTHER FEATURES

Here the photogrammetrist is interested in the mapping of alongshore details as well as in compiling the MLW and/or MHW line. The delineation of the shoreline and other features can be readily accomplished, as long as one of the emulsions used to photograph the area is natural color.

PHOTOGRAMMETRIC BATHYMETRY

Classical hydrographic mapping in shallow waters with surface craft is slow, hazardous, and expensive. Photogrammetric surveys preceding hydrography can assist the hydrographer by showing many of the submerged features. Natural-color is usually the best choice for photogrammetric bathymetry because of its deeper water penetration capability and is ideal for interpreting underwater details. While false-color infrared emulsion has less water penetration capability, the bottom details are nearly as sharp as on natural-color, and the photointerpretation is good once the photogrammetrist becomes used to the false rendition of familiar colors.

Black-and-white panchromatic has a water penetration capability between that of natural-color and false-color infrared. However, the black-and-white tones hinder the interpretation of bottom details and provide images that are not quite so sharp as the other two emulsions. Thus, black-and-white panchromatic emulsion is not recommended for underwater mapping.

MLW/MLLW DELINEATION

The delineation of the MLW line is necessary to underwater mapping because the water depths are referred to the MLW datum. Typical emulsion applications are discussed below:

- Natural-color stereomodels are used for contouring the MLW line and compiling the bottom details. While only one camera and emulsion are used, more vertical control may have to be established in the field or by office aerotriangulation procedures.
- Natural-color and black-and-white infrared photography is taken of the area. The black-and-white infrared photos yield the MLW line directly if the pictures are taken at MLW. The MLW line helps as vertical control for leveling the natural-color models to be used in mapping the underwater features. When the black-and-white infrared photos are not taken at MLW, a water-land interface line of known elevation is obtained, which will aid in leveling the natural-color models for use in contouring the MLW line and mapping the underwater details. This procedure reduces the amount of vertical control to be established by field or office methods.
- False-color infrared photography can be used alone whenever its water penetration capability exceeds the water depth in the area. An equivalent black-and-white infrared photo sliced from the false-color in-

frared photography taken at MLW will yield the MLW line directly. This line provides vertical control for leveling the false-color infrared stereomodels used in mapping the underwater features. When the photography is not taken at MLW, the equivalent black-and-white infrared pictures provide a water-land interface line of known elevation. The interface line helps in leveling the false-color infrared stereomodels used in contouring the MLW line and mapping the underwater features. Only one camera and emulsion are needed, and less vertical control has to be established by field or office methods.

Photogrammetric Circulatory Surveys (PHOCIS)

Tidal current tables are published annually by the National Ocean Survey, predicting the times of slack water and the times and velocities of the maximum flood and ebb currents at many locations in coastal waters. Current charts are issued for the principal harbors and bays, showing the tidal current direction and speed for each hour of the tidal cycle.

Conventional methods of measuring current velocities generally employ current meters suspended from buoys moored at specific locations within the area of study. These observations are expensive and difficult to obtain, and therefore only a skeletal network of observations is usually made. For this reason, photogrammetric methods have, in selected areas, been combined with the conventional current meter survey techniques during the last decade to obtain a more highly detailed circulatory survey than would be feasible otherwise. The principal feature and advantage of the PHOtogrammetric CIrculatory Survey (PHOCIS) is that it can provide an instantaneous synoptic measurement of surface and subsurface currents over a large area.

In order to apply photogrammetry to circulatory surveys it is necessary to have the water surface marked to permit the identification of specific surface points stereoscopically. The current causes the surface mark to change position during the time interval between the first and second photograph comprising the stereomodel. This permits the current velocity to be computed to within approximately 0.1 knots.

The area must be seeded with suitable drift-type floating targets, and their movements recorded on aerial photography taken throughout the tidal cycle. Aluminum powder has been found to give the most effective targets for photogrammetric surface-current surveys. The powder is packaged in water-soluble polyvinyl alcohol bags and seeded into the area from a small aircraft. The bags either rupture on contact with the water surface or dissolve in 15 seconds. The target has the reflective characteristics of a silver paint which makes for an easily distinguishable white image on the photography. According to results of known research, the aluminum powder is not toxic in the form and concentrations we use and will not break down into other compounds which constitute a danger to the environment or to an ecosystem. The targets for a subsurface-current survey usually consist of a submerged drogue suspended from a floating surface-marker target, which is recorded on the aerial photography.

Natural-color emulsion is the principal emulsion now employed for current surveys. The emulsion aids in model orientation on the plotters because it records bottom details in shallow waters. It also permits the color coding of different types of painted floating surface targets, which may be used in surface and subsurface current surveys. However, natural-color does not record natural surface markings well and gives a larger sun-spot size.

Black-and-white panchromatic yields good overall results when trying to record target and water-surface details on the same emulsion. In addition, the sun-spot image is smaller than on the natural-color emulsion. Black-and-white panchromatic, however, is limited in its use for subsurface current surveys, when different depth drogues may require a color coding of the painted surface marker targets.

Recent studies indicate that the best choice of all may be false-color infrared film. The emulsion appears to provide nearly all of the benefits of the other emulsions, with the exception of water penetration which is limited to about 25 feet in clear water. Surface markings show up exceptionally well, the sun-spot image is somewhat reduced in size, and the separable colors recorded by the emulsion permit the use of a color coding on surface-marker targets.

Black-and-white infrared is not used for photogrammetric current surveys, because the black tone of the water surface hinders the identification of any natural foam markings on the surface. Tenuous aluminum powder target images are also somewhat reduced in size.

Aids To Navigation

Aeronautical aids generally are elevated structures such as lighted radio masts, painted red-and-white to increase their visibility. Nautical aids to navigation include lighthouses, buoys, and beacons which are painted different colors to facilitate identification. Natural-color emulsion is therefore desirable, because it records the true colors of the aid and helps to distinguish it from others in the vicinity.

Mosaics And Orthophotography

A mosaic is an assembly of individual aerial photographs fitted together to form a composite view of the entire area covered by the pictures. Mosaics are used as a background to map detail on airport obstruction charts, large-scale marine harbor charts, and other special projects.

A mosaic assembled from nonrectified photographs will contain tilt and local relief displacements. Even when assembled from rectified prints, the mosaic still will contain local relief displacements which can hamper the matching of images between adjacent photographs. The problem of local relief displacements is minimized by employing orthophotographs to construct the mosaic. An orthophotograph can be made by removing the effects of tilt and relief from standard perspective photographs by using optical or electronic orthoprinters.

When the ground relief is minimal, the photo negatives are simply rectified and ratioed to a common scale before the prints are made. Black-and-white prints are more desirable than color prints in constructing mosaics, because a better tonal match can be secured between adjacent photographs.

When the ground relief is significant, the orthophotographs are made outside the agency on a contractual basis, because our office has chosen not to purchase orthoprinter equipment at this time, due to rapid advances in the state of the art. The contractor provides a film negative which is a true orthophotograph except for the taller buildings. Black-and-white prints are then made for constructing the mosaic.

PHOTOGRAPHY FOR MOSAICS

A good image resolution is desirable on mosaics, because the terrain features are portrayed as realistic photographic images instead of by standard symbols as on a map. The poor image quality provided by black-and-white infrared thus makes this emulsion unsatisfactory for mosaics. The advantages of the color emulsions are lost on the black-and-white positive-tone prints that must be generated from the positive-tone film to construct the mosaic. Also, an intermediate set of black-and-white negatives must be made during this process. This additional regeneration of the imagery serves to degrade the image resolution. For this reason, black-and-white panchromatic emulsion is recommended whenever the sole purpose of the photography is the contruction of a mosaic.

Natural-color or false-color infrared emulsions may be necessary when the photography is to be used for other purposes, in addition to constructing a mosaic. Then it will be necessary to generate the black-and-white negatives prior to printing the black-and-white positive-tone pictures. In such an event, natural-color photography is favored because the false-color infrared cannot see as well into the shadows produced by elevated objects.

Photography should be secured at sun angles of around 60°, and at higher altitudes, in order to minimize the loss of image detail caused by the shadows and layover of elevated objects. It is also advisable to fly at overlaps of 80 to 90 percent in heavily built-up urban areas to permit a selection to be made of those photographs affording a clearly visible vertical view of the tall buildings.

Airport Obstruction Chart Surveys

The Airport Obstruction Chart (OC) surveys were initiated during World War II and have continued without interruption to this day. The entire program, involving field work, photography, aircraft operation, and office compilation, is performed by the Coastal Mapping Division on a reimbursable basis for the Federal Aviation Administration (FAA). There are a total of 686 airports in the current airport obstruction chart program, and approximately 250 airports are photographed and about 180 are surveyed each year as requested by the FAA.

The airport obstruction chart is designed to show selected planimetry, a plan of the airport (including all obstacles in the circling areas), and a plan and profile of the runways, their approaches, and obstacles therein. An aerial photographic mosaic portraying the entire chart area, or only the airport and its immediate surroundings, may appear as background on the charts which are published at a scale of 1:12,000.

Aerial photography for routine airport surveys is secured at a scale of 1:30,000. However, special airport surveys may require photography ranging in scale from 1:24,000 to 1:60,000. The photography must provide the highest possible image resolution on the pictures and mosaic background. This is an absolute necessity in stereoplotter operations, where the elevations of sometimes tenuous treetops must be accurately measured. For this reason, aerial photography is secured only when the trees are in full foliage in order to facilitate identification of the treetops.

Black-and-white infrared emulsion is never used in airport surveys because of its poor image-sharpness capability. Despite a sharper image capability, false-color infrared film also is not used, because this advantage is lost on the black-and-white positive-tone prints that must be generated from the film to construct mosaics. Mosaics are normally constructed whenever an airport revision survey is undertaken. Since natural-color has the same disadvantages in this endeavor as does false-color infrared emulsion, black-and-white panchromatic film is used almost exclusively for routine revision surveys. Natural-color may be used only for airports undergoing an original survey, because mosaics are seldom prepared in such cases.

Conclusion

Aerial photography is one of the principal components comprising the pohotogrammetric surveying complex, the others being supplemental field surveys and photogrammetric office measurements. This system is subject to a wide variety of applications, with a great many possible arrangements of the components to suit the requirements and the economy of a specific task. Judicious planning of the aerial photography mission is vital to a successful completion of the photogrammetric operation, because the aerial photograph serves as the basic source of data for applying the science of photogrammetry to the making of maps. Such planning can only be achieved after carefully considering all of the parameters affecting the ability of the photographs adequately to satisfy the demands of the map being constructed.

BOOK REVIEW

***Elements of Photogrammetry*. By Paul R. Wolf, University of Wisconsin, Madison, Wisconsin; McGraw-Hill Book Company, New York, 1974. Hard cover, 562 pages, 7 × 9¼ inches, with 322 illustrations. Price $16.50.**

This informative volume is a most welcome addition to the many books that have been published in recent years on photogrammetric technology. While the book has been prepared primarily as a text for an introductory college course in photogrammetry, it should also be a valuable addition to the libraries of practicing photogrammetrists and others who use photographs in their work.

The book consists of 20 chapters arranged so that the early chapters establish fundamental principles, while the later chapters discuss the more specialized aspects of photogrammetry with emphasis on practical applications. In general, the more important material is presented first in each chapter, thereby making it convenient to cover only the first parts of certain chapters if time limitations preclude reading the entire book.

The traditional photogrammetric topics discussed include photogrammetric optics; aerial cameras; stereoscopic viewing; principles of photography; vertical and tilted photographs; photographic measurements and refinement; planning aerial photography; control for aerial photography; mosaics; stereoscopic plotting instruments; radial-line triangulation; photogrammetric control extension; etc. Also included are chapters devoted to oblique and panoramic photographs; terrestrial and close-range photogrammetry; photographic interpretation; orthophotography; and remote sensing. New subjects, such as holography and X-ray photogrammetry, are integrated into the text.

The material in this book is presented in a clear, forthright manner that uses elementary terms as much as possible and is accompanied by numerous illustrations and diagrams. A selected list of references is given at the end of each chapter so that readers may expand their knowledge on particular subjects of interest. A variety of homework problems are included after each chapter, and a solution manual is available to instructors from the publisher.

While the material has been kept as elementary as possible, the depth of coverage is sufficient to make the book suitable as an introductory text to modern computational photogrammetry. This is facilitated by the latter chapters and by the inclusion of appendixes dealing with random errors and least-squares adjustment, coordinate transformations, and the development of the collinearity equations.

—*Morton Keller*