Chapter 5
Aerial Photography

5-1. General

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

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

Table 5-1
Uses of Film Types

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

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

b. Aerial mosiacs. Since the photographic image will have scale variation caused by the perspective view of the camera, photo tilt, unequal flying heights, and terrain relief, each aerial mosaic product must be evaluated according to how the scale variation problem is treated. Aerial mosaics may be uncontrolled, semiuncontrolled, or controlled. They may be constructed from unrectified, rectified, or differentially

rectified photographs. A controlled mosaic is prepared using photographs or scanned digital images that have been rectified to an equal scale, while an uncontrolled mosaic is prepared by a "best fit" match of a series of individual photographs.

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

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

5-2. Subcontracted Photography

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

Section I
Aircraft Flight Specifications

5-3. General

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

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

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

5-4. Operational Procedures

The camera and its mount shall be checked for proper installation prior to each mission. Particular attention shall be given to vacuum supply. Except on short flight lines, a minimum of two runoff or blank exposures is

required between usable frames immediately prior to the start of the photography for each flight line or part of a flight line. Any exposures within the project area with a color balance shift compared to the remainder of the roll will result in unacceptable exposures. Some unexposed film must be retained at the beginning or end of each roll for a step wedge, which is required for controlled processing.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

5-5. Flight Line Maps

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Section II
Aerial Cameras

5-6. General

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

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

5-7. Types of Aerial Cameras

There are three types of aerial cameras:

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

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

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

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

5-8. Analog Aerial Cameras

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

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

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

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

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

5-9. Camera Filters

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

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

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

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

5-10. Camera Classifications

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

5-11. Camera Mounting Requirements

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

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

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

5-12. Camera Criteria/Reporting

The camera shall meet the following criteria:

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

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

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

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

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

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

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

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

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

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

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

Section III
Photographic Film

5-13. General

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

5-14. Radiant Energy and the Electromagnetic Spectrum

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

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

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

Note:
Yes = Applicable
No = Not Applicable

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

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

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

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

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

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

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

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

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

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

5-15. Film Characteristics

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

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

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

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

5-16. Type of Diapositives

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

5-17. Film Processing and Handling Specifications and Criteria

All aerial film shall be processed under controlled conditions in automatic, continuous film processors. The film shall be processed in accordance with the manufacturer's instruction. The processing, including development and fixation and washing and drying of all exposed photographic film, shall result in negatives free from chemical or other stains, containing normal and uniform density and fine-grain quality. Before,

during, and after processing, the film shall not be rolled tightly on drums or in any way stretched, distorted, scratched, or marked and shall be free from finger marks, dirt, or blemishes of any kind.

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

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

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

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

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

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

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

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

5-18. Camera Panel

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

5-19. Film Report

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

a. Film number.

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

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

d. Film type and manufacturer's emulsion number.

e. Lens aperture and shutter speed.

f. Date of photography.

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

h. Negative numbers of all offered photography.

i. Indicated flying height.

j. Scale of photography.

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

l. The calibrated focal length of the lens unit.

m. Contractor's name.

5-20. Negative Annotation

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

a. Year, month, and day of flight.

b. USACE project identification.

c. Photo scale (ratio).

d. Film roll number.

e. Negative number.

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

5-21. Container Labels

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

a. Name and address of the contracting agency.

b. Name of the project.

c. Designated roll number.

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

e. Date of each strip.

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

h. Focal length of lens in millimeters.

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

j. Contract number.

5-22. Photo Index Map Requirements

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

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

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

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

5-23. Contact Prints

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

Project_____
USACE Contract No. DAXXXX _____
Date of Photography _____
Calibration of Camera Date_____
Contractor_____
Address_____
Telephone_____

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

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

5-24. Contract Deliverables

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

(1) All film exposed on the project.

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

(3) The flight log.

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

(5) Camera Calibration Report.

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

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

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

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

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

(5) Weekly progress reports.

(6) Monthly progress reports.

(7) Camera log.

(8) Film edit log.