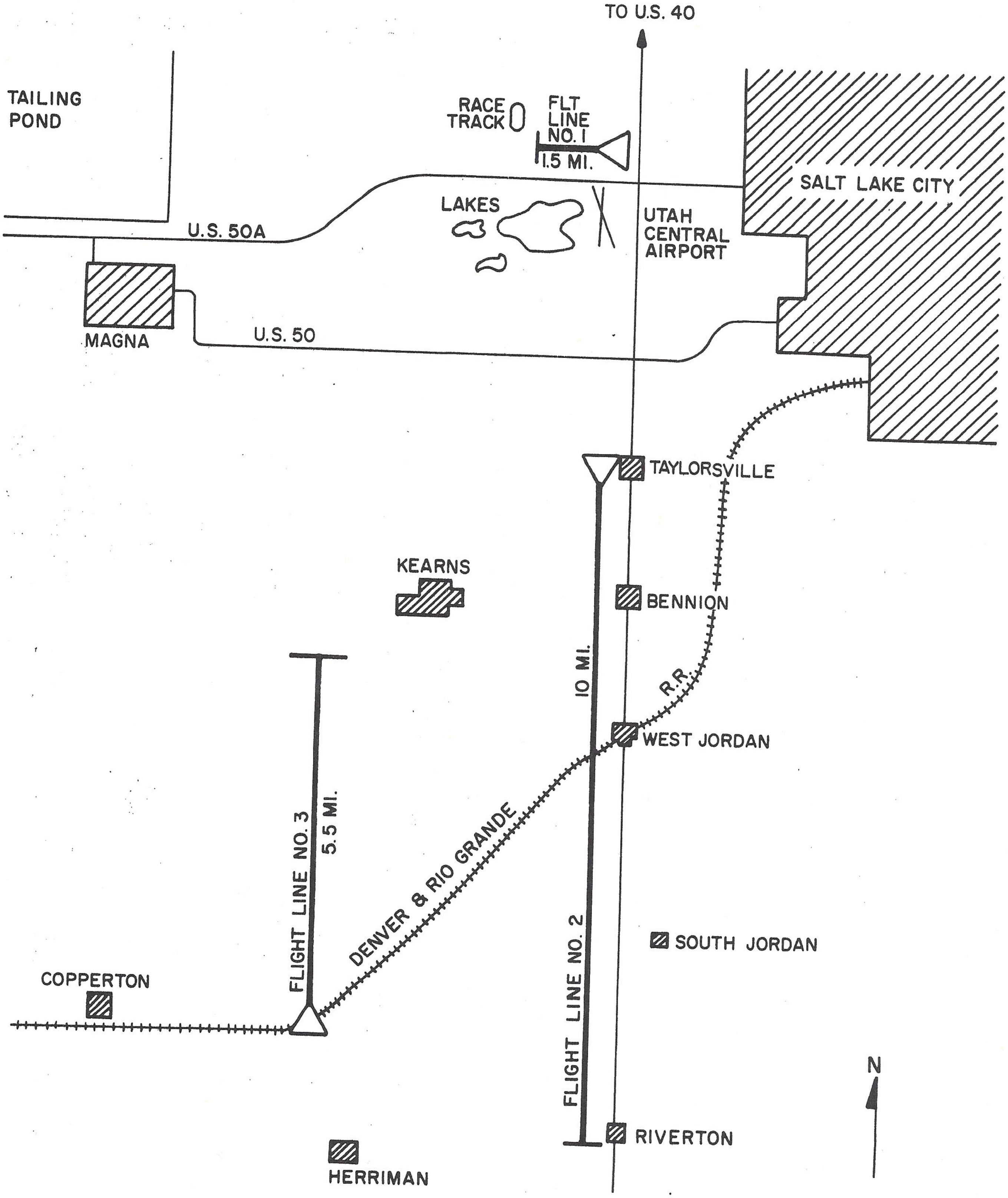


Figure 1.- Sketch map showing flight lines near Salt Lake City, Utah.

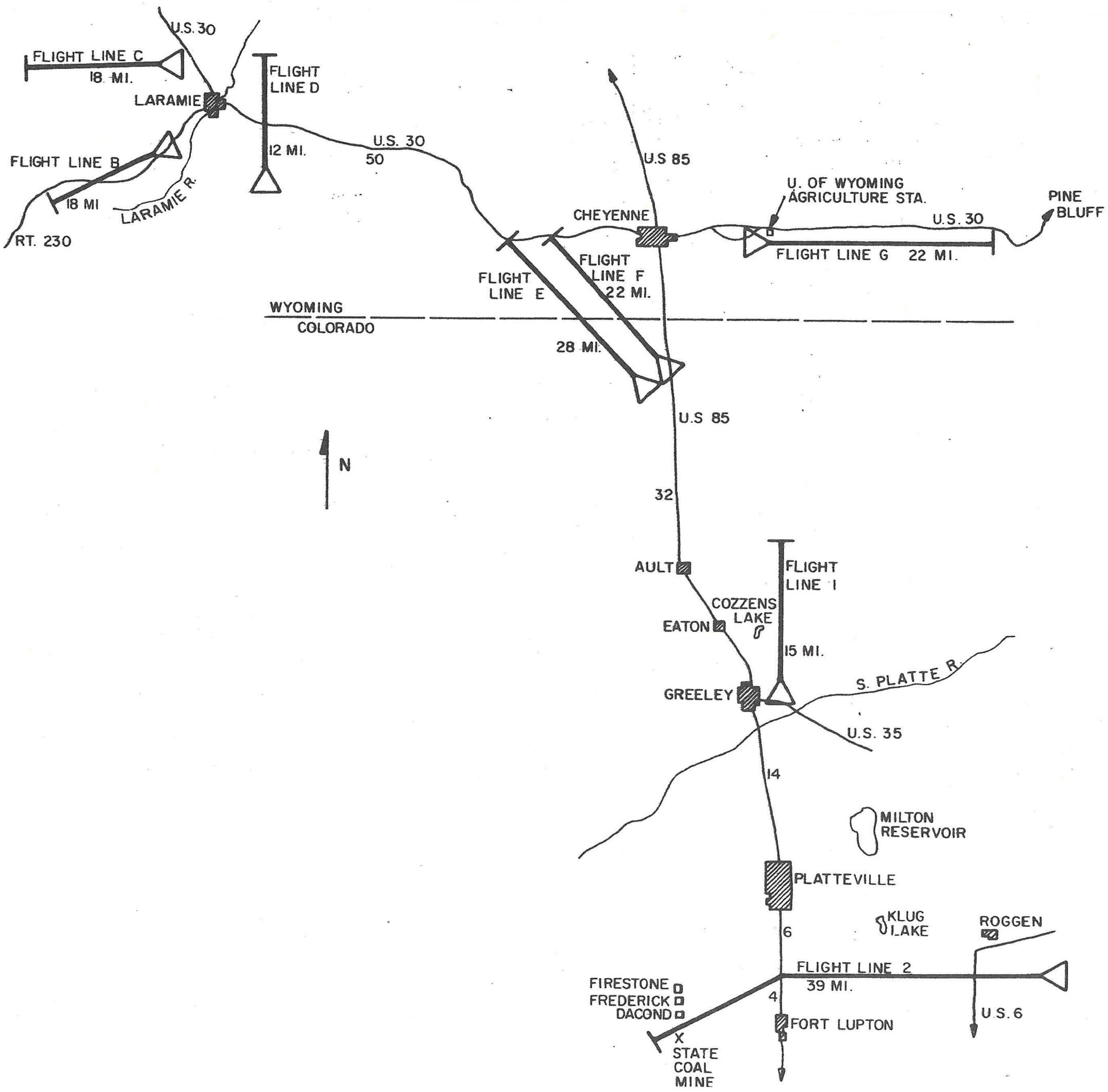


Figure 2.- Sketch map showing flight lines in Wyoming and Colorado.

Figure 3.- Portion of exposure 343, pass 10, enlarged ten times. Contract scale about 1:13,000. This photograph represents the limiting case for the success of an operational livestock survey: detection of sheep and lambs at minimum photo scale. Images are small, but contrast and resolution are good and animals are detectable. Accurate lamb count is difficult, but possible.

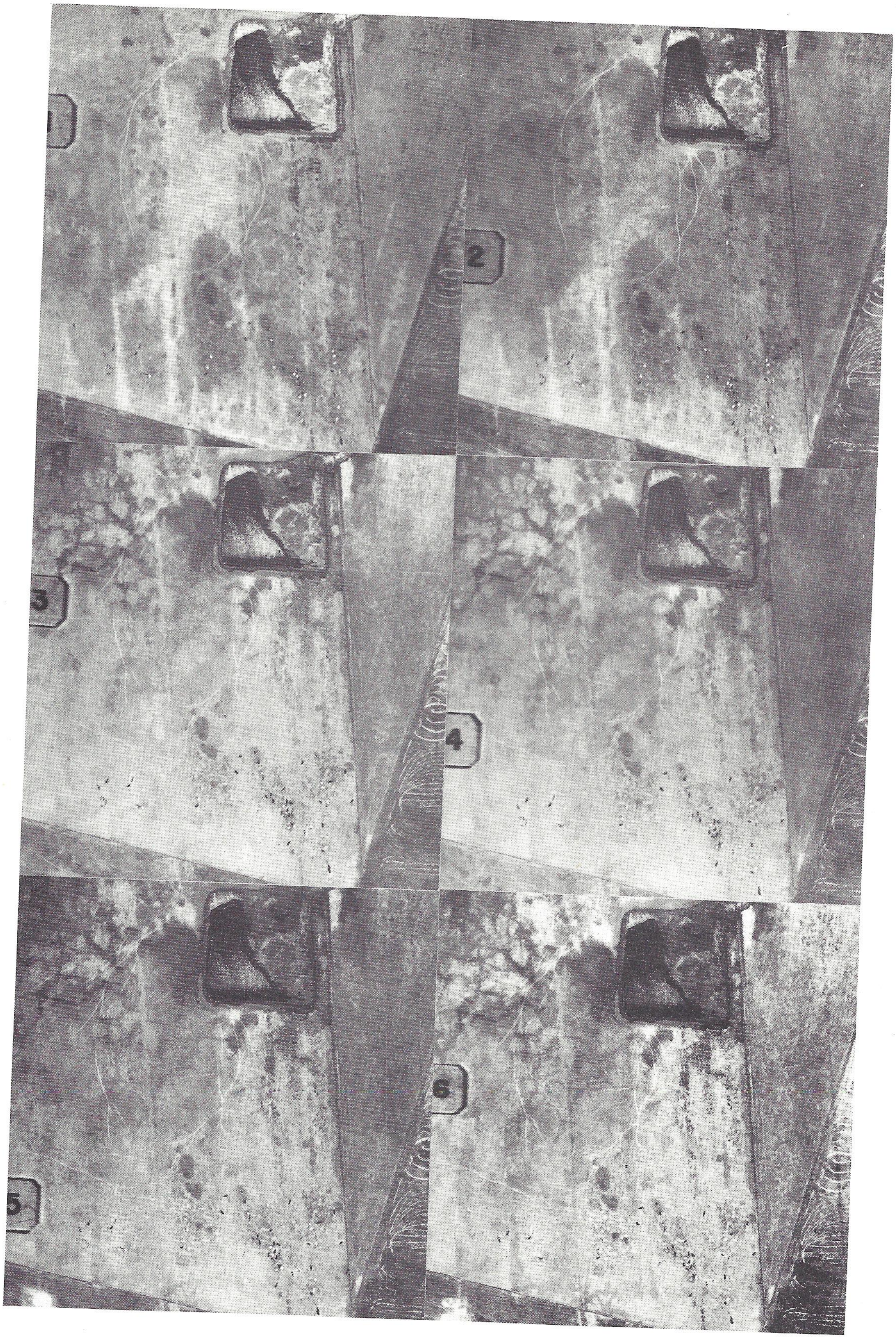


Figure 4.- Bands 1 through 6, exposure 123, from multiband photography of Milpitas area, showing Holstein cattle in pasture. Note differences in tones of background and their effect on detection and identification of stock.

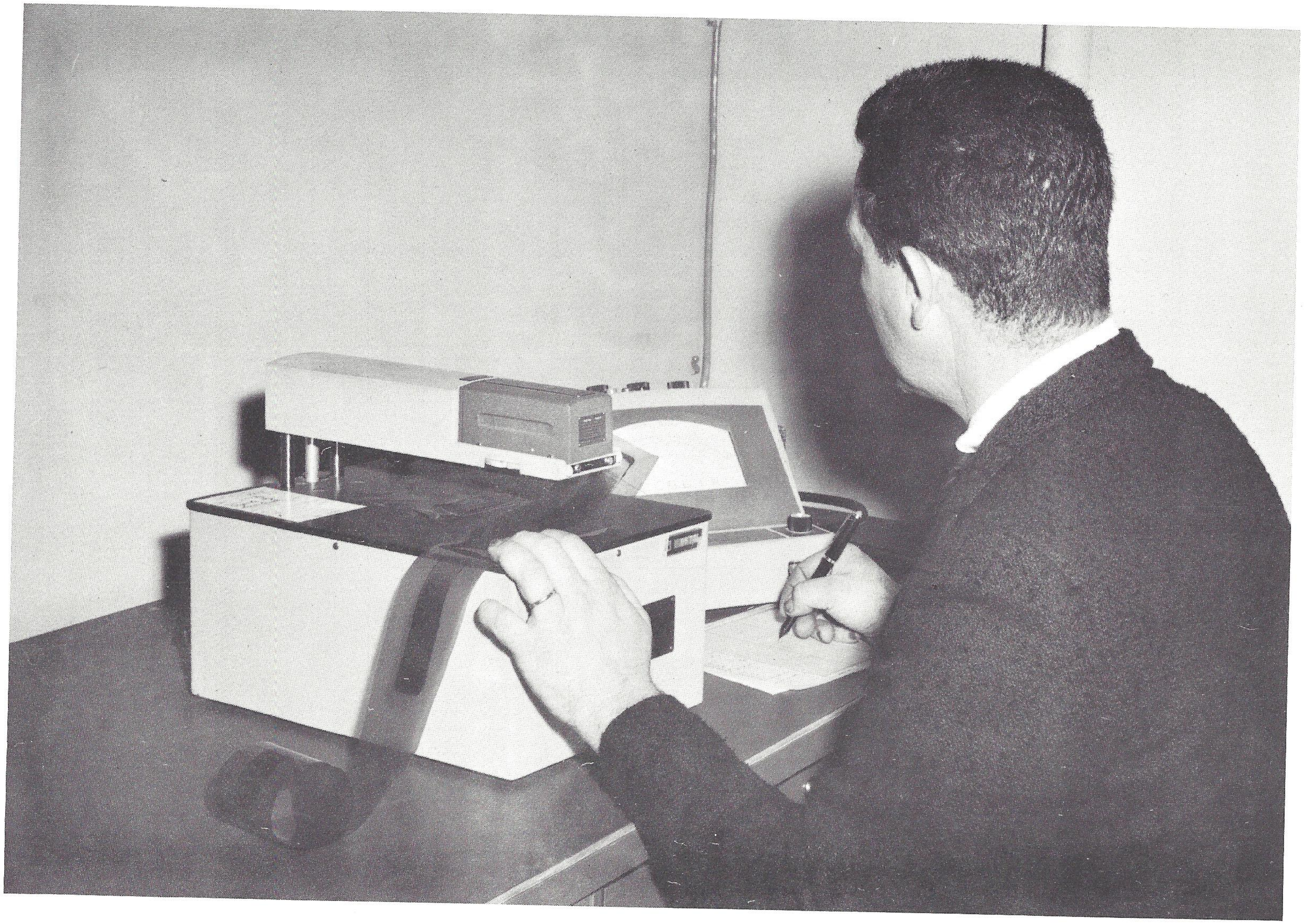


Figure 5.- Reading gray scale on Vidya microdensitometer.

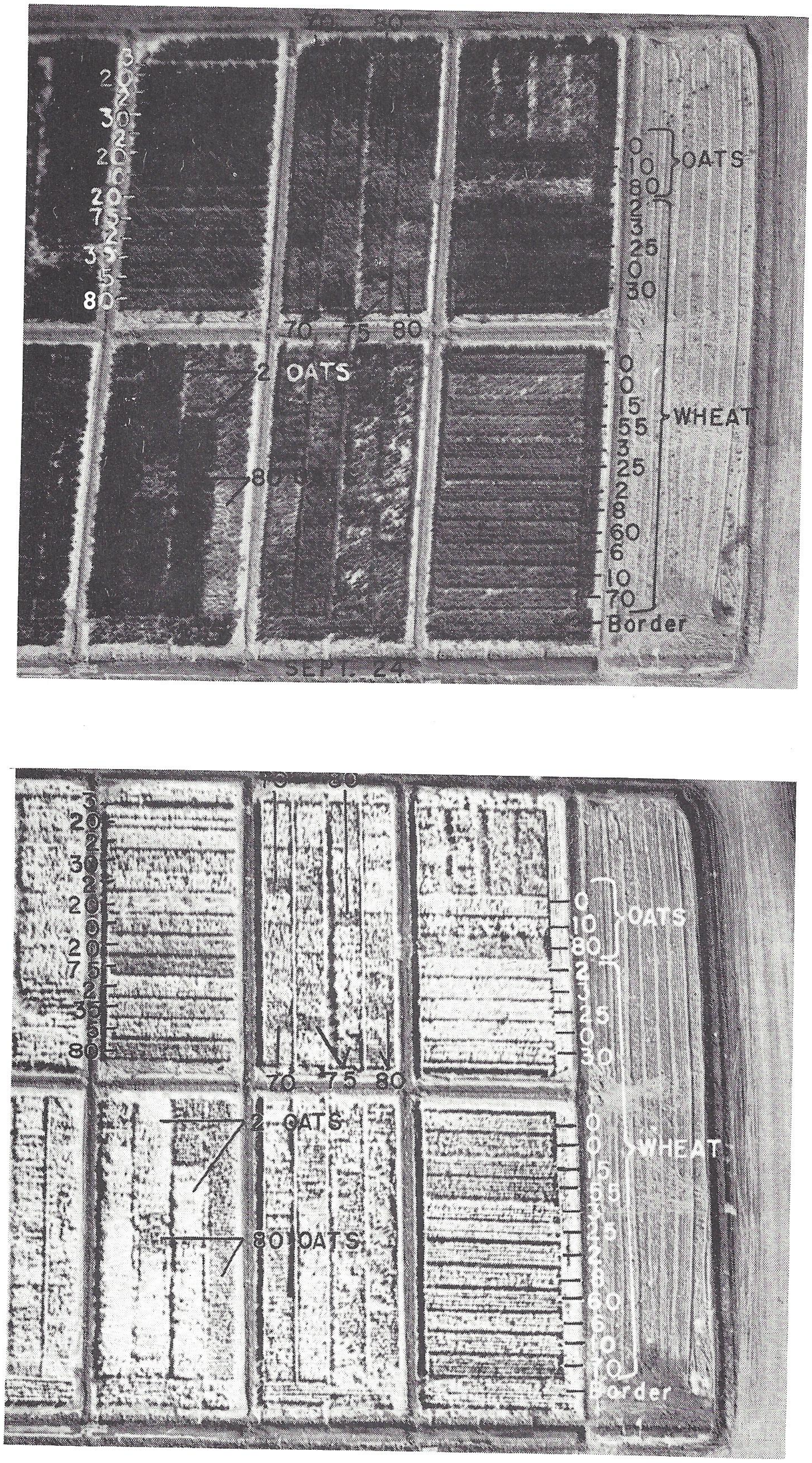


Figure 6.- Panchromatic (top) and infrared (bottom) vertical photographs showing plots of oats and wheat infested with stem rust. Most heavily infested oats plots, labelled "75" and "80," appear dark in the infrared photo but light in the panchromatic. Diseased wheat appears dark in the infrared photo and normal in the panchromatic. Reproduced by permission of Professor Colwell.

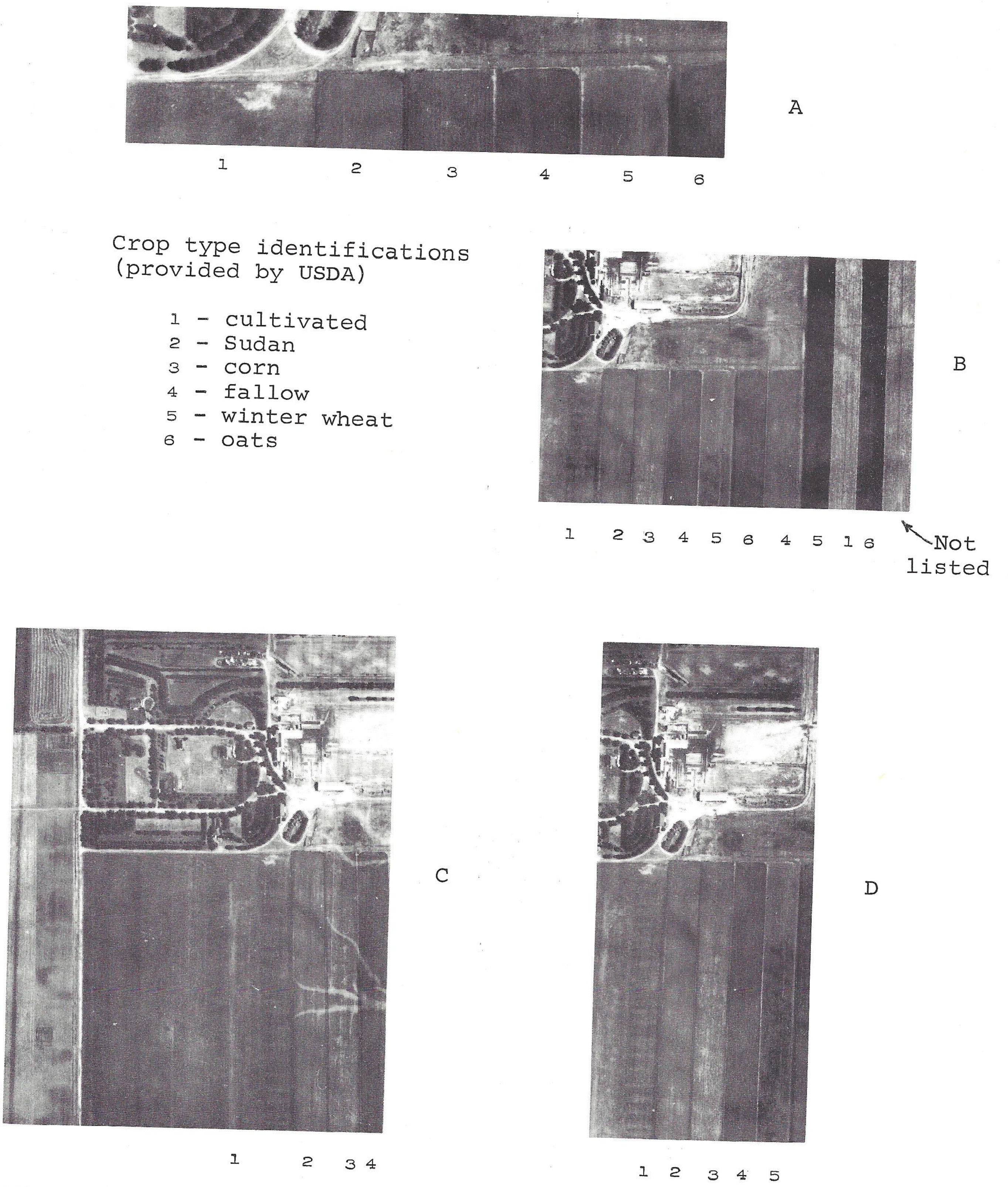


Figure 7.- Portions of exposures 180 and 181, pass 7, showing part of Archer Experimental Substation near Cheyenne, Wyoming. Photos C and D (2X enlargement) form a stereogram. Photo A shows parts of the same fields at 5X enlargement. Photo B (2X enlargement) is a crop type key, according to sketch map provided by USDA. The accuracy of the map is questionable: note differences in tone and texture between the two fields marked "5" and between those marked "6" in Photo B.

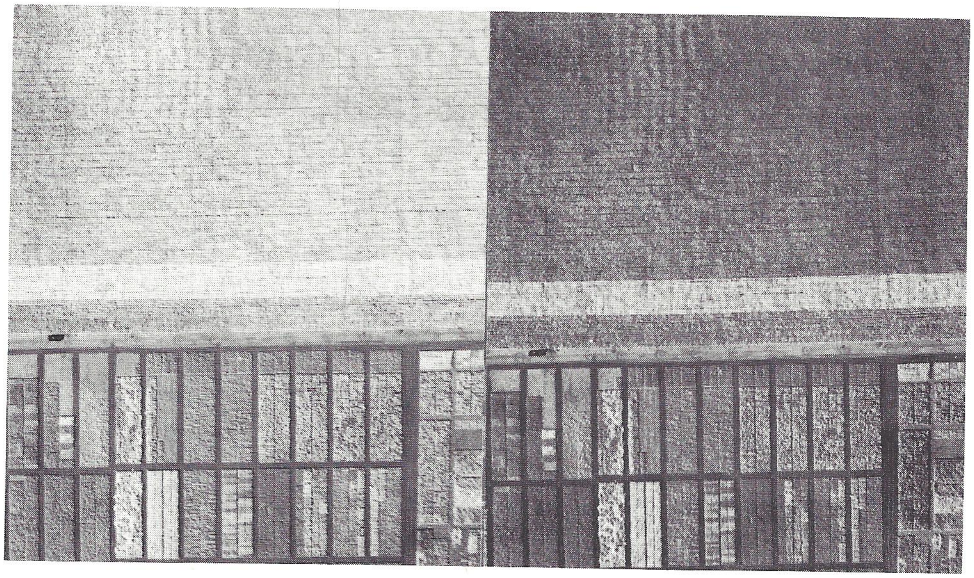


Figure 8.- Infrared stereogram showing portion of Davis campus of the University of California at the scale of 1:3,000. Great differences is tone and texture between different crop types are visible in this stereogram. Ground confirmation of crop identity was not available. It is clear, however, that additional research will make tone-texture combinations on large-scale photography valuable clues to crop identity. Photography by Clair A. Hill and Associates, Redding, California. Exposures 125 and 126, camera focal length 6 inches, flight altitude 1,500 feet.

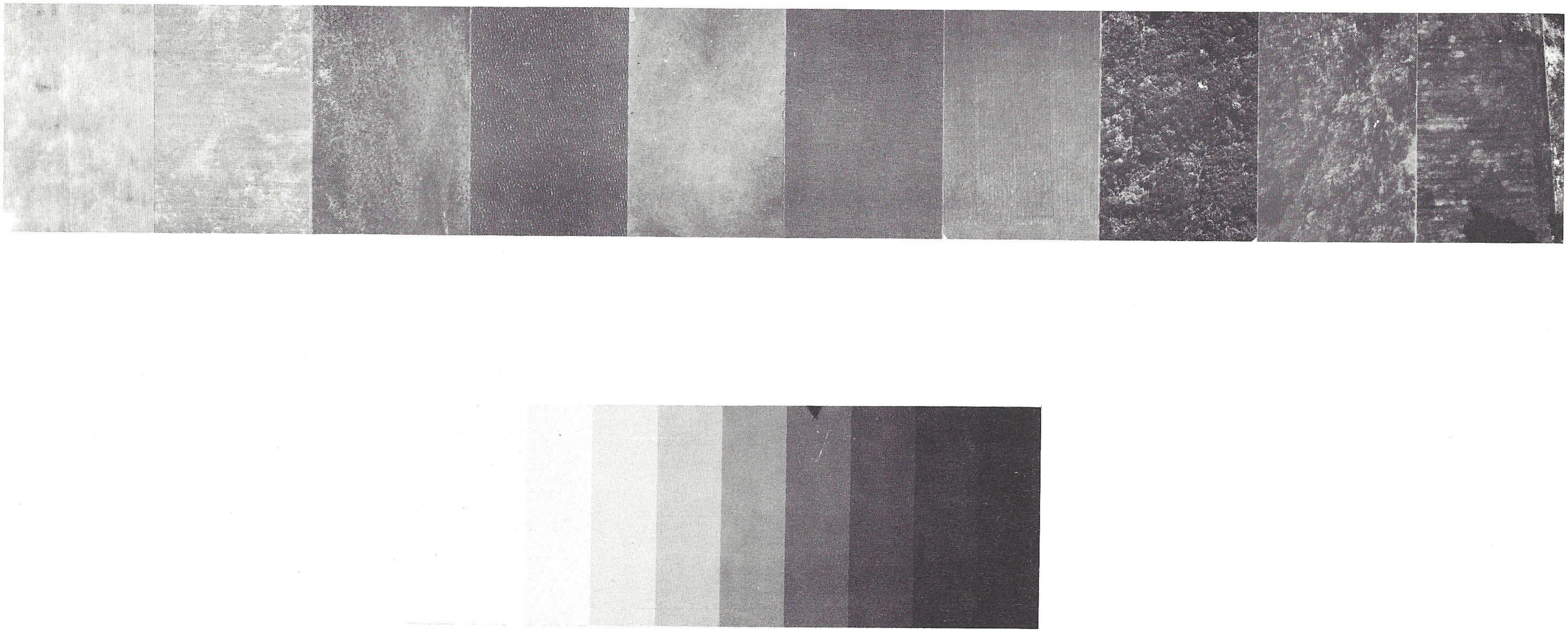


Figure 9.- Comparative scale for texture (top) and tone (bottom) can be used as identification guide by matching the texture and tone of a known crop with that of an unknown. For example, if several fields of winter wheat in a given photographic mission conform to texture 6 and tone 4, it is likely that all other 6-4 combinations in that mission are also winter wheat.

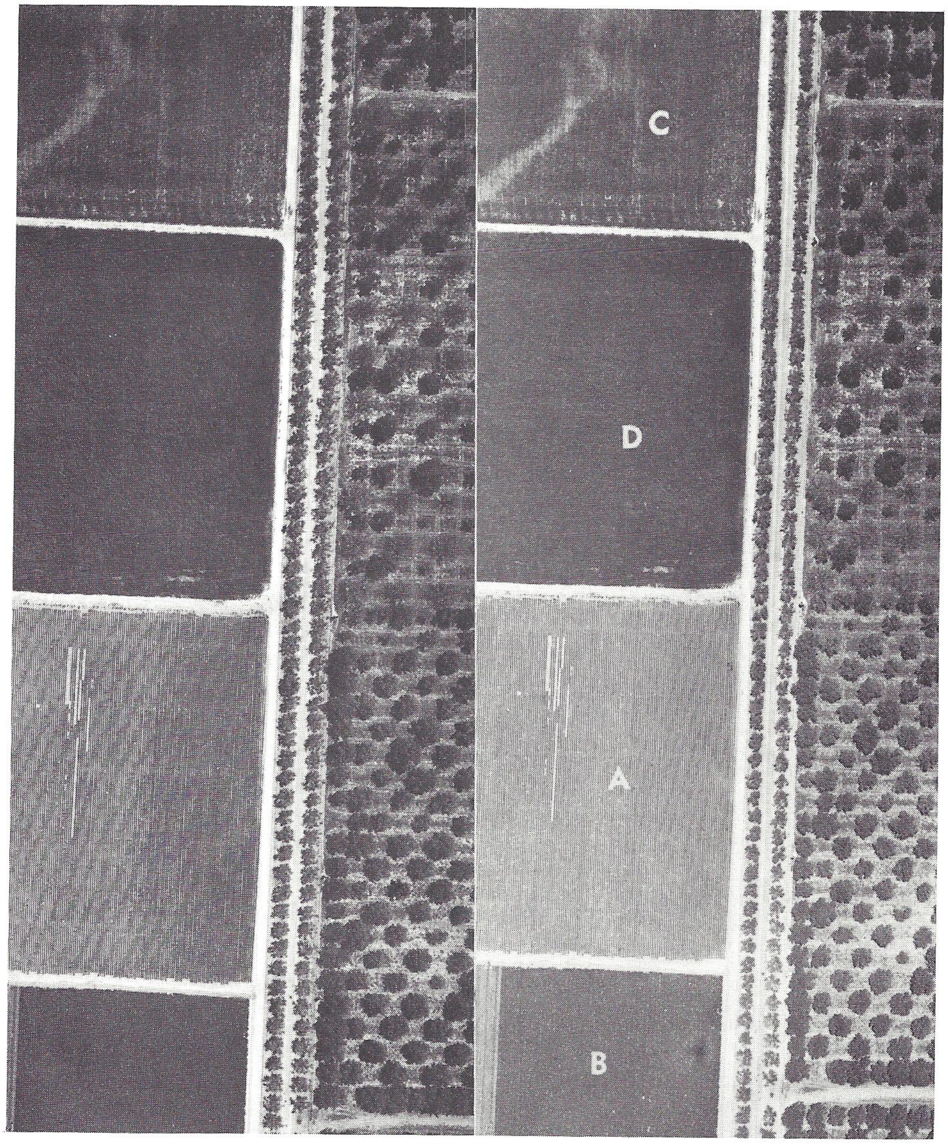


Figure 10.- Stereogram showing portion of Davis campus of the University of California at the scale of 1:3,000. In this stereogram, row crops A and B can be readily distinguished from grain crops C and D. Pattern, shape, and tone appear to be the most valuable identifiers of row crops at large photo scales. Photography by Clair A. Hill and Associates, Redding, California. Exposures 56 and 57, camera focal length 6 inches, flight altitude 1,500 feet; panchromatic film, filter unknown.

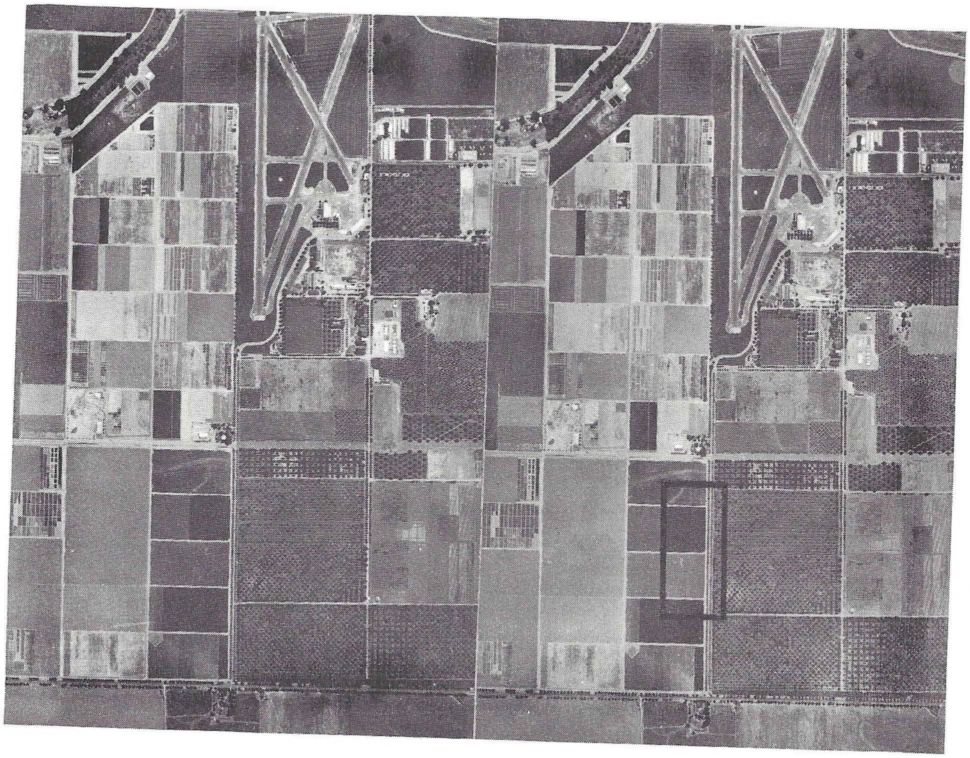


Figure 11.- Stereogram showing portion of Davis campus of the University of California at the scale of 1:24,000, including the area shown at large scale in Figure 10. At this small scale, row patterns and plant shapes blend together, creating textures which offer less potential for crop identification than the detailed patterns and shapes visible in Figure 10. Photography by Clair A. Hill and Associates, Redding, California. Exposures 3 and 4, camera focal length 6 inches, flight altitude 12,000 feet; panchromatic film, filter unknown.

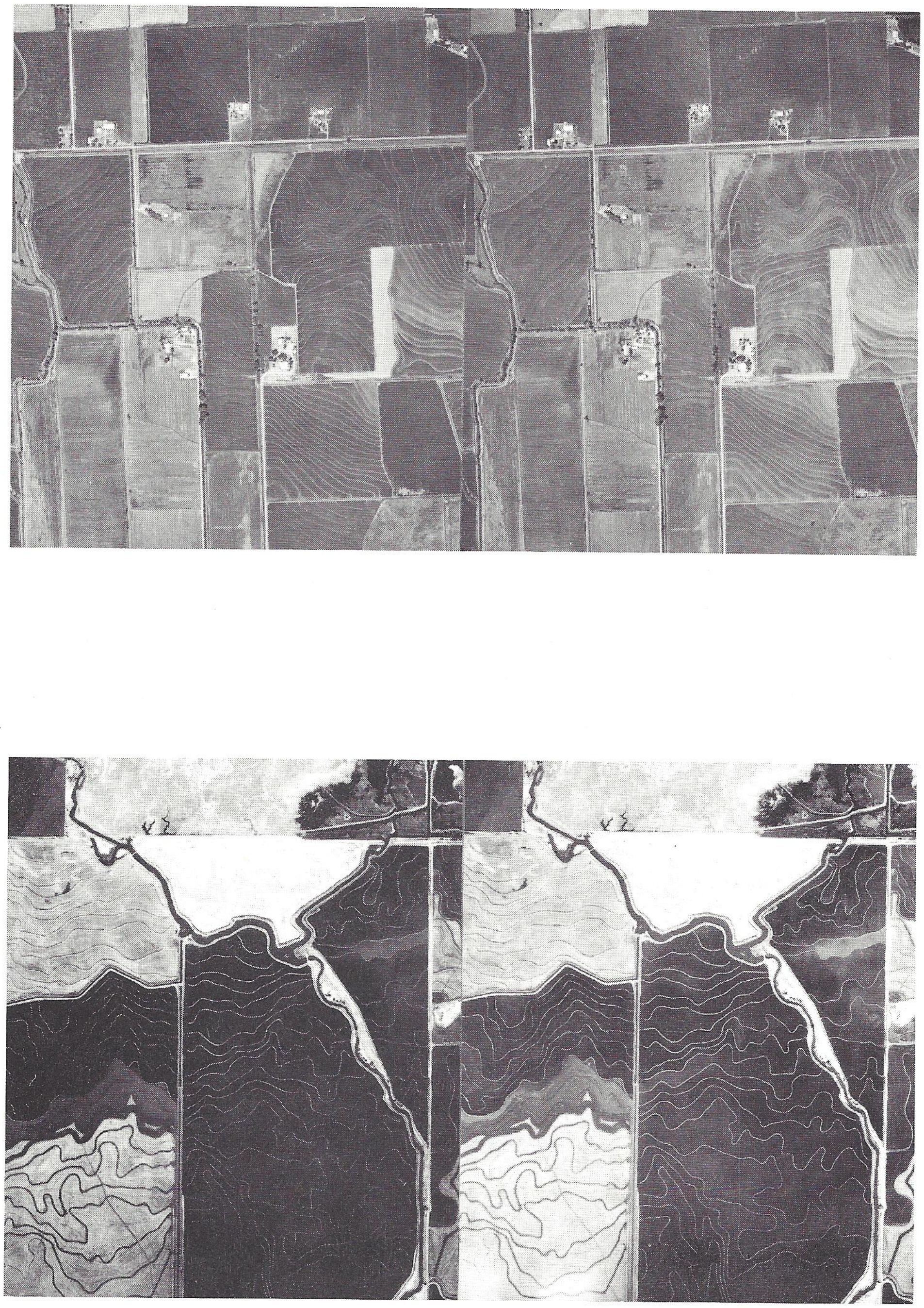


Figure 12.- Stereograms showing rice fields. Top, panchromatic film and Wratten 12 filter; bottom, infrared film and Wratten 12 filter. These fields are in California, where extreme land-use water-use economy is practiced. Dikes between fields follow the topography and form "contour" maps; this is vividly seen in stereo. Photography by Clair A. Hill and Associates, Redding, California, May 6, 1962. Scale 1:24,000.

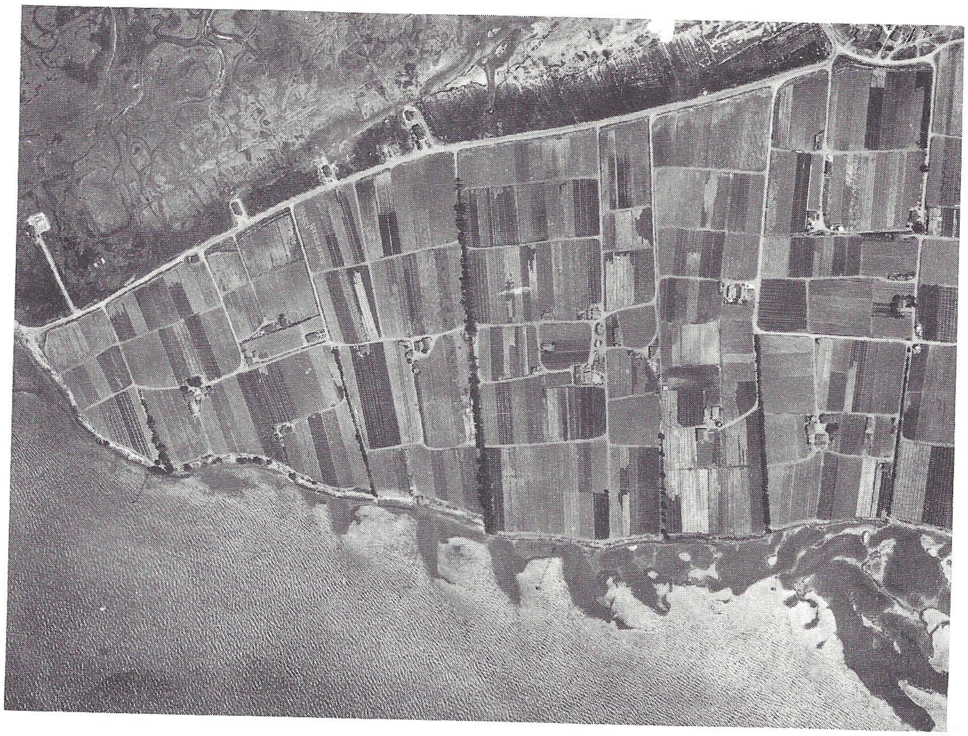


Figure 13.- Near-maximum agricultural land-use economy is practiced in raising table vegetables near metropolitan centers. This photograph shows vegetable plots on Bay Farm Island, near Oakland, California. Size, shape, tone, texture, location, row spacing, and other factors offer potentially reliable identification criteria. Photograph courtesy Professor Robert N. Colwell. Photo no. 43-633, scale approximately 1:15,500.

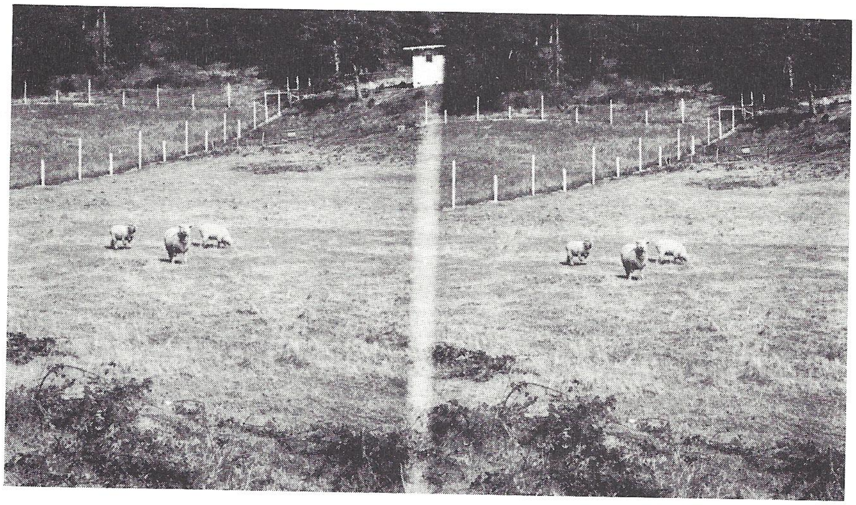


Figure 14(a).- Close-up ground stereogram of sheep, two in profile, one head-on. Note roundness of bodies, light gray tone of wool.

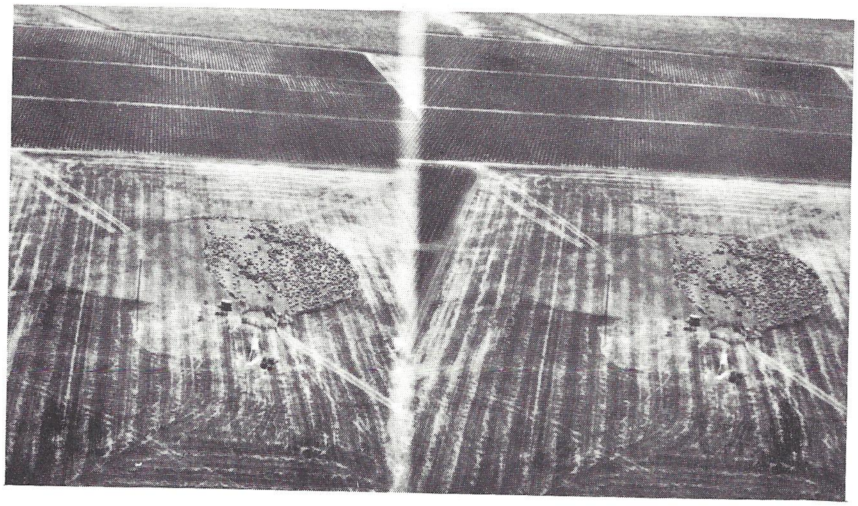


Figure 14(b).- Low-altitude oblique stereogram of flock of sheep in Contra Costa County, California. Note round oval form of bodies seen from above, light gray tone of wool, dark tone of shadows.

Figure 15.- Portion of exposure 354, pass 10, enlarged ten times, showing flock of sheep against grass background. Note visibility of animals even in wash. Images of lambs are small but detectable.

Figure 16.- Portion of exposure 296, pass 9, enlarged ten times, showing flock of sheep crossing rock outcrop. Animals are easily visible against both rock and grass backgrounds. Note round oval of bodies, light gray tone of wool.

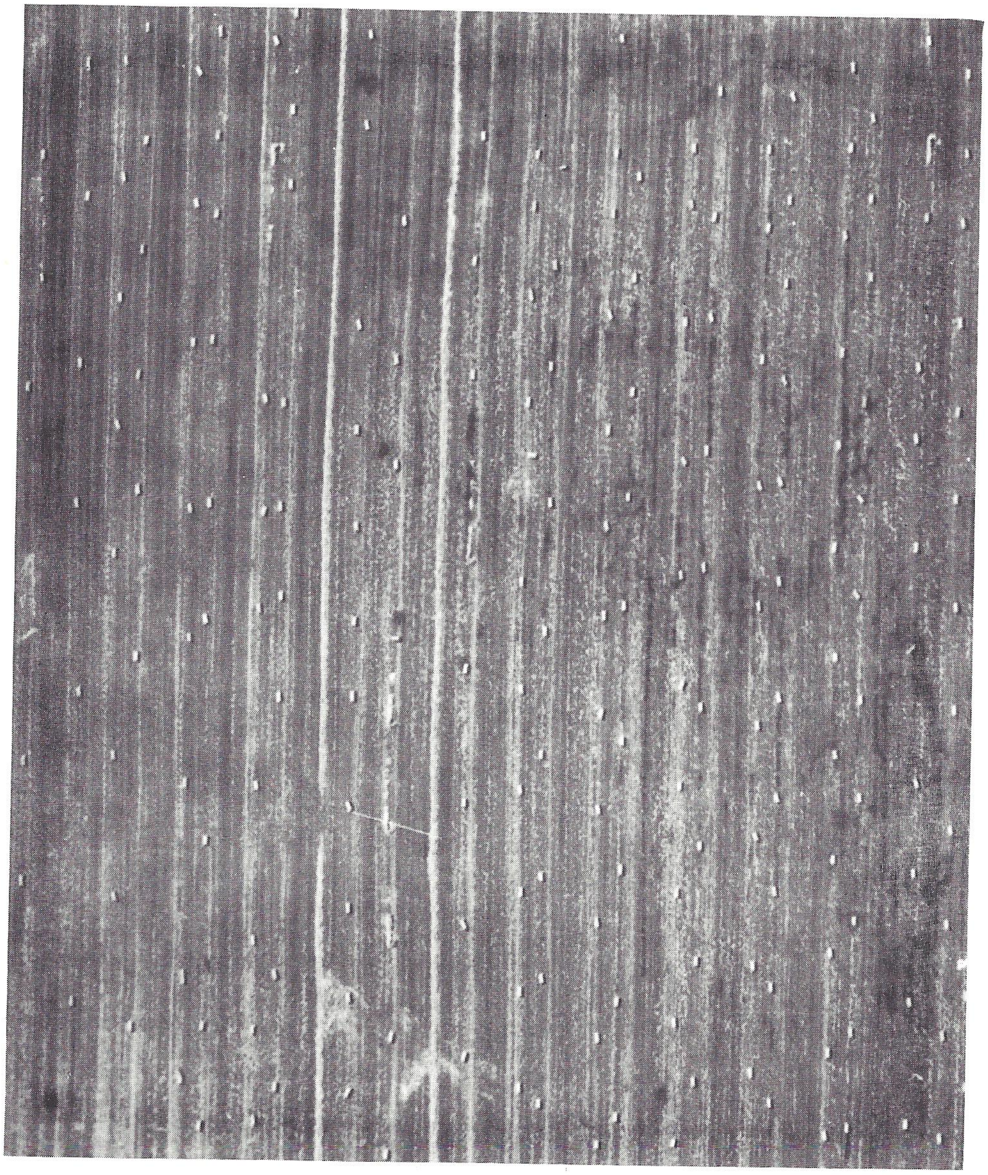


Figure 17.- Portion of exposure 592, pass 14. These are bales of hay, not sheep. Note rectangular form of bales <u>and</u> their shadows, regular arrangement unlike flocked animals.

Figure 18(a).- Close-up ground stereogram of Holstein dairy cattle. Note black and white color patterns varying from almost black to almost white. Mature cows in foreground and right background, heifers in left background; note difference in size and body build.

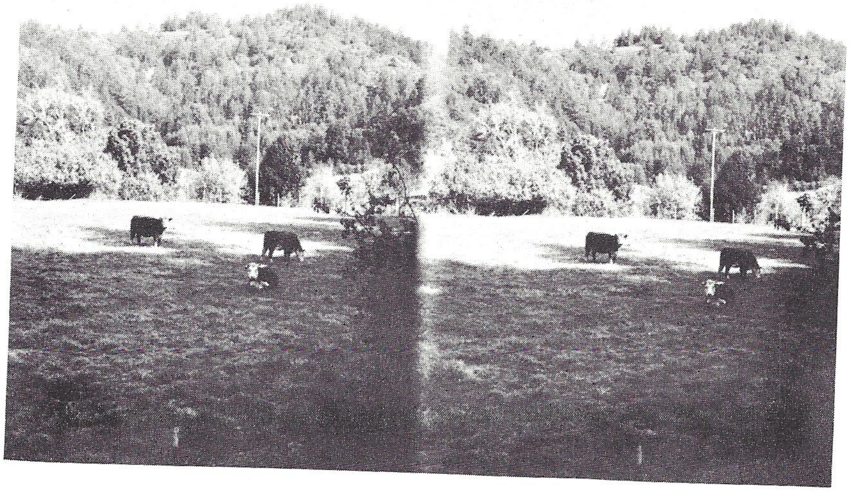


Figure 18(b).- Close-up ground stereogram of Hereford beef cattle (steers). Note white faces, white streak on crest of shoulder; these marks are easily visible from the air. Note heavy bodies, short legs.

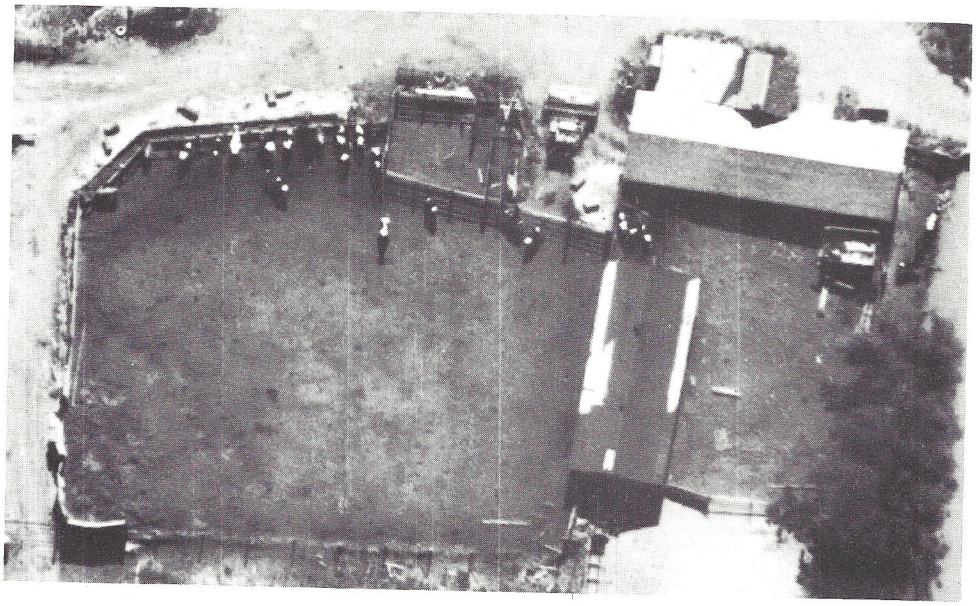


Figure 19(a).- Portion of exposure 084, pass 5, enlarged ten times. Contact scale about 1:6,000. Dairy cattle in feed lot. Two may be Guernsey or white Holstein; rest are Holstein. Note distinctive black and white color markings.

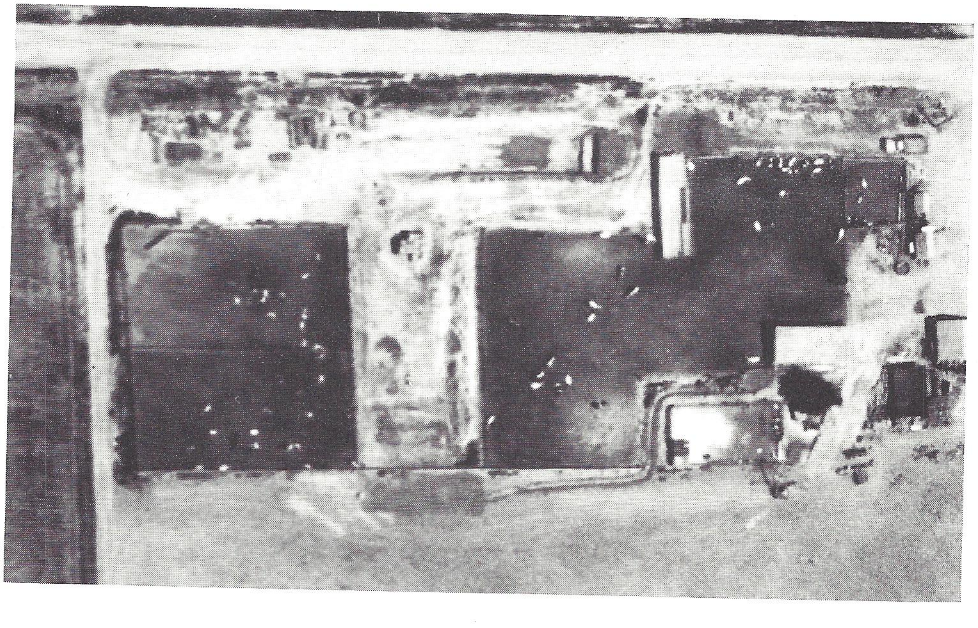


Figure 19(b).- Portion of expousre 585, pass 13, enlarged ten times. Contact scale about 1:11,500. Holstein and Guernsey or Jersey dairy cattle in feed lot and pens. Note that Holstein color markings are still visible at small photo scale. Small pens on right and left contain heifers, center lot mostly mature cows.

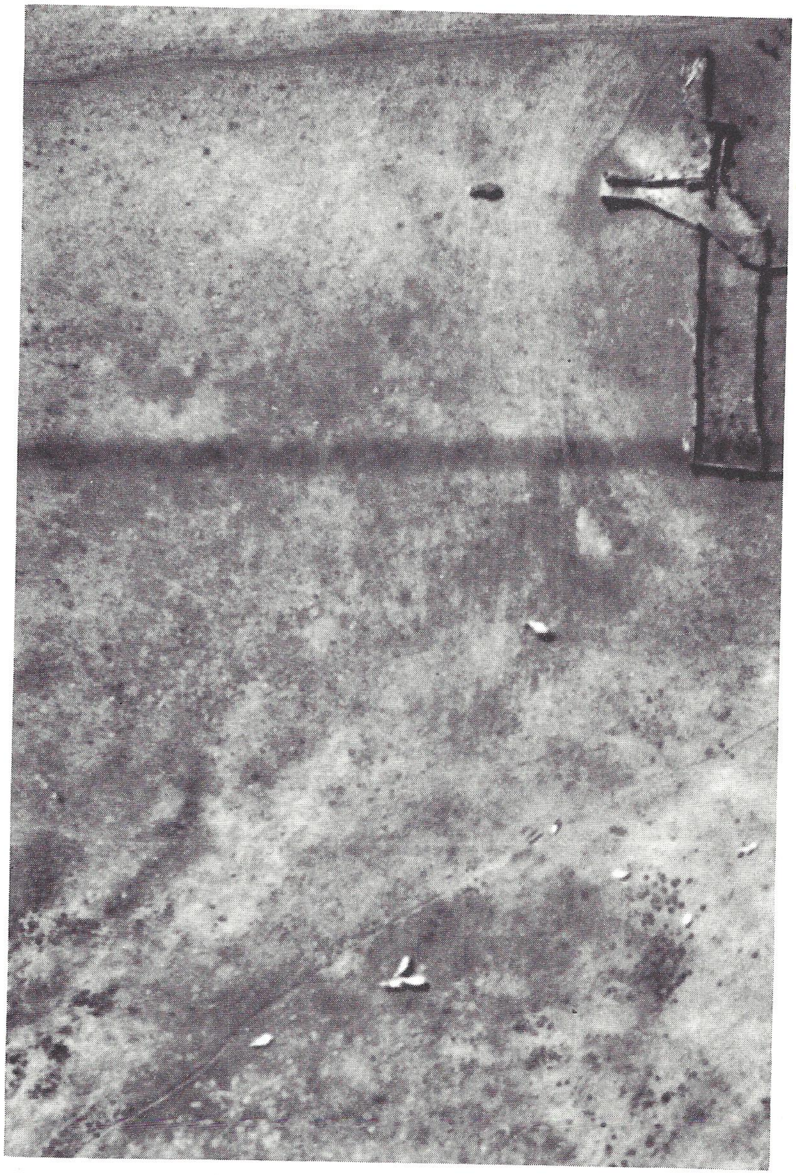
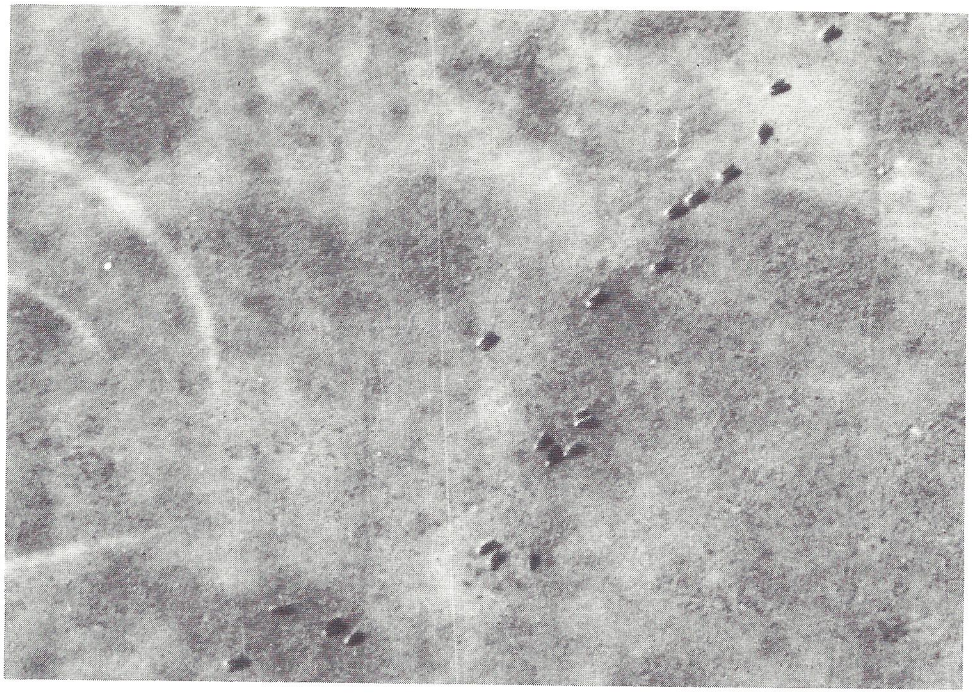
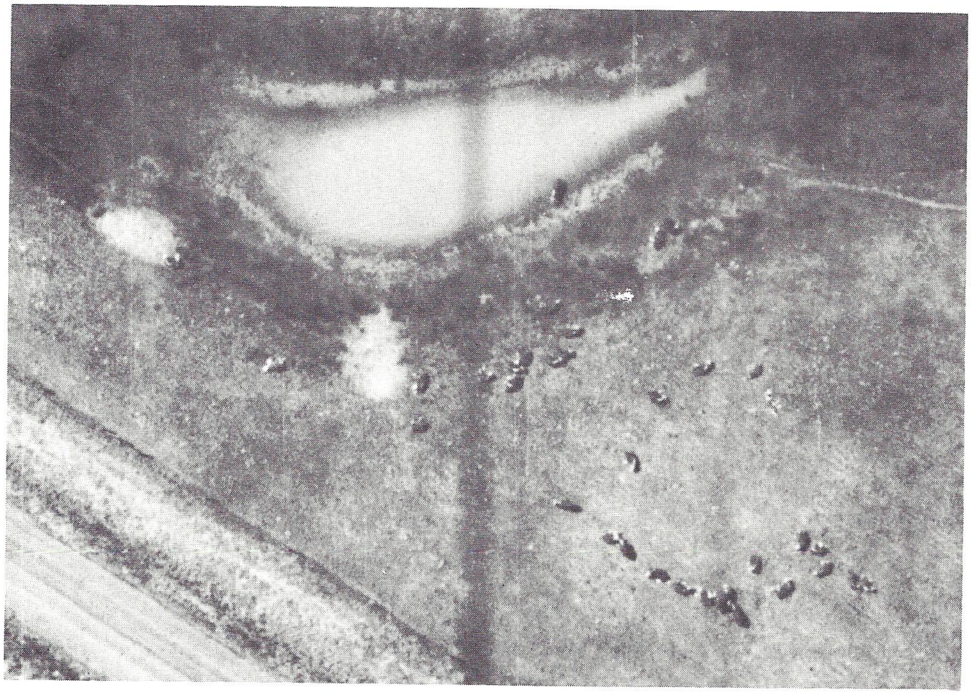


Figure 20.- Portion of exposure 637, pass 18, enlarged ten times. Contact scale about 1:5,500. Guernsey dairy cattle, one Hereford at top of view. Guernsey in center of view may be steer. Breed identification is necessary to establish use class; fortunately Hereford are among easiest of breeds to identify. Note corral with chute at top right.



(a)



(b)

Figure 21.- Portions of exposure 276 (a) and 240(b), pass 8, enlarged ten times. Contact scale about 1:6,000. Hereford beef cattle on range. White faces and brown bodies clearly visible in both views. Cattle lying down in view (b) show white markings on legs and bellies as well.

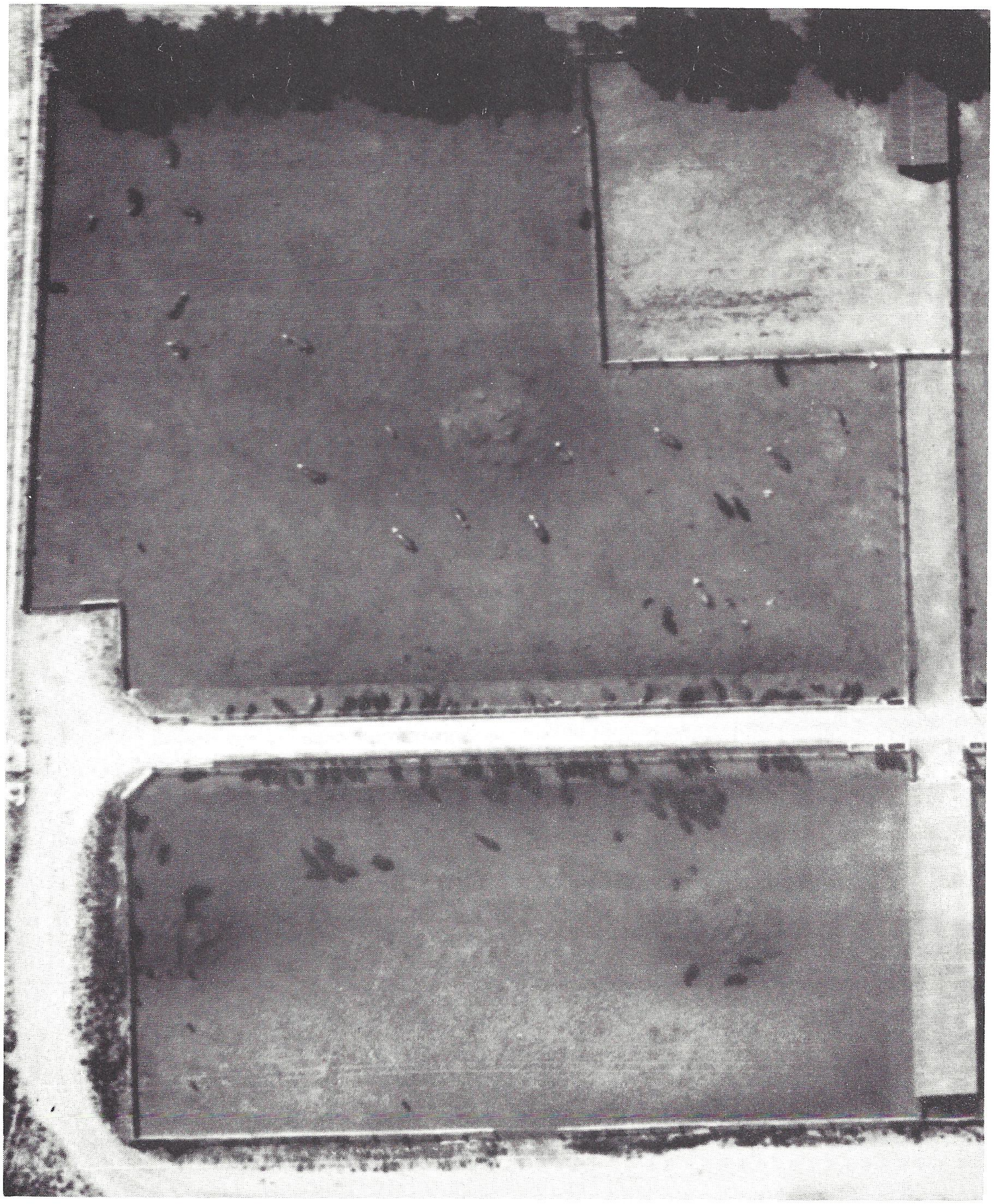


Figure 22.- Portion of exposure 622, pass 17, enlarged ten times. Contact scale about 1:5,500. Mixed herd of Hereford and Black Angus beef cattle. Corral at top of view contains mostly Hereford, and that at bottom all Angus. White faces of Hereford, even some of those feeding, are visible. Note difference in tone between red-brown Hereford and dense black Angus.

Figure 23.- Portion of exposure 616, pass 16, enlarged ten times. Contact scale about 1:5,500. Mixed herd of dairy (Holstein and probably some Guernseys) and Black Angus beef cattle in agricultural area. Interpretation of shape of Angus cattle is often hampered by difficulty of distinguishing between black shadow and black animal. However, no other common breed is all black. An occasional Holstein may be all black, but an entire field or corral of black cattle must be Angus.

APPENDIX A

COMPARATIVE ANALYSIS OF DIFFERENT AERIAL CAMERA SYSTEMS FOR CROP/LIVESTOCK SURVEYS

A.1 GENERAL

Basic aerial photographic system requirements for crop/livestock surveys include:

(1) Rapid coverage of large land areas.

(2) Maximum amount of extractable information per photograph.

(3) Dependable, economical operation.

Large land area coverage is achieved by using a camera system which will picture the maximum ground area per exposure. The need for such a system stems from the vast size of the areas which must be photographed in a minimum amount of time, at the lowest possible cost.

The maximum amount of extractable information per photograph is achieved by:

(1) Using cameras which yield the highest possible ground resolution throughout the entire format of the picture, and

(2) Using film and filter combinations which combine extreme resolution with spectral sensitivity in the optimum portion of the photographic spectrum.

Several different types of aerial camera systems are discussed and compared in this Appendix.

The information content of conventional black-and-white aerial photography per unit area is proportional to the square of the resolution and to the number of quantum changes in density which can be differentiated on the film. If maximum information content is to be achieved, maximum ground resolution must be combined with a quantum density change between an object on the ground which must be identified and the object's background. This is achieved by selection of an optimum aerial photographic film and filter combination for the type of analysis to be made. Photographic film and filter combinations are discussed in Appendix B.

Extremely high ground resolution is required to accurately picture small details such as animals and crop plants. This presents special problems in aerial reconnaissance. Not only are ground resolution requirements very exacting, but large geographic areas must be pictured.

Unfortunately, high resolution levels and wide angular coverage are basically counteracting requirements.

The maximum theoretical resolving power (Nm) of a lens, on its optical axis, may be expressed by the equation:

$$\text{Nm} = \frac{1500 \text{ lines/mm}}{\text{f-number}}$$

where the f-number is the focal length of the camera divided by the effective diameter of the lens. For instance, if the focal length of the camera is 12 inches (1 foot), and the effective diameter of the lens is 3 inches, the f-number, or relative aperture, is

$$\frac{12}{3} = 4, \quad \text{or } f = 4$$

which provides a lens with a theoretical maximum resolution of 375 lines per millimeter.

Off-axis resolution for tangential lines diminishes as the cosine^3 of the angular separation from the optical axis. For radial lines, resolution off-axis diminishes only as the cosine of the angular separation from the optical axis. In practice, this means that wide-angle lenses yield much lower resolution at the edges of photographs than they do at the optical center (principal point) of the format. Tangential lines 45° off-axis offer only 35 percent of the on-axis resolution maximum. Radial line resolution is reduced to about 70 percent. In addition to reduction in radial and tangential resolution, photographs taken with wide-angle lenses frequently are troubled by distortions caused by coma, lateral color distortion, field curvature, and astigmatism. It is much more difficult to manufacture wide field angle lenses which are free of these distortions than it is to manufacture narrow field angle lenses. This is one of the principal reasons why cameras fitted with longer focal length narrow field angle lenses are preferable for high resolution aerial photography.

An important consideration in picturing small ground features is the focal length of the optical system. From a given altitude, ground resolution is increased by use of longer focal length optics. As the focal length becomes longer, however, it becomes more difficult to manufacture lenses with reasonably low f-numbers.

A.2 TYPES OF AERIAL CAMERA SYSTEM

There are essentially six types of aerial camera system which might be used for crop/livestock aerial surveys. These are:

(1) Vertical frame camera systems.

(2) Strip-Film camera systems

(3) Trimetregon (frame) camera systems

(4) Divergent forward oblique (frame) camera systems.

(5) Forward oblique (frame) camera systems.

(6) Panoramic (vertical) camera systems.

Each camera system offers certain advnatages. Each system also has its disadvantages. The advantages and disadvantages of each of the listed types of aerial camera system may stem from the weight and physical size of the cameras and necessary components, from the electrical power requirement for operation, the area which can be photographed in a single mission, the image quality of the photography which is obtained, basic operational costs and dependability, and other factors.

In the following sections each of the six aerial camera systems which are listed are described.

A.2.1 Vertical Frame Aerial Camera Systems

Standard vertical frame aerial cameras are composed of two basic units - a film magazine and a "lens cone," which holds the lens system and shutter in position. The film is held in rigid position in the lower face of the magazine. Most of the frame aerial cameras utilize vacuum to hold the film rigidly in position at the time of exposure. Figure A-1 illustrates the Wild RC-9, one of the more advanced short-focal-length super-wide angle (SWA) aerial cameras. The Wild RC-9 was designed primarily for photogrammetric mapping. Aerial cameras are usually mounted in gyrostabilized mounts. Gyrostabilization aids in keeping the axis of the camera vertical, so that the film plane is parallel with the ground datum plane. Image motion compensation (IMC) is sometimes used to offset the effects of forward motion of the aircraft. As the aircraft advances, exposures are made at a predetermined time interval. The time interval between exposures is normally based on flight altitude, camera focal length, and the size of the ground area pictured in each exposure, so that each photograph overlaps its predecessor 60 percent in the direction of flight. The inset in Figure A-1 shows how consecutive photographs overlap.

The advantages of vertical frame camera systems are:

(1) The format of the ground area which is pictured in each exposure is essentially rectangular (usually square).

(2) Photographic scale at the datum plane is essentially uniform.

(3) Standard methods permit stereo coverage of large areas.

The disadvantages of single frame vertical cameras include:

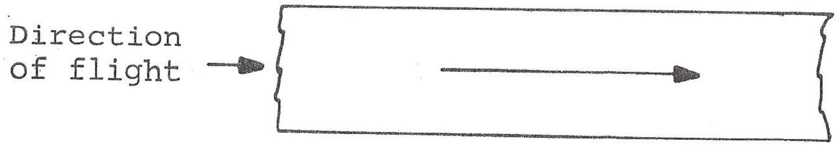
(1) Lowered off-axis resolution reduces ground resolution.

(2) Maximum amounts of film must be used to photograph given ground areas.

In Vidya's opinion, the two disadvantages outweigh the advantages for livestock surveys, because of the information (content) per exposure requirements, and for reasons of economy. Vast land areas should be pictured in as short a time period as possible, with a minimum amount of film.

A.2.2 Strip-Camera Systems

A strip camera records a continuous strip of terrain as the aircraft flies over it. The sketch below illustrates the shape of the ground area which is pictured with a strip camera.



In its simplest form, this type of camera consists of a fixed lens mounted in the camera which records on the film that which is directly below. The shutter is kept open during the entire recording period. The amount of exposure is controlled by a slit. The width of the slit can be adjusted for exposure control. During exposure, the film is moved backward to compensate for the forward motion of the aircraft. This offsets image blur in the direction of flight.

The advantages of strip-camera systems are:

(1) Image motion is automatically compensated for by the movement of the film during exposure.

(2) The terrain is pictured in a continuous single strip in the direction of flight.

(3) Best realized in low-altitude coverage.

Disadvantages of strip-camera systems include:

(1) Imagery cannot be studied in stereo (except in the special case of the Sonne Stereo Strip Camera) but then only from low altitudes.

(2) Lateral distortions may be induced in photographic imagery by vector movement of aircraft.

(3) Image distortions sometimes occur due to turbulent air during photography.

(4) Large volume film requirements.

In Vidya's opinion, strip cameras are of limited value in crop/livestock surveys.

A.2.3 Trimetregon (Frame) Camera Systems

Trimetregon (frame) camera systems were developed for production of small scale aeronautical charts. The name "Trimetregon" evolved because three cameras are used, and because metregon lenses have been used most frequently for this type of work. The three cameras are mounted so that the center camera is in vertical position. (See "Vertical-Frame Camera Systems.) The other two cameras are mounted so that oblique photographs to the right and left of the line of flight are exposed at the same time the vertical exposures are made. In operational use for compilation of small-scale (1/250,000 and 1/1,000,000) aeronautical flight charts, frame cameras which use film 9-1/2 inches wide (picture sizes 9 by 9 inches) have been most frequently used. The focal length of these cameras has normally been 6 inches, resulting in an angular coverage of approximately 74° across the axis of the focal plane.

The two oblique cameras are mounted so that their optical axes are inclined at an angle of 30° downward from the horizontal. One camera is pointed to the right of the aircraft, the second to the left. In view of the angular coverage obtained, this mounting provides a side overlap of approximately 14° between the fields of coverage of the two oblique cameras and the single vertical camera. With the aircraft in level flight at the high altitudes at which trimetregon photography is normally flown, the oblique cameras cover approximately 7° above the horizon. All three cameras are activated simultaneously by a single intervalometer. Figure A.2 illustrates the shape of the area which is pictured.

The cited advantages of a trimetregon system for small-scale reconnaissance mapping are:

(1) For a given flying height, a single flight covers a wider strip of terrain than does vertical frame photography alone. (Normally horizon-to-horizon when used for small scale reconnaissance mapping.)

(2) The precise flying required for vertical photography is not required.

(3) Variations in flight altitudes, directions, and spacing of flights do not represent serious map compilation difficulties.

(4) The amount of geographic control per unit area required for map compilation is greatly reduced.

(5) The requirements for personnel, aircraft, cameras and film, per unit area, are much lower.

Only advantages 1, 2, and 5 are applicable to crop/livestock surveys. While a modified form of a trimetregon system might be used for crop/livestock surveys, the disadvantages of the system present serious problems. The disadvantages include:

(1) Lower resolution resulting from wide angle coverage.

(2) Inherent film resolution deficiencies in standard aerial films.

(3) Weight-carrying and space requirements for installation of three cameras and associated equipment for simultaneous operations.

(4) Film processing and handling problems are great.

(5) Photographic-interpretation procedures necessitate three repetitive screen viewings to study area from horizon to horizon (or full width of area covered).

In Vidya's opinion, the disadvantages of a timetregon aerial camera system are greater than the advantages.

A.2.4 Divergent Forward Oblique (Frame) Aerial Camera Systems

Divergent forward oblique (frame) aerial camera systems have been used to obtain aerial photography for compilation of planimetric maps in regions of low relief. The most extensive use of this system has been made in Canada. Measurement analysis for planimetric mapping in Canada has been done by use of perspective or "Canadian" grids.

The type of camera system utilized in Canada consists of three cameras which are mounted in much the same configuration as outlined for trimetregon systems, except that all three cameras have been rotated about an axis into a forward oblique position.

Figure A-3 is a sketch map showing the configuration of the ground area which is pictured by the simultaneous activation of all three cameras.

The major advantages of a forward divergent oblique system for crop/livestock surveys are:

(1) Extremely large land area coverage per set of three exposures.

(2) The precise flying required for vertical coverage of a given area is not required.

(3) The requirements for personnel, aircraft, cameras and film per unit area are much lower.

(4) Livestock under trees may be pictured.

The disadvantages of a forward divergent oblique system include:

(1) Off-axis resolution losses inherent in frame-type cameras.

(2) Three separate rolls of film must be processed and studied.

(3) Terrain irregularities may mask crops and livestock which should be included in a survey.

(4) Lack of stereo coverage capability for crop/livestock surveys.

Under certain conditions, divergent forward oblique camera systems might be very suitable. However, it is Vidya's opinion that for most of the types of crop/livestock survey operations, they are unsuitable.

A.2.5 Forward Oblique (Frame) Aerial Camera Systems

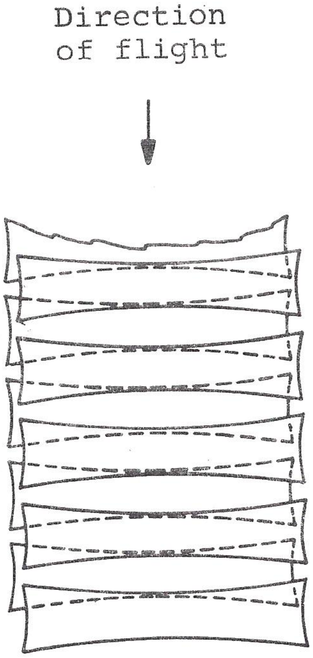
Forward oblique (frame) aerial camera systems consist of single aerial cameras which are mounted in aircraft so that consecutive single exposures are exposed as the aircraft flies along a given course. Figure A-4 is a sketch map illustrating the shape of the ground area covered by three consecutive forward oblique exposures.

The principal use of this type of photography is for very high speed low-level military reconnaissance. Much of the aerial photography released by the Department of Defense to the press during the October 1962 Cuban crisis was of this type.

While this type of aerial camera system offers certain military advantages, and is good for obtaining photography for illustrative purposes, only limited suitability is seen for crop/livestock surveys.

A.2.6 Panoramic Camera Systems

Panoramic cameras are scanning camera systems. As shown in the following sketch, panoramic camera systems picture the terrain in a broad swath at right angles to the direction of flight. The swath of coverage may extend from horizon to horizon, or just through a portion of this distance. Directly under the aircraft, the ground is pictured in a true vertical presentation. As one extends in either direction (right or left), the photo presentation becomes more oblique. These characteristics permit panoramic camera systems to record a much wider swath of ground than either



frame or strip cameras. The scope of coverage is more like that afforded by a Trimetregon camera system - except that all imagery is pictured in a single photograph. Because of this, all images bear a metrical relationship to the same photographic principal point.

As in the case of frame cameras, continuous cover is obtained by proper spacing of photographs. This is governed by the time interval between exposures, as in the case of frame camera systems. Timing is governed by angular coverage, speed and altitude of the aircraft, and the amount of overlap which is desired. This procedure limits the effectiveness of panoramic camera systems for photography at low altitudes and high speeds. The area covered in the direction of flight is limited by relatively narrow camera angles. A high cycling rate is required when the photo plane is traveling at a low altitude. The duration of a complete sweep cycle from side-to-side is usually longer than the cycle of a frame camera. Panoramic camera systems are thus most advantageous for applications requiring resolution of small ground details from high altitudes.

If frame cameras with focal lengths comparable to those employed in panoramic camera systems are used for wide area coverage, either a large array of cameras must be used to cover a reasonable swath (90° or more), or a single camera must be recycled and indexed from one position to another very rapidly.

Tables A-1 and A-2 list the extent of lateral and forward coverage achievable with wide angle, super wide angle, and the HyAc panoramic camera system from various altitudes.

The name "HyAc" is derived from "high acuity" - because Vidya has combined the advantages of large relative aperture (f-number) narrow field angle lenses with extreme resolution films in a unique way for provision of panoramic coverage. The advantages of the HyAc camera system stem from the fact that it permits broad area coverage with a narrow field angle lens. A one-foot (12 inch) focal length, coupled with film, requires a lens performing to only about 11° off axis. This relatively narrow field angle makes it possible for the lens design to achieve an image close to perfection, for the focal length and aperture required, over the total width.

As shown below, resolution through the full lateral angle of coverage of the HyAc system remains the same. This is so because the lens is scanned, and is always on or near its optical axis. It can be seen in the AWAR calculations, and in the table below, how ground resolution deteriorates off axis in wide angle and super-wide angle systems, but does not fall off in the scan angle of the HyAc system.

Coverage Angle		0	5	10	15	20	25	30	35	40	45	50
6"	Wide angle	70	68	66	65	63	60	56	53	50	--	--
3.5"	Super wide angle	81	80	76	71	60	48	43	38	39	45	31
12"	Panoramic	100	100	100	100	100	100	100	100	100	100	100
24"	Panoramic	120	120	120	120	120	120	120	120	120	120	120

Figure A-5 shows a HyAc camera, exposing the inner components of the camera. The HyAc camera system is characterized by rotation of the lens about its rear nodal point. The film is positioned along a curved focal plane which does not move during scanning. The optical path is not folded, so that the principal ray encounters only the minimum number of glass-air interfaces.

An image-motion compensation (IMC) system translates the motion of the lens along its axis of rotation with a flat cone surface. This design avoids the complexity of synchronized film motion. The absence of folding mirrors and the structural simplicity of a rigid tie between the lens axis of rotation and the platen minimize the image degrading effects of vibration.

Where variables such as focal length, angular coverage, flying height, and photographic resolution all influence the choice of a system for any particular application or applications, an <u>image content</u> factor is required for comparison.

To determine the image content, the following photographic resolution figures were used. All results were balanced for high contrast targets, high resolution film, bench resolution.

I.C.I. = Photo Scale × Computed AWAR

Example: $\text{I.C.I.} = \frac{1}{20{,}000} \times 61$ lines/mm

Check: 6" W.A. Scale ratio = 2

12" Pan Res. ratio factor $= \frac{1.4}{2.8}$ $\frac{\text{I.C.I. } 12''}{\text{I.C.I. } 6''} = 2.8$

AWAR or Area Weighted Average Resolution according to MIL-STD-15A is computed by:

$$\text{AWAR} = \sum \frac{A_1}{A_o} \sqrt{R_1 T_1}$$

where

A_1 is the area of any one angular zone

A_o is the total format area

R_1 is the radial resolution

T_1 is the tangential resolution

For the wide-angle lenses, the zones are concentric circles computed with the focal length and radius.

For the panoramic, the zones are scan zones computed as the arc of the scan angle.

$\sum$ is the sum of the zone resolutions.

For our comparison:

AWAR for the	6"	Wide angle is	61 lines/mm
	3.5"	Super wide angle is	43 lines/mm
	12"	PAN - 70° is	85 lines/mm
	24"	PAN - 70° is	102 lines/mm
	12"	PAN - 100° is	73 lines/mm
	24"	PAN - 100° is	88 lines/mm
	12"	PAN - 70° Con. is	85 lines/mm
	12"	PAN - 100° Con. is	73 lines/mm
	24"	PAN - 70° Con is	102 lines/mm
	24"	PAN - 100° Con. is	88 lines/mm

A table of comparative Image Content Indexes for photography obtained from different altitudes is listed below. The higher Image Content Index numbers point out the effect of the superior resolution of the HyAc system.

		10,000 ft	30,000 ft	60,000 ft
6"	Wide angle	3.05	1.02	0.51
3.5"	Super wide angle	1.23	0.41	0.20
12"	PAN - 70° (HyAc)	8.50	2.83	1.42
24"	PAN - 70° (HyAc)	20.40	6.80	3.40
12"	PAN - 100° (HyAc)	7.30	2.43	1.22
24"	PAN - 100° (HyAc)	17.60	5.87	2.93
12"	PAN - 70° Con. (HyAc)	8.17	2.72	1.36
12"	PAN - 100° Con. (HyAc)	7.02	2.34	1.17
24"	PAN - 70° Con. (HyAc)	19.61	6.54	3.27
24"	PAN - 100° Con. (HyAc)	16.92	5.64	2.82

TABLE A-1

LATERAL COVERAGE 1 PHOTO ALONG FLIGHT LINE

	10,000 ft	30,000 ft	60,000 ft
6" Wide angle	14,000 ft (2.65 mi)	42,000 ft (7.95 mi)	84,000 ft (15.9 mi)
3.5" S.W.A.	24,000 ft (4.5 mi)	72,000 ft (13.6 mi)	144,000 ft (27.2 mi)
12" - 70° Pan	14,000 ft (2.65 mi)	42,000 ft (7.95 mi)	84,000 ft (15.9 mi)
24" - 70° Pan	14,000 ft (2.65 mi)	42,000 ft (7.95 mi)	84,000 ft (15.9 mi)
12" - 100° Pan	24,000 ft (4.5 mi)	72,000 ft (13.6 mi)	144,000 ft (27.2 mi)
24" - 100° Pan	24,000 ft (4.5 mi)	72,000 ft (13.6 mi)	144,000 ft (27.2 mi)
12" - 70° Con.	14,600 ft (2.77 mi)	43,600 ft (8.25 mi)	87,500 ft (16.6 mi)
12" - 100° Con.	25,000 ft (4.73 mi)	75,000 ft (14.2 mi)	150,000 ft (28.4 mi)
24" - 70° Con.	14,600 ft (2.77 mi)	43,600 ft (8.25 mi)	87,500 ft (16.6 mi)
24" - 100° Con.	25,000 ft (4.73 mi)	75,000 ft (14.2 mi)	150,000 ft (28.4 mi)

TABLE A-2

FORWARD COVERAGE 1 PHOTO ALONG FLIGHT LINE

	10,000 ft	30,000 ft	60,000 ft
6" Wide angle (9 by 9 inch)	14,000 ft (2.65 mi)	42,000 ft (7.95 mi)	84,000 ft (15.9 mi)
3.5" S.W.A. (9 by 9 inch)	24,000 ft (4.5 mi)	72,000 ft (13.6 mi)	144,000 ft (27.2 mi)
12" - 70° Pan (70 mm)	2,200 ft (0.42 mi)	6,600 ft (1.25 mi)	13,200 ft (2.5 mi)
24" - 70° Pan (5 inch)	2,200 ft (0.42 mi)	6,600 ft (1.25 mi)	13,200 ft (2.5 mi)
12" - 100° Pan (70 mm)	2,200 ft (0.42 mi)	6,600 ft (1.25 mi)	13,200 ft (2.5 mi)
24" - 100° Pan (5 inch)	2,200 ft (0.42 mi)	6,600 ft (1.25 mi)	13,200 ft (2.5 mi)
12" - Con. 15° (70 mm)	2,280 ft (0.435 mi)	6,860 ft (1.30 mi)	13,800 ft (2.61 mi)
24" - Con. 15° (5 inch)	2,280 ft (0.435 mi)	6,860 ft (1.30 mi)	13,800 ft (2.61 mi)

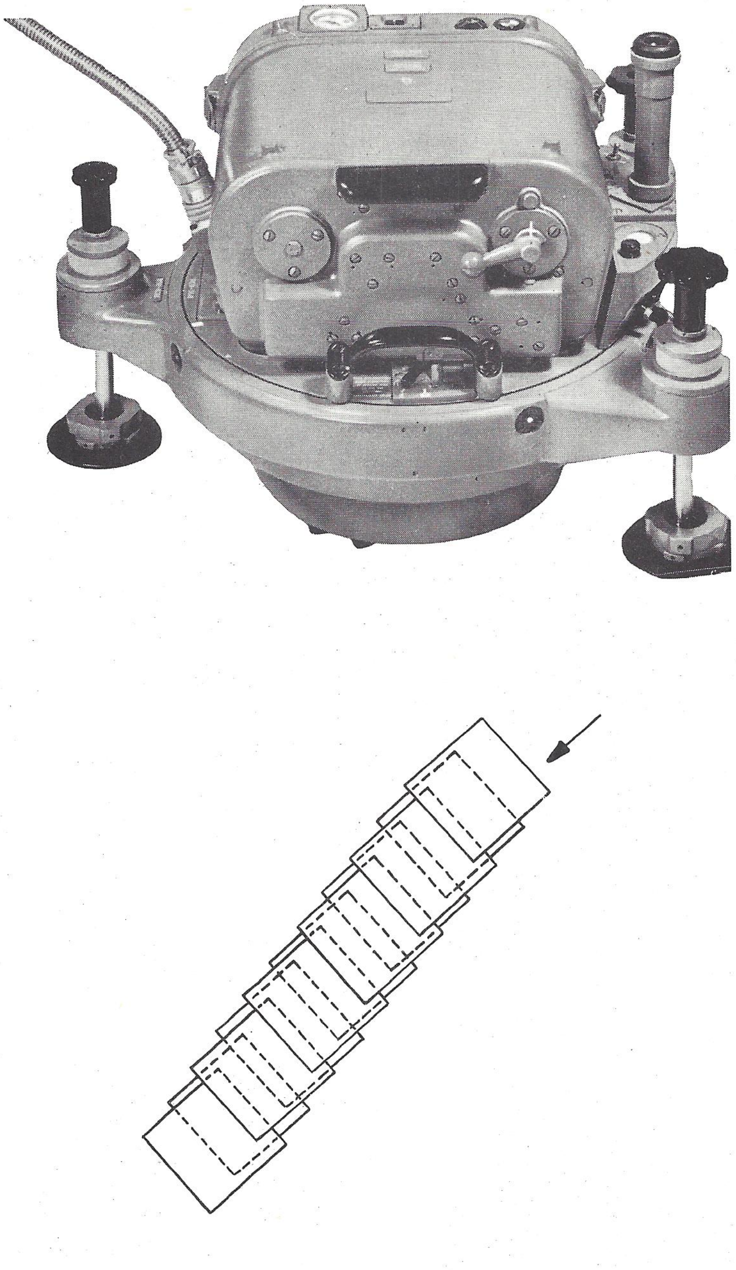


Figure A-1.- Wild RC-9 aerial frame camera. Super wide-angle lens, 3.5 inches in focal length; format size 9 inch by 9 inch. This camera is capable of photographing large areas at small scales, but resolution falls off near margins of format. Inset shows coverage of frame photographs overlapping by 60 percent.

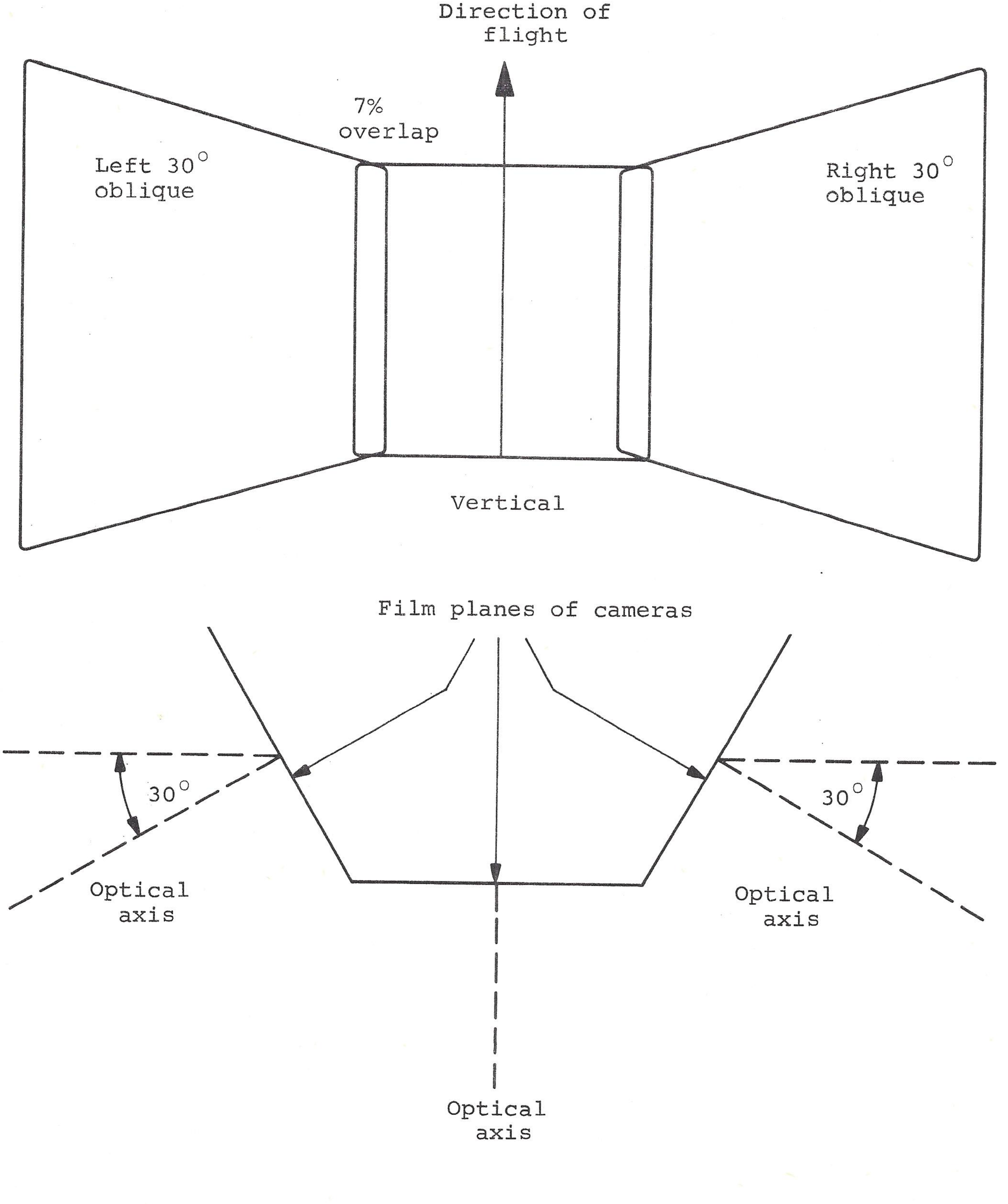


Figure A-2.- Ground coverage of trimetrogon camera system.

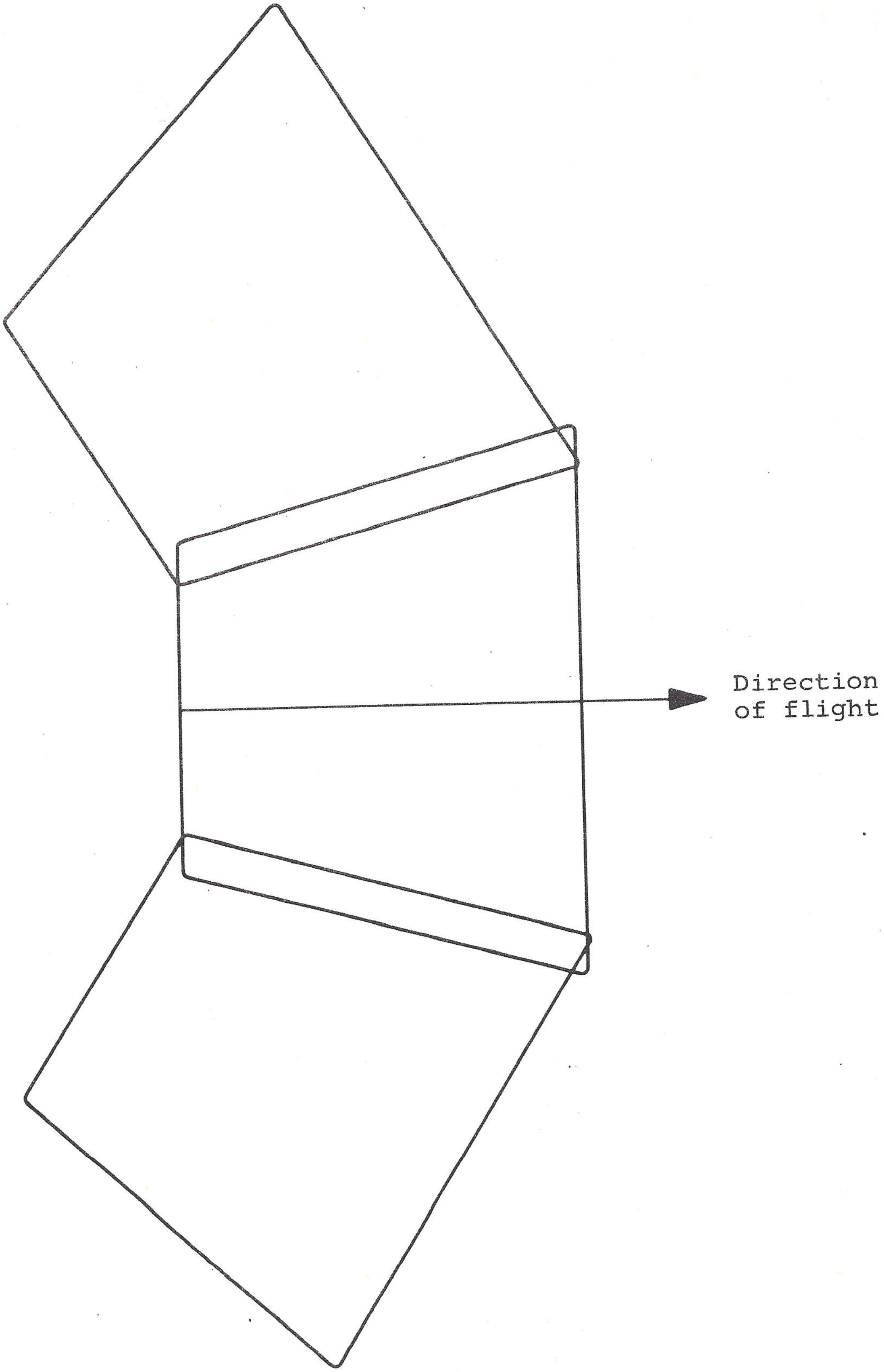


Figure A-3.- Ground coverage of divergent forward oblique camera system.

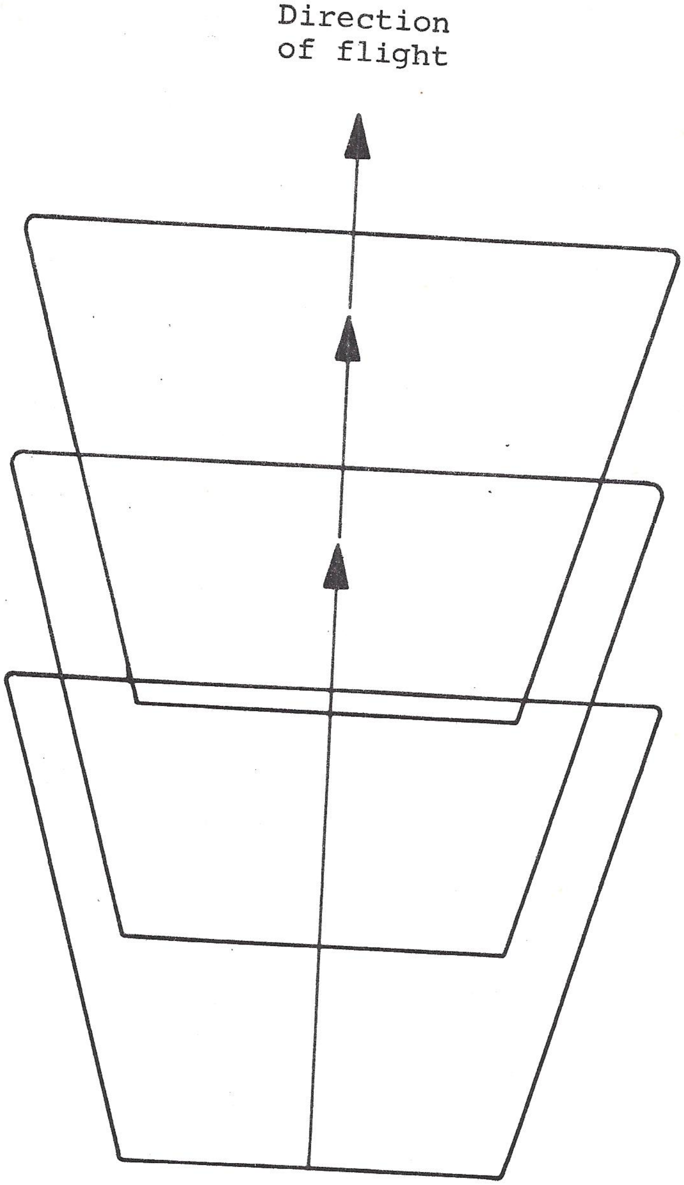


Figure A-4.- Ground coverage of forward oblique camera system.

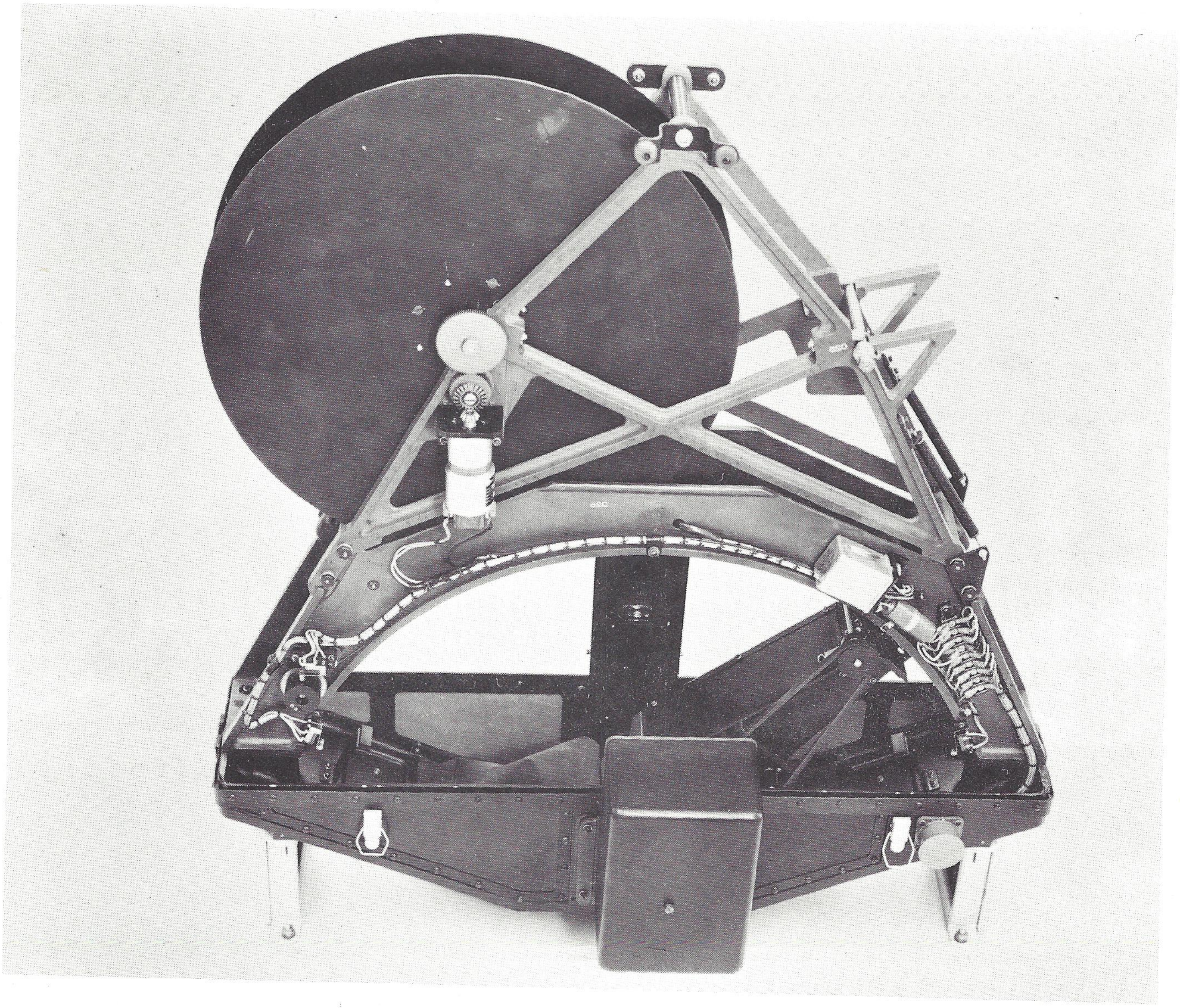


Figure A-5.- HyAc aerial panoramic camera.

APPENDIX B

AERIAL PHOTOGRAPHIC FILM AND FILTER COMBINATIONS FOR LIVESTOCK AND CROP SURVEYS

B.1 GENERAL

Special aerial photographic film and filter combinations are used to improve aerial photography in two general ways:

(1) To reduce or eliminate the image degrading effects of light scatter.

(2) To enhance differences in contrast between specific objects or areas and their surroundings.

Special film and filter combinations have been developed for many purposes. These include obtaining aerial photography for color-enhanced presentations, making specific types of vegetation or background materials distinctly different and recognizable within their surroundings, aiding in detection of buried, camouflaged, or otherwise indistinct features, and penetrating different depths in water.

No special panchromatic film and filter combinations have yet been developed for agricultural purposes. Lack of spectral measuring instruments which could be used in the field for measurements of living plants has restricted capabilities in this area, until recently.

B.2 FILMS

All of the films in use today have a natural sensitivity to ultraviolet light. Non-color sensitized films, such as Eastman fine-grain positive film, which is used for making positive transparencies from negatives, are sensitive to ultraviolet and to the shorter visible wavelengths (blue) of light. Orthochromatic films are sensitive to ultraviolet, blue, and green light, the wavelengths of which are longer than blue light. The term "panchromatic" means "all colors." Panchromatic films have been sensitized so that they react to yellow, orange, and red light as well as to ultraviolet, blue, and green. Panchromatic films with extended red sensitivity react to light energy, the wavelengths of some of which are longer than visible light. Infrared films are sensitive to ultraviolet and to the near or "photographic" infrared, the wavelengths of which extend to about 860 mμ. Infrared films are sensitive to red and orange light, but not other visible light. Some special films, used primarily for spectroscopic analyses, are sensitive to infrared energy whose wavelengths are longer than 860 mμ.

The range of sensitivity of films is frequently shown by "equal energy" or "daylight" spectrograms.

B.3 FILTERS

Photographic filters are glass or gelatin elements which can be fitted over camera lenses. The glass or gelatin has been coated or dyed with a substance which prevents light energy of selected wavelengths from passing through the lens to the film. Most filters also reduce the total amount of available light from reaching the film in the process of restricting the passage of light of certain wavelengths. When filters which reduce the total amount of available light from reaching the film are used, the camera must be adjusted to allow more light to reach the film. If this is not done, the film will be underexposed. Two camera adjustments may be made to allow more light to reach the film under given available light conditions; the lens aperture may be enlarged, or exposure time may be increased.

The amount of allowance which must be made is expressed as a filter factor. If the filter factor demanded by a given filter for use with a certain film is 2, the filter blocks one-half of the light to which the film is sensitive from passing. This may be compensated for by slowing down the shutter speed (from 1/500 to 1/250 second, for instance) or by opening up the relative aperture (from f/5.6 to f/4, for instance).

B.4 FILM CONTRAST

Film contrast refers to the number of shades of gray which can be seen or measured on a given section of developed film, as produced by a subject of equally spaced luminance inputs to all films tested. High-contrast films allow very few shades of gray to register, but usually show those few which can be recorded in distinctly different tones. In the process, however, many subtle tone variations may be lost. Lower-contrast films record more shades of gray, but the difference between recorded tone values is less.

Film contrast is shown by use of density-log exposure sensitometric curves, abbreviated "D-log-E" curves. The most commonly used term expressing amount of contrast is "film gamma." On a D-log-E chart, the gamma is the tangent (trigonometric function value) of the angle between the straight-line portion of the curve and a horizontal line. If the straight-line portion of the curve is at an angle of 45°, the gamma of the film is 1, since the tangent value for 45° is 1. The higher the gamma, the steeper the line, the fewer gray tones, and the greater the contrast between recorded tones.

Film gamma may be varied by use of different developers, by changing processing temperatures, and to a certain extent by changing processing times.

Figures B-1 and B-2 illustrate the D-log-E curves and the spectrogram to daylight for SO-226 film. Figure B-3 is a transmittance diagram for the Wratten 21 filter, which has been successfully used with SO-226 for Vidya's raisin lay survey for the California Department of Agriculture.

B.5 THE VIDYA MULTIBAND CAMERA

With the Vidya multiband camera the same ground area may be simultaneously pictured using up to nine filter combinations and three types of film.

Figure B-4 illustrates the multiband lens system.

Nine matched f/2.8 Schneider Xenotar lenses have been mounted in a single lens board. Behind the lens board, rolls of 70-mm film pass along three tracks. Three photographs, one from each of three lenses, are exposed simultaneously on each section of film. In much of the experimental work to date, two rolls of panchromatic film and one roll of infrared film have been used simultaneously. The selected filter packs have permitted creating imagery in six bands about 50 mμ wide in the visible spectrum (400 to 700 mμ), and three selected areas in the infrared. Figure B-5 illustrates the differing imagery created in each photograph.

B.5.1 Special Film and Filter Combinations for Haze Penetration

Haze is the most persistent problem in aerial photography. Haze causes light to scatter so that images of small ground features do not register on the film. Haze consists of small particles in the atmosphere. Most persons have observed "dust" in a beam of light in a dark room. The same condition, frequently much more severe, exists outside. These small particles cause light to scatter in a predictable way. When the light scatters, a "brightness flux" is created which obliterates much of the otherwise recordable imagery and reduces contrast.

According to Rayleigh's law, within the visible spectrum light scattering is inversely proportional to the fourth power of the wavelength of the light. Blue light, then, is scattered more than 16 times as much as red light. Ultraviolet light is scattered even more than blue light. Yet for picturing minute details on the ground, the shorter the wavelength, the smaller the detail which can be imaged - <u>if</u> the shorter image-forming rays are not scattered in the atmosphere prior to reaching the camera.

For most aerial photographic purposes, it is desirable to eliminate ultraviolet and visible blue light completely. This has resulted in development of "pan-minus-blue" combinations for most "general purpose" aerial photography. The blue and ultraviolet light is eliminated by filters, the Wratten 8, 9, 12, 15, 16, 21, and 25 being the most frequently used. Figure B-6 is a panel illustration showing the filter transmission diagrams of the Wratten 8 (K-2), Wratten 9(K-3), Wratten 12, Wratten 15, Wratten 16, and Wratten 25 filters. The transmission diagram of the Wratten 21 is shown in Figure B-3. The diagrams show that the Wratten 12 and 15 filters do transmit some ultraviolet light, which tends to degrade imagery. For this reason, the Wratten 8, 9, 16, 21, and 25 filters are preferred for most pan-minus-blue aerial photography.

Figure B-7 illustrates the spectral regions which these filters allow to pass when SO-226 aerial film is used.

Infrared aerial photography is also normally obtained through filters to block transmission of ultraviolet light. As has been stated, infrared film is sensitive to both ultraviolet and the longer visible red rays. True infrared photography must be obtained through filters which transmit only the infrared. These include the Wratten 87 and 88A, illustrated in Figure B-8. Modified infrared aerial photography is obtained through filters which transmit some visible and/or ultraviolet light, as well as infrared. Examples are all of the filters shown in Figure B-6. A very deep red filter, the Wratten 89A, is also sometimes used.

B.6 SPECIAL FILM AND FILTER COMBINATIONS TO ENHANCE CONTRAST DIFFERENCES

Combinations of films and filters for this purpose are selected by spectral reflectance analysis colorimetric comparison. Contrast differences may be either positively or negatively enhanced. For instance, if a red apple growing on a tree with green leaves is photographed through a red filter (such as a Wratten 25), on pan film, the image of the apple will appear very light against an almost black background. If, on the other hand, the same scene is photographed through a cyan (blue-green) filter, the apple will appear almost black against a much lighter background.

Giving due consideration to film speed, if a narrow band-pass filter or combination of filters is used, practically everything in nature can be either positively or negatively enhanced from its surroundings, if any reflectance difference exists. Very high film speeds are necessary because extremely high filter factors may apply to some special filter combinations.

Ground and aerial spectral reconnaissance (see Appendix E) is necessary for measurement of reflective differences.

B.7 COLOR AND "FALSE"-COLOR FILMS AND FILTERS

Color photography is normally obtained through filters which block out only ultraviolet light which scatters excessively, creating an undesirable brightness flux. Blue light also scatters undesirably, but is required for creating other colors.

The filters most commonly used to obtain aerial color photography are those whose transmission diagrams approach those of the Wratten 2A illustrated in Figure B-8.

Colored filters may, of course, be used with color films. The special effects used are sometimes very helpful in special aerial analyses. The additive tristimulus series, for instance from short to long wavelengths, consists of blue, green, and red light. If blue, green, and red beams of light are projected so that they superimpose on a point, the result is white light. The tristimulus subtractive series is yellow, magenta, and cyan. If these three color filters are superimposed, the result is devoid of color, or black. If a magenta filter is used with color film, everything in the scene which is green in nature will appear black in the resultant color photography.

Very little work has been done to exploit the aerial potential of selected filters with color films, which hold considerable promise in many areas of analysis.

In "false" color films the dye layers have been altered so that the tristimulus results do not yield colors as they appear in nature. The most common type of false color film is Eastman Kodak Ektachrome Infrared Aero (process E-3). This film, which must be exposed through a Wratten 15 filter, has been developed as a replacement for camouflage-detection film. With both the new film and its predecessor, features which reflect infrared light appear red-magenta, and features which do not reflect infrared appear black, blue, or cyan. For instance, a grain field in which one section is dead or diseased will appear red-magenta in the healthy areas, but cyan in the unhealthy area.

The value of these films in agricultural surveys is obvious.

B.8 APPLICATIONS FOR AGRICULTURAL SURVEYS

Spectral reflectance field data are required to optimize selection of film and filter combinations. If it is found that reflectance differences exist between certain crop types and their surroundings, it may be possible to develop a film and filter combination which will yield a predictable, identifiable tone for those crop types.

In the case of livestock, the problem is in many ways less complex. It appears more desirable to preserve a long gray scale by use of a minus blue filter such as the Wratten 8 or 9. If desired, of course, a special combination could be used. For instance, if it is desired to conduct a sheep inventory in the spring, it might be desirable to use a magenta (minus green) Wratten 32 filter paired with a Wratten 2A to eliminate ultraviolet light. The green grass would then appear black, while the sheep and lambs would appear white. In this case, the background has been negatively enhanced (made black) so that the gray-white animals can be seen more clearly.

B.9 SUMMARY

Special film and filter combinations are very desirable for specialized aerial reconnaissance. They aid in obtaining distinct, usable imagery by overcoming at least part of the handicap of haze scatter. They have special value for enhancing contrast between ground features and their surroundings, *if* the differences in spectral reflectance are known.

DESIGNATION Special Fine Grain Aerial

EMULSION CODE NUMBER SO-226

DESCRIPTION

Special Fine Grain Aerial (SO-226) is a slow speed, high contrast, fine grain film for extreme high altitude aerial photography. This film has extended red sensitivity which makes it particularly useful with minus blue filters. SO-226 is coated on a 4.0 mil Estar base. This film is manufactured by Eastman Kodak Co. and is a special order product with a 45 to 60 day delivery, and a minimum order requirement.

SENSITOMETRIC CHARACTERISTICS

SPEED ($\gamma/2$) — 7.4

NORMAL CONTRAST — High

DMAX — 2.5

LINEAR EXPOSURE RANGE — 0.8 log E

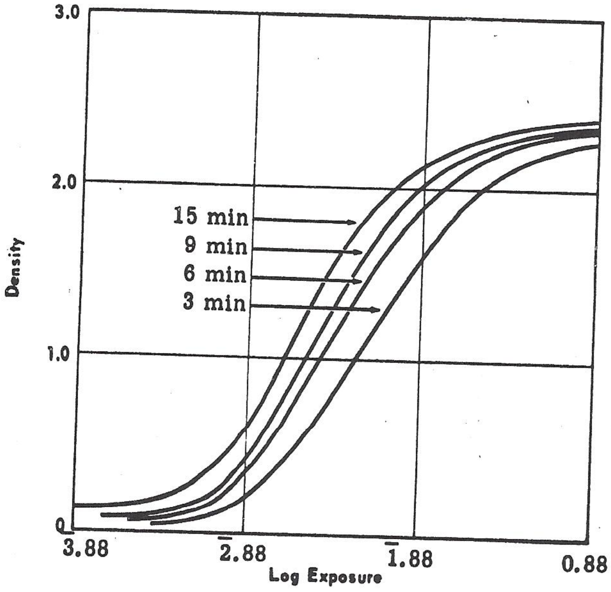
SPECTRAL SENSITIVITY — Extended red

RECOMMENDED SAFELIGHT — None

FILTER FACTORS

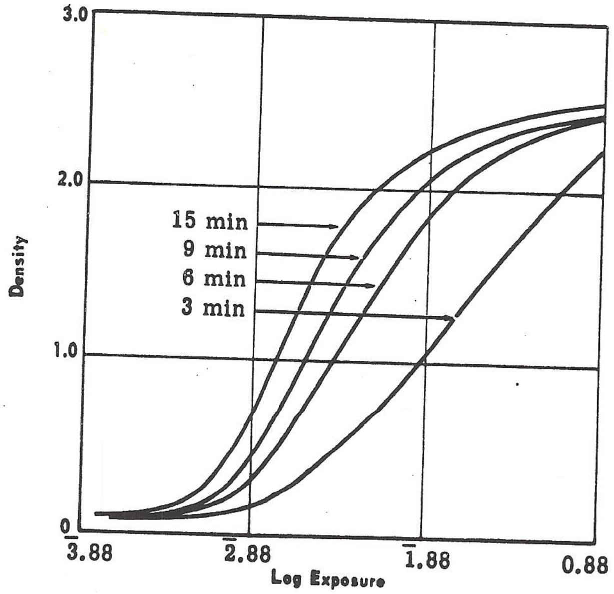
No. 12	= 2.0
No. 21	= 2.3
No. 25	= 3.6

SENSITOMETRIC CURVES FOR
D-19 **DEVELOPER AT** 68 °F



EXPOSED 0.01**SEC. TO** Day**LIGHT**
AGITATION Sensitometric processor

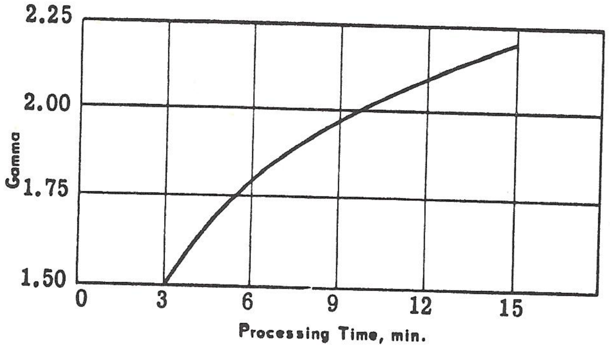
SENSITOMETRIC CURVES FOR
Cramer H-D **DEVELOPER AT** 68 °F



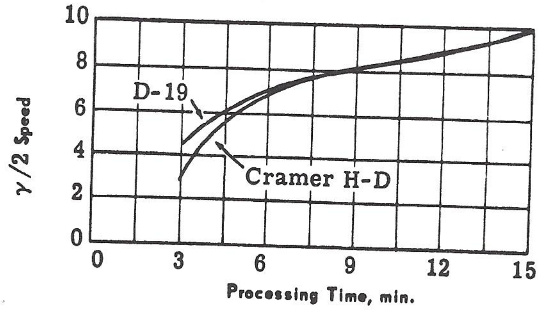
EXPOSED 0.01**SEC. TO** Day **LIGHT**
AGITATION Sensitometric processor

Figure B-1.- Data sheet for SO-226 film.

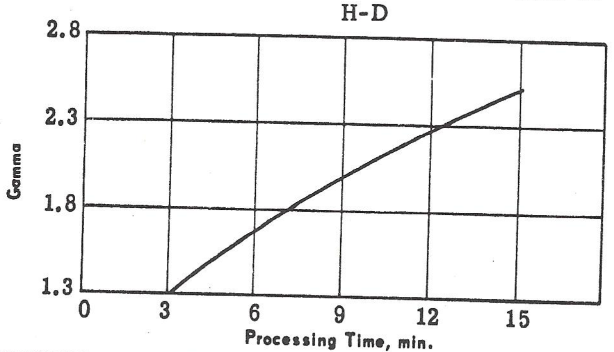
TIME • GAMMA CURVES FOR D-19 DEVELOPER AT 68°F



TIME • γ/2 Speed



TIME • GAMMA CURVES FOR Cramer H-D DEVELOPER AT 68°F



SPECTROGRAM TO Daylight

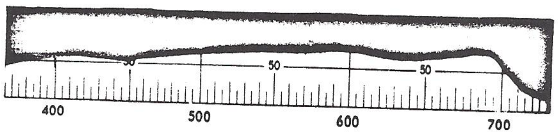
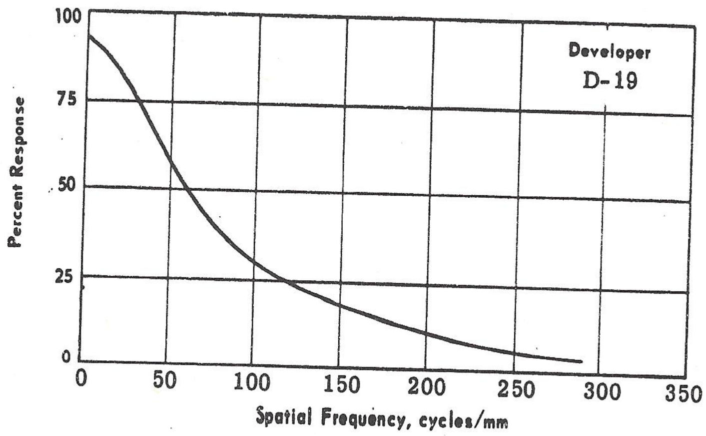


IMAGE QUALITY CHARACTERISTICS

MODULATION TRANSFER FUNCTION



MAXIMUM RESOLVING POWER, lines/mm

Target Contrast	D-19 Developer
1000:1	340
6.3:1	260
2:1	165

GRANULARITY

Not Available

PHYSICAL PROPERTIES

BASE THICKNESS — 4.0 mils
BASE COMPOSITION — Estar
EMULSION THICKNESS — 0.5 mil
WEIGHT PER SQ. FT. — 0.032 lbs at 50% R.H.

ANTIHALATION TYPE — None
BASE COLOR — Clear
HIGH TEMPERATURE PROCESSING — Yes, to 100°F

Figure B-2.- Data sheet for SO-226 film, concluded.

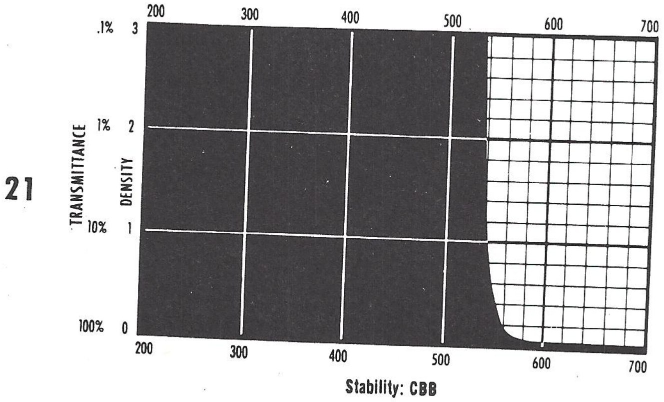


Figure B-3.- Transmission diagram for Wratten No. 21 filter. Unshaded area represents the part of the spectrum which the filter allows to pass. The Wratten 21 allows almost all visible red (wavelengths longer than 540 mμ) and near infrared to pass. From Eastman Kodak data book "Kodak Wratten filters for scientific and technical use."

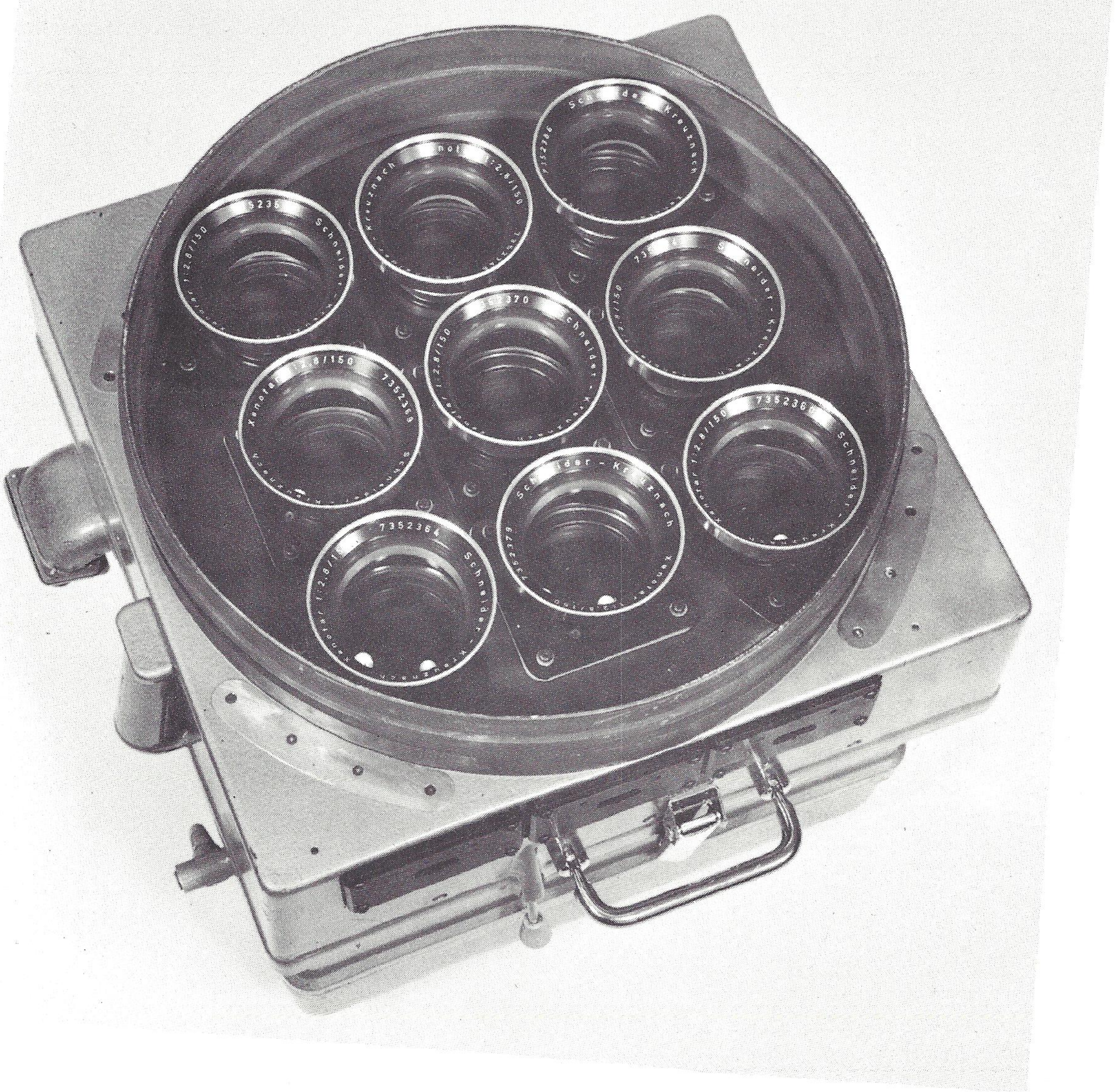


Figure B-4.- Vidya multiband aerial camera. Photographs are exposed simultaneously through nine lenses on three rolls of film. With a different film-filter combination for each exposure, this gives nine sets of tone contrasts for each scene photographed.

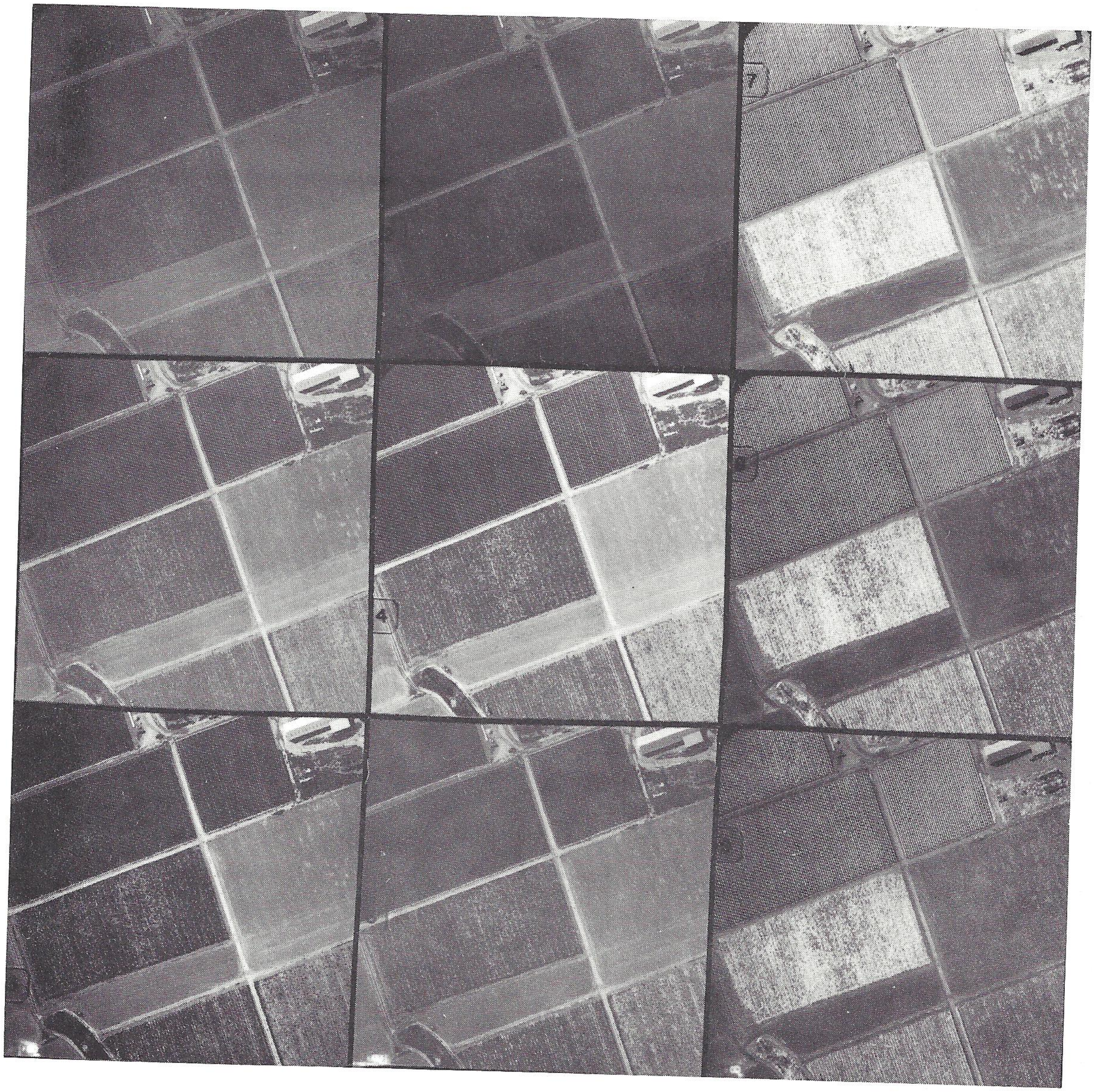


Figure B-5.- Multiband photographs showing row crops. Note different tone contrasts in different parts of the spectrum. Measurement of spectral reflectance from growing crops may permit determination of tonal signatures for certain crop types.

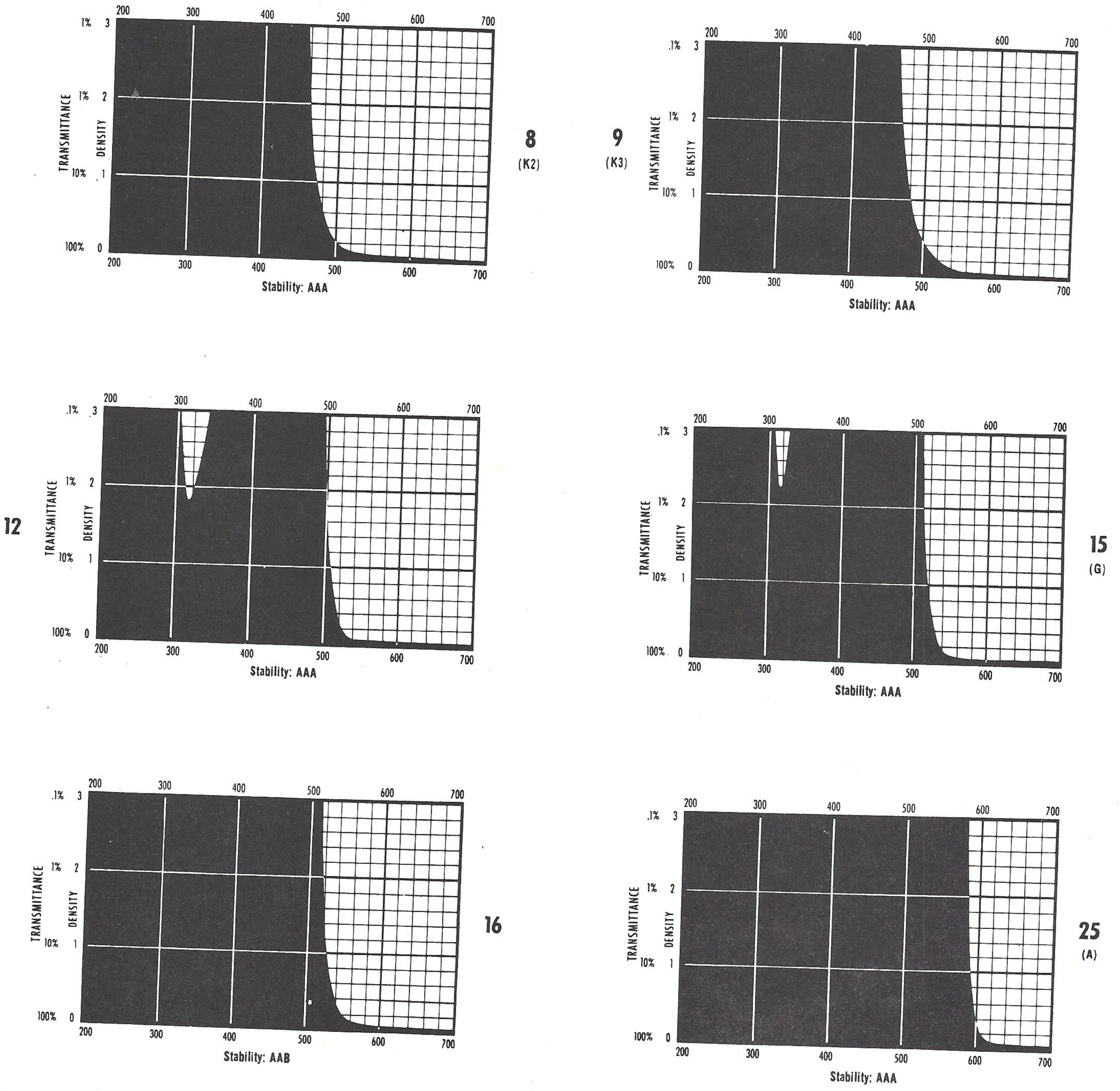


Figure B-6.- Transmission diagrams for Wratten filters Nos. 8, 9, 12, 15, 16, and 25. From Eastman Kodak data book "Kodak Wratten filters for scientific and technical use."

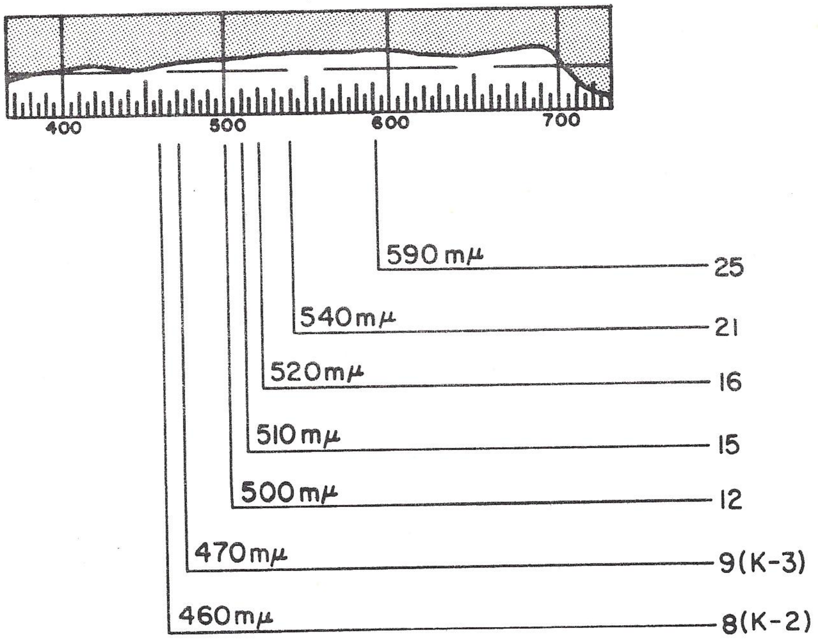
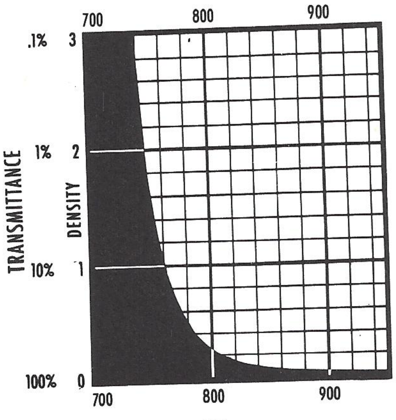
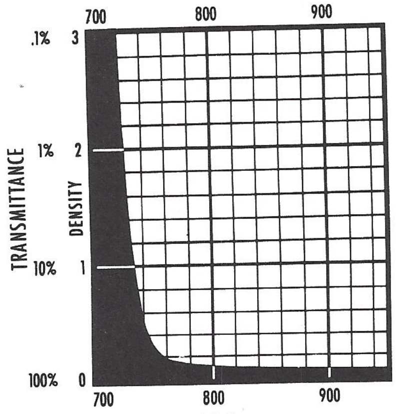


Figure B-7.- Equal energy spectrogram of SO-226 film, showing peak transmission of Wratten filters.

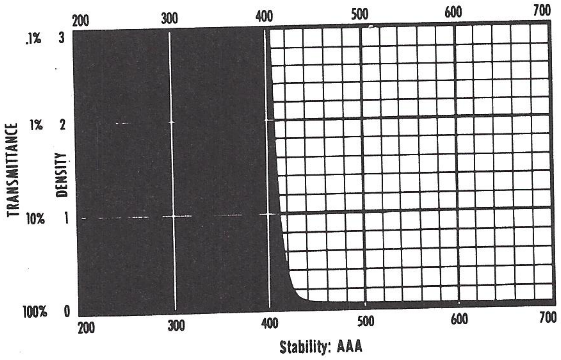


87



88A

2A



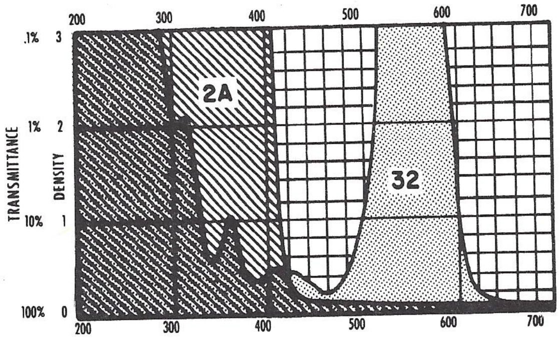


Figure B-8.- Transmission diagrams for Wratten filters Nos. 87 (top left), 88A (top right), 2A (center), and 2A and 32 superimposed (bottom). From Eastman Kodak data book "Kodak Wratten filters for scientific and technical use."

APPENDIX C

FLIGHT MISSION PLANNING

C.1 GENERAL

Flight Mission Planning is the term applied to the procedural steps which must be taken prior to an aerial reconnaissance mission to insure that:

(1) The correct areas are photographed.

(2) Photographic scale requirements are met.

(3) The optimum aerial camera system for the task is used.

(4) The optimum aerial photographic film and filter combination is used.

(5) The individual flight lines span the area effectively, so that there are no gaps in coverage. This requirement includes overlap of consecutive photographs as well as overlap of coverage flown in parallel flight lines (if any).

(6) The photo aircraft will arrive "on station" (at the beginning of the first selected flight line) at the time of day and at the required altitude to obtain the required photography. This requirement includes that, if more than one area must be pictured, and/or if flight lines must be flown at different altitudes, flight time between positions "on station" is reduced to a minimum.

(7) The weather and light conditions in the area(s) to be photographed be known in advance (if possible) so that correct camera exposure adjustments can be made (or so that flights can be postponed or cancelled, if necessary).

<u>Selection of areas to be pictured</u> is the first step to be taken. The basic decision to be made is whether a vast area must be pictured, or whether study can be localized by pre-selection of smaller, representative areas. The factors involved are of an operational category; is it necessary to get as much information as possible by study of an entire area, or can sufficiently reliable data be obtained by:

(1) Photographing and studying only known critical areas, or;

(2) By statistical analytical methods, random selection of a sufficiently large "population" of near-equally sized portions of the entire area to yield an answer with a sufficiently high confidence level that the answer is, in fact, correct for conditions in the entire area.

Factors to be considered are time, personnel, aircraft, equipment and amount of film required.

Time considerations ultimately depend upon how soon the final analyzed data are needed. The amount of work which can be performed prior to that deadline depends upon the time of day and the time of year in which photography must be flown, flight, film processing, image analysis and reporting time factors. Allowances should be made, if possible, for delays caused by adverse weather and other delaying factors.

Personnel factors include availability of personnel to perform all flight, film processing, and image-analysis work, plus assignment of personnel to go into the field and obtain "ground truth" data for confirmation of image analyses.

Aircraft and equipment factors include availability of photo aircraft with all necessary equipment where and when needed.

Film requirements depend upon magazine capacity of the types of cameras to be used, and the photographic scale required to obtain the ground resolution needed for the type(s) of analysis to be made.

The smallest scale which will permit the required identification accuracy should normally be selected. Considering vertical-frame type photography, for instance, doubling the scale (from 1/20,000 to 1/10,000, for example) requires more than four times as much film to obtain the same coverage.

After these basic decisions have been made, the area(s) to be photographed should be plotted on a map of suitable scale.

If the ground size of the area has not been specified, just that coverage is needed in the area bounded by lines connected by three or more points at given locations, the area must be delineated on a map or chart, and the ground area determined. This permits calculation of film and many of the time, personnel, aircraft and equipment requirements.

C.2 PHOTOGRAPHIC SCALE - REQUIRED FLIGHT ALTITUDE

Photographic scale is the size of images on the film relative to the actual size of the features on the ground. It is a factor in determining both the amount of information which can be extracted from photographs and the size of the ground area which can be pictured in a photograph of a given size.

Photographic scale in vertical photography is directly proportional to flight altitude above the ground and to the focal length of the camera. For instance, if the focal length of the camera is 12 inches (1 foot), and the altitude above level ground is 10,000 feet, the scale of the photographs will be 1/10,000. If two points are exactly one inch apart on the photographs, the ground distance between them is 10,000 inches (833.3 feet).

Scale and ground resolution requirements for crop/livestock surveys are quite large. For row crops, as has been stated, identification of individual plants which are (on the average) one foot in diameter on the ground is required.

The exact formula for determining ground recognition resolution based on the fact that an image, to be recognized or identified, must be five times larger than for mere detection, is:

$$G = \frac{5S}{304.8R}$$

where:

G = ground recognition resolution

S = photo scale number (20,000 of scale 1/20,000, for instance)

304.8 = number of millimeters per foot

R = film-camera viewing equipment system resolution

If, for example, one can resolve 100 lines per millimeter on the film, and if ground features one foot in diameter must be recognized, then photo scale, theoretically, can be no smaller than 1/6096 or 1/7,000.

If a camera with a 12-inch (1 foot) focal length is to be used, the aircraft must be flown no more than 7,000 feet above the ground.

Altitudes are sometimes given "MSL" or height above mean sea level. When this is done, the ground elevation in the area must be substracted from the "MSL" flight altitude to determine the flight altitude above the ground for photo scale and area coverage determination.

Appendix A contains a discussion of aerial camera systems which should be studied for more complete understanding of photographic scale - flight altitude requirements.

C.3 AERIAL-CAMERA SYSTEM SELECTION

Each aerial-camera system in use today has been developed to fill specific needs. Readers are advised to study Appendix A for a discussion of this vital element.

C.4 SELECTION OF OPTIMUM AERIAL PHOTOGRAPHIC FILM AND FILTER COMBINATION

The basic requirement (and problem) in aerial photography is that images of objects must stand out from their background (or surroundings) so that each can be detected and recognized.

Readers are advised to study Appendix B for a discussion of this vital element.

C.5 FLIGHT-LINE PLANNING

Flight-line planning includes all steps necessary to make sure that the area(s) which are to be pictured are covered as efficiently as possible.

This requirement includes ensuring that flight lines are parallel (if more than one is required), and that the ground distance between flight lines is such that there are no gaps in side overlap. It is not efficient, of course, to plan parallel flight lines so close together that the same areas are pictured repeatedly in the same mission.

The time interval between exposures must also be calculated, so that there are no gaps (or "holiday") between consecutive photographs. The factors which must be predetermined for calculation of exposure interval are the speed of the aircraft over the ground, flight altitude, and ground area in the direction of flight which will be pictured in each photograph. When this distance has been determined, the amount of "ground gained forward" (sometimes abbreviated "GGF") can be calculated. If consecutive photographs are to overlap 60 percent in the dimension and in the direction of flight, the GGF is 40 percent of the ground area pictured in each photograph. The steps taken in these calculations permit determination of the number of photographs which will be taken along each flight line.

Assuming an irregularily shaped area, it is most efficient to plan flight lines so that "turn around" time is kept to a minimum. If possible, an area should be covered by a few long flight lines rather than several short ones. Figure C-1 is a sketch illustrating this point. Sometimes this cannot be done. Sometimes, for location and orientation purposes, flight lines must be flown straight north-south or east-west.

If the same area must be photographed at several different altitudes, or if several areas are to be photographed (perhaps each one at more than one altitude), it is usually desirable to schedule the highest-altitude flights earliest in the day. This is desirable because of atmospheric conditions which influence both flight performance of aircraft and light transmittance characteristics. It is usually cooler earlier in the day. Cooler air is denser, which results in better aircraft performance. Aircraft can climb to altitudes more efficiently in cooler, denser air. Early in the day, there is usually less haze present in the air. Haze causes light of the wavelengths preferred for most aerial photography to scatter. Further, depending upon relative humidity and dew point conditions, clouds which form locally usually build up later in the day. Cloud cover obviously obscures the ground from higher altitudes. High, thin cloud cover (cirrus clouds, meteorological types "High 1, 2, and 3") is usually desirable if photography is to be flown at altitudes less than 18,000 feet (in the mid-temperate zone). This type of high, thin cloud cover filters out ultraviolet light. Since all of the photographic films in current use are sensitive to ultraviolet light, UV scatter must be kept from reaching the film. This, of course, is best done by use of photographic filters as outlined in Appendix B.

C.6 COVERAGE OF MORE THAN ONE AREA

If several areas a considerable distance apart are to be photographed, the flight time distances between them must be considered. Flight range economy calculations should be made to determine the flight course procedure which will:

(1) Reduce flight time during which photographs <u>are not</u> being exposed to a minimum;

(2) Optimize vertical transfer from one altitude to another; depending upon the distance separating areas which are to be photographed, it may be more economical to fly all high altitude photography initially, and then return to each area to obtain coverage at lower altitudes.

(3) Keep to a minimum, "turn around" time and travel distance when moving from one flight line to another. For instance, if four parallel flight lines a mile apart are to be flown, it is about 30 percent more efficient (based on air travel distance) to fly them in order 1, 2, 3, and then 4 than it is to fly them in order 1, 3, 2 then 4. With light propeller-driven aircraft (such as the Cessna 180), normal turn-radius is quite small. In the case of high-speed

jet aircraft or larger multi-engine aircraft, it may be more efficient to fly the flight lines in order 1, 3, 2, then 4. This is because of the greater turning radius of high-speed or large aircraft.

Obtaining photography in the morning is important in crop/ livestock surveys. Morning photography is preferred because:

(1) Shadows which show profile views of animals are desirable.

(2) Animals are less apt to seek out shade early in the day.

It is necessary, therefore, to determine the distance and difference in altitude between the "home" airport and the first area of which photography is to be obtained, so that the aircraft will arrive "on station" in time to optimize the target area conditions which are to be analyzed.

C.7 TARGET AREA WEATHER CONDITIONS

Fairly reliable long-range weather forecasts can be obtained from the U. S. Weather Bureau State Climatologists. Local weather conditions in distant areas can be determined by calling the Federal Aviation Agency "Flight Service Station" (FSS) nearest to the area to be photographed. The location of the nearest FSS can be obtained by telephoning the nearest Federal Aviation Agency office or by reference to the FAA "Flight Information Manual" (FIM).

Weather conditions in an area may be determined in flight by calling (by radio) the FSS nearest the target area.

In long-range planning, it can generally be predicted that less atmospheric haze will be encountered in areas which usually have considerable range between minimum night and maximum day temperatures.

This stems from the fact that moisture (gaseous water vapor) in the air absorbs and holds heat during the day. This tends to cool the atmosphere. After the sun goes down, and the earth begins to cool, heat is released by the water vapor in the air, warming the atmosphere. The end result is more even temperature in areas in which the quantity of total water vapor is higher. Since haze and atmospheric gaseous water vapor content of the air are interrelated, wide ranges in temperature indicate (but do not guarantee) that less atmospheric haze will be encountered. Reduction in haze shortens exposure times and reduces scatter of light, so that better use can be made of the shorter wavelengths.

At certain times of the year, ground-fog problems may be encountered. These may stem from temperature inversions near the ground. In the fall of the year, particularily in marshy areas or near open bodies of water, ground fog occurs when colder air overrides the warmer water on the surface. These problems are normally most severe early in the morning and late in the afternoon.

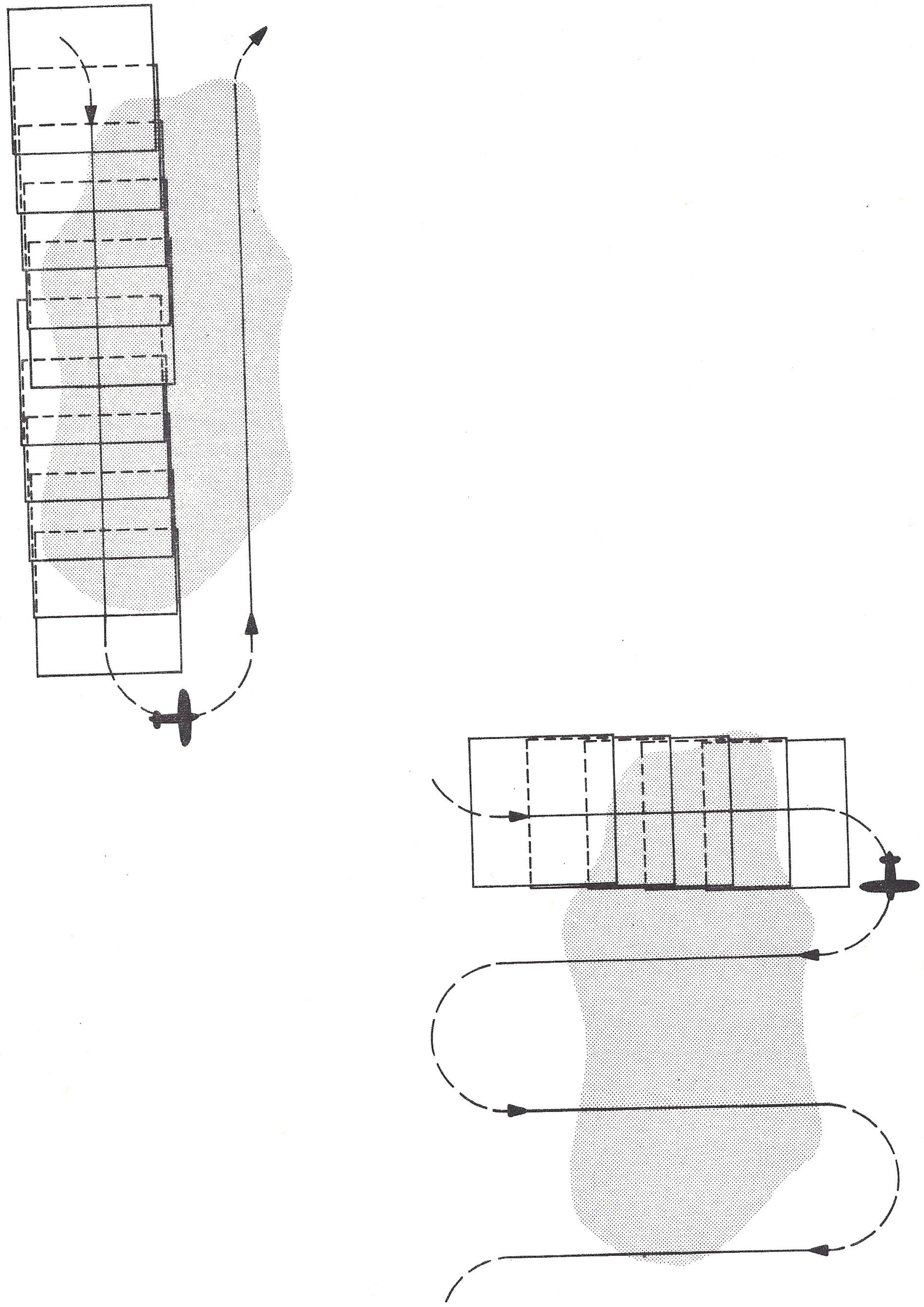


Figure C-1.- Efficient coverage of ground area, minimizing turn-around time.

APPENDIX D

AERIAL PHOTOGRAPHIC INTERPRETATION KEYS FOR AGRICULTURE

Two definitions should be cited for better understanding of what is meant by "aerial photographic interpretation keys for agriculture." First, a definition of aerial photographic interpretation; second, the accepted definition of a "key."

Aerial photographic interpretation is "the act of examining photographic images for the purpose of identifying objects and judging their significance."

Aerial photographic interpretation keys are "reference material designed to facilitate rapid and accurate identification and determination of the significance of objects by the photo-interpreter." Both definitions have been drawn from the Manual of Photo Interpretation (American Society of Photogrammetry, 1960).

Aerial photographic interpretation keys help analysts detect, identify, and report on things which can be seen in aerial photography. Several types of keys have been developed. Their prime purpose is to provide analysts with reference sources of background information. This is a basic requirement if reliable information is to be extracted solely from study of images. Keys should be extensively and accurately illustrated, so that analysts will be able to identify images in aerial photography without transforming a word description to a mental image. Because of the importance of illustrations in keys, the photographic quality must be extremely high. The illustrations in keys which are prepared in book form almost have to be photographs. This requirement has greatly increased production costs and restricted the distribution of keys.

It is rarely enough to picture and describe an image. The user should also be coached or led so that he understands the significance of what he sees. This is particularly true if users are not expected to have broad background experience both in the art-science of aerial photographic interpretation and in the specific technical field in which analyses must be made.

Aerial photographic interpretation keys are usually prepared in book form. Illustrations may consist of both vertical and oblique aerial photographs and ground photographs, single photographs, and stereograms. Supporting illustrations may consist of sketches and drawings which accentuate and draw attention to significant identifying features. Photographs are frequently annotated to draw the user's attention to specific features.

It is frequently desirable to start an illustration series with a large-scale ground photograph which approximates the impression an untrained user has of the feature to be identified. The illustration series then extends from the ground view to the aerial oblique, and culminates in the vertical view at approximately the scale at which operational photography is to be studied.

However, many important identification criteria cannot be seen in a horizontal view on the ground. This is particularly true where understanding depends on study of a large ground feature or area and mass effects are important.

Since World War II, more than 200 photointerpretation keys have been prepared, most of them for limited distribution. The distribution of many military keys is restricted by security reasons as well as cost of publication.

The section which follows has been extracted verbatim from a report by the Interservice Committee on Photointerpretation Research, Keys and Techniques, The Committee on Geophysics and Geography, Research and Development Board, Washington 25, D. C.

Scope of Photointerpretation Keys

a. An Item Key is one concerned with the identification of an individual object or condition.

b. A Subject Key is a collection of item keys concerned with the identification of the principal objects or conditions within a given subject category.

c. A Regional Key is a collection of item or subject keys concerned with the identification of the principal objects or conditions characteristic of a particular region.

d. An Analogous Area Key is a subject or regional key which has been prepared for an accessible area and which by extrapolation may be used in the interpretation of objects or conditions in inaccessible areas having similar characteristics.

Technical Level of Photointerpretation Keys

a. A Technical Key is one prepared primarily for use by photointerpreters who have had professional or technical training or experience in the subject concerned.

b. A <u>Non-Technical</u> <u>Key</u> is one prepared primarily for use by photointerpreters who have not had professional or technical training or experience in the subject concerned.

Intrinsic Character of Photointerpretation Keys

a. A <u>Direct</u> <u>Key</u> is one designed primarily for the identification of discrete objects or conditions directly discernible on photos.

b. An <u>Associative</u> <u>Key</u> is one designed primarily for the deduction of information not directly discernible on photos.

Manner of Organization or Presentation of Photointerpretation Keys

All photointerpretation keys are based upon diagnostic features of the photo images of objects or conditions to be identified. Depending upon the manner in which the diagnostic features are organized, two general types of keys are recognized. "<u>Selective Keys</u>" are so arranged that the photointerpreter simply selects that example corresponding to the image he is trying to identify. "<u>Elimination</u> <u>Keys</u>" are so arranged that the photointerpreter follows a prescribed step-by-step process that leads to the elimination of all items except the one he is trying to identify. Where feasible of formulation, the latter type of key is considered preferable.

a. Selective Keys

(1) An <u>Essay</u> <u>Key</u> is one in which objects or conditions are described in textual form using photos only as incidental illustrations.

(2) A <u>File</u> <u>Key</u> is an item key composed of one or more selected photo images, together with notes concerning their interpretation, assembled by an individual interpreter largely for his personal use.

(3) A <u>Photo</u> <u>Index</u> <u>Key</u> is an item key composed of one or more selected photo images, together with notes concerning their interpretation, assembled for rapid reproduction and distribution to other photointerpreters.

(4) An Integrated-Selective Key is one in which photo images and photo recognition features for any individual object or condition, within a subject or regional key, are so associated that by reference to the appropriate portion of the key the object or condition can be identified.

b. Elimination Keys

(1) A Disc Key is one in which selected photo recognition features are grouped or arranged on one or more discs so that when the recognition features are properly aligned, all but one object or condition of the group under consideration is eliminated from view.

(2) A Punch Card Key is one in which selected photo recognition features are arranged in groups on separate punch cards so that when properly selected cards are superimposed upon a coded base, all but one object or condition of the subject group under consideration is eliminated from view.

(3) A Dichotomous Key is one in which the graphic or word description assumes the form of a series of pairs of contrasting characteristics which permit progressive elimination of all but one object or condition of the subject group under consideration.

APPENDIX E

SPECTRAL MEASUREMENTS FOR AGRICULTURAL SURVEYS

E.1 INTRODUCTION

Everything in nature reflects, emits, and absorbs energy. Over the past several years, theoretical and field studies have been made to determine what wavelengths of energy are reflected by different substances and natural features. This has been done primarily to extend the capabilities of aerial photographic interpretation. Knowing the amplitude and wavelength of the light reflected from any feature, the identity and significance of the image which it produces on film is easier to determine.

Several factors have to be considered in measurement of spectral reflectances which are to be used to improve aerial photographic interpretation. Most important is that the spectral reflectances which are measured be truly representative of those which exist in nature. In the case of living vegetation, care must be taken to ensure that the samples from which measurements are being made are themselves representative of their species, and that the reflectances which are measured from them are the same as they reflect when growing in their native setting. Moreover, the samples must be in the life condition which is significant for the particular study.

Two general types of measurement should be made of living vegetation in the field: measurements of the tops of individual plants, and profile measurements. It is desirable to measure the reflectance of both individual plants and of their immediate surroundings. If differences exist, it may be possible to select a film and filter combination which will produce discrete images of individual plants or of small homogeneous stands.

E.2 INSTRUMENTATION

E.2.1 Laboratory Instruments

The reflectance of objects occurring in nature has been measured with laboratory instruments for a number of years. Generally, samples of the objects have been removed from their natural surroundings and transported (often in a destructive manner) to the laboratory, where they were measured on instruments too heavy, too delicate, and too temperamental to operate satisfactorily outside the confines of an air-conditioned laboratory.

The measurement of natural objects under laboratory conditions does not necessarily determine how these objects look in nature. Many objects change when dug up and transported to the laboratory.

Therefore, there have been attempts to transport the laboratory instruments to the field. In one case this was accomplished by putting the laboratory instrument in a trailer and towing it to the site where the measurements were to be taken of the sample within the trailer. This procedure still removes the samples from their environment for measurement; however, it does considerably reduce sample deterioration during transport.

In another case, a "portable" version of a laboratory instrument has been built (this instrument is portable only by definition; with its power generator, it weighs over 1/2 ton). Besides being cumbersome, this instrument requires more time to record measurements than an equivalent laboratory instrument.

E.2.2 Radiometers

Another approach to spectral reflectance measurement has been the use of narrow-band radiometers. These instruments sacrifice the high spectral resolution of the laboratory instruments to gain the advantages of greater portability and operational speed.

E.2.3 Block Spectrometer

The Block Associates interferometer spectrometers used in the airborne spectral measuring system of Project VELA represent a design departure from the common spectral measuring instruments. These spectrometers have good portability and speed combined with good spectral resolution, and are among the best instruments for ground spectral measurements. The spectral resolution of the Block spectrometers is not as high as that of the laboratory-type instruments, but is more than sufficient for any analysis yet devised for ground data.

E.2.4 Vidya Spectroterrometer

"Spectroterrometer" (a contraction of "terra" and "spectrometer") is the term coined to describe the system of portable self-contained ground spectral reflectance measuring instruments developed by the Vidya Division of Itek Corporation for use in the research phases of Project VELA. The spectroterrometer consists of an interferometric spectrometer combined with photographic and electronic recording devices. It performs any of the functions of a laboratory spectrophotometer over most terrain without vehicular support.

The stand-mounted unit with the associated electronics, battery pack, and the tape recorder weighs less than 60 pounds. During an 8-day field exercise conducted in September 1963, data on approximately 250 specimens were collected with this unit. This unit has also been used extensively for the collection of ground data at test sites near Mercury and Fallon, Nevada, during October and November 1963.

Two mounting configurations are presently being used. The first of these, shown in Figure E-1, consists of a boom made of a 7-inch diameter aluminum tube 10 feet long mounted on a folding base. The spectrometers on the optical unit are aimed through the boom at a mirror mounted at the top end of the boom. The position of this mirror is usually adjusted to allow the spectrometer to look at the ground area directly below the mirror. The geometry of this unit is such that plants up to 10 feet in height can be readily viewed. This boom unit with the associated spectrometers, electronics, battery pack, and recorder weighs under 100 pounds and can be readily transported in the field by a three-man crew.

Recently, another mounting configuration, called a "profiler track," has been constructed. When this unit becomes operational, it will be possible to take complete spectral data at 20 points lying along a straight line 8 feet long in about 20 minutes. This rate will allow the acquisition of data on 200 points during a 5-hour day. (The data rate on the boom-and-stand units is 30 to 60 points per day.) Figure E-2 shows the profiler track mount.

Recent improvements in the data-reduction technique have reduced the required data recording time to less than 1 minute per sample. The result of these improvements is a ground spectral measuring system, shortly to become operational, that weighs under 100 pounds (including power and recorder) and can make measurements on 30 to 60 subjects per 5-hour day (dependent upon terrain) for periods of 2 to 3 days, completely independent of power-generating facilities. The speed of data acquisition and the versatility of this system was recently demonstrated during a 3-day field exercise in which spectral data on 109 subjects were collected during a total ground operating time of less than 10 hours. The prime environmental limitations of the system are those inherent to normal optical systems of simpler size and rigidity.

E.3 PRESENTATION OF SPECTRAL REFLECTANCE DATA

The energy reflected from samples is plotted on graphs to form curves. The curves show the relative amounts of different wavelengths composing the reflected energy. The term "energy" has been used because much of the reflectance falls outside the visible spectrum, yet can be recorded photographically. Figure E-3 is a curve showing the relative amounts of photographically recordable energy reflected from freshly laid raisin grapes.

E.4 UTILIZATION OF SPECTRAL REFLECTANCE DATA FOR AGRICULTURAL SURVEYS

The basic concept guiding spectral measurement programs is that once the spectral reflectance to be expected from a sample of a given type is known, aerial photographic film and filter combinations can be selected which will permit images to form from objects which reflect light of the desired spectral character, eliminating light reflected from their surroundings.

Data may be utilized for either positive or negative accentuation. In black-and-white photography, objects may be imaged as white against a black background, or black against a white background. If the images are to appear white against a black background (positive accentuation), a film and filter combination is selected to accept the reflectance from the object but not from its surroundings. If the images are to appear black against a white background (negative accentuation), a film and filter combination is selected to accept reflectance from the background but not the object. Rather than attempt to achieve an extreme contrast (black against white or white against black), it is frequently desirable to cause given objects or areas to be recorded in distinctive shades of gray. This is usually preferred because in aerial photographic interpretation it is usually necessary to search for several different things simultaneously rather than restrict search to one class of features.

An extensive ground data collection program must be undertaken to ensure that the spectral data which are collected are truly representative for given types of objects. For agricultural surveys, measurements must be made from different types of crops growing in different soils, at different times of day throughout the growing season.

Such a large volume of data can be produced by a ground and airborne spectral measurement program that manual methods of data reduction are impractical. When properly reduced and manipulated, the great volume of data will produce a large statistical base which gives promise of determining the presence or absence of changes. In order to make better use of spectrometer data, Vidya has proposed for Project VELA a modest program of equipment construction and computer programing, which will allow the use of a small digital computer as a data reduction and analysis aid. If the proposed data reduction program is undertaken, magnetic tapes containing spectral reflectance data will be returned to Vidya's Palo Alto facilities and translated into paper-tape data for the IBM 1620-II computer. The data resulting from correlation of curves, once those which are truly representative have been determined, must then be correlated with the spectral acceptance of different types of films, and the spectral transmission of various types of filters.

E.5 SUMMARY

Spectral measurements are made so that the wavelengths composing the total reflectance from objects (different types of crops) is known. The measurements which are made must be representative of the selected crop type, as seen from the angle and/or direction from which they may be photographed from the air. Lightweight truly portable field instruments must be used to make these measurements. Measurements must be made of undamaged living specimens in the field. Vidya has developed equipment which permits such field measurements to be made. In view of the great volume of data which must be analyzed, efforts have been initiated to use a digital computer for data correlation. The end aim of this work is to permit optimum aerial photographic film and filter combinations to be selected, for improvement of reliability in aerial photographic interpretation analyses.

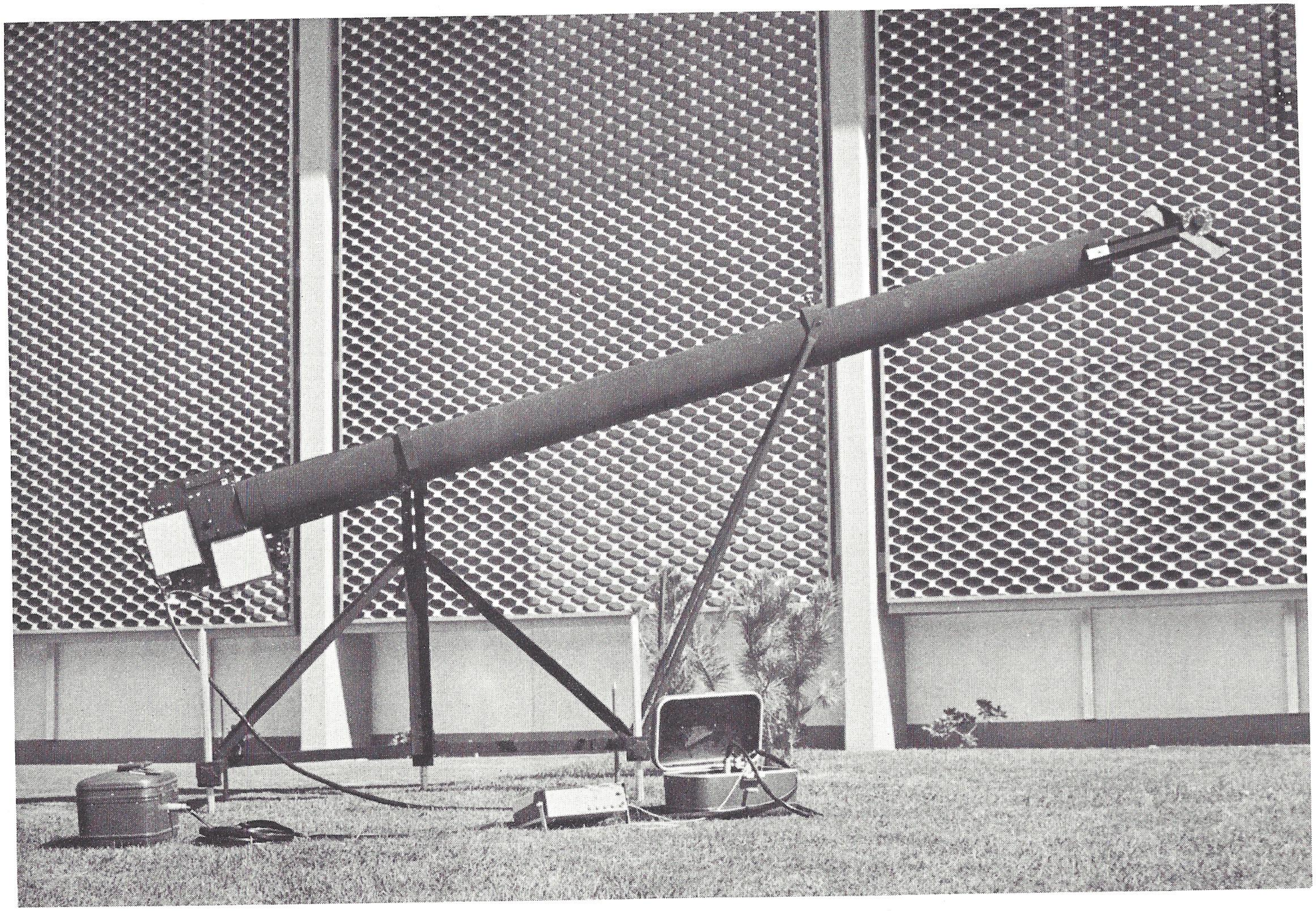


Figure E-1.- Boom mount for spectroterrometer system.

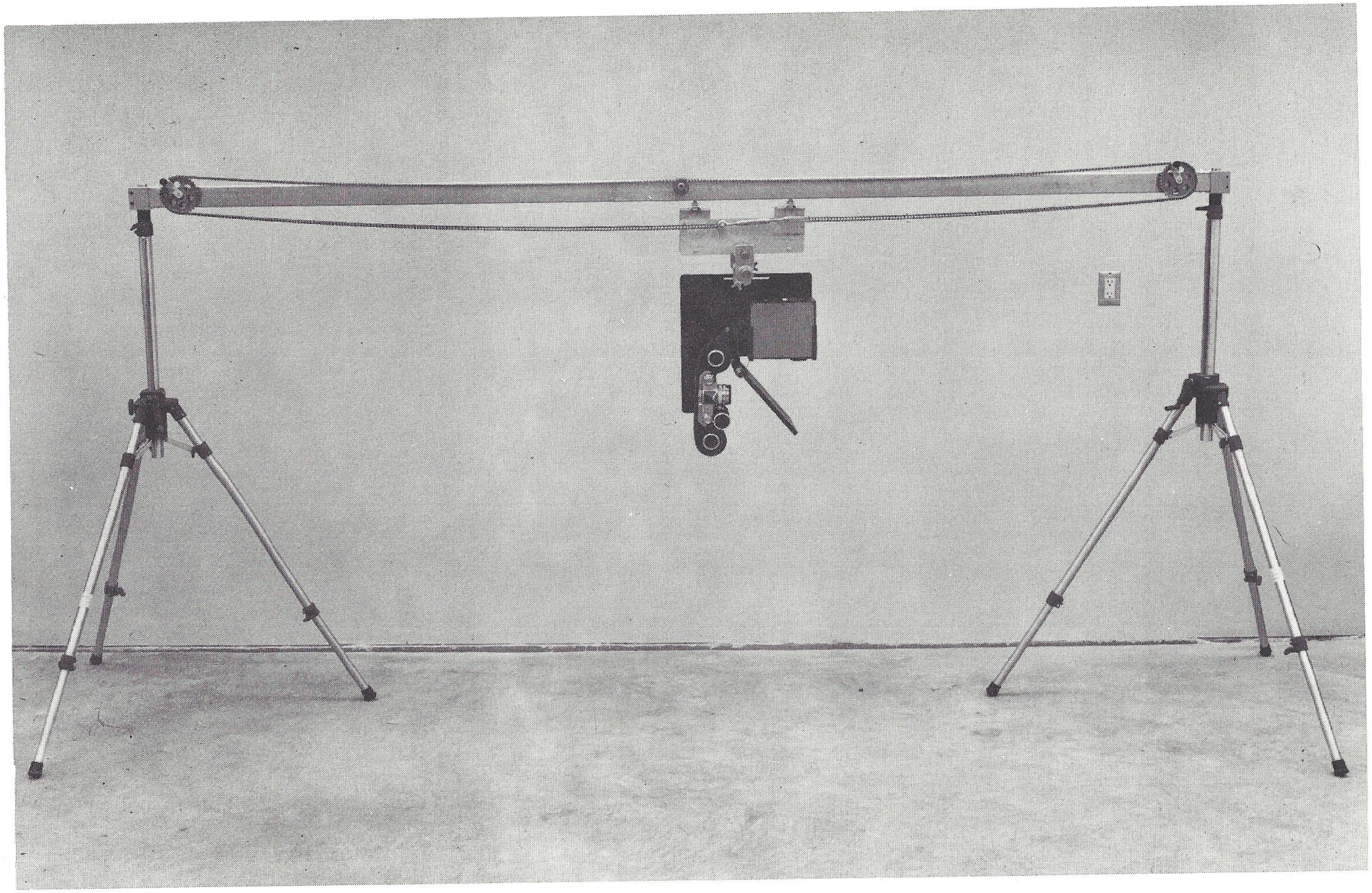


Figure E-2.- Profiler track mount for spectroterrometer system.

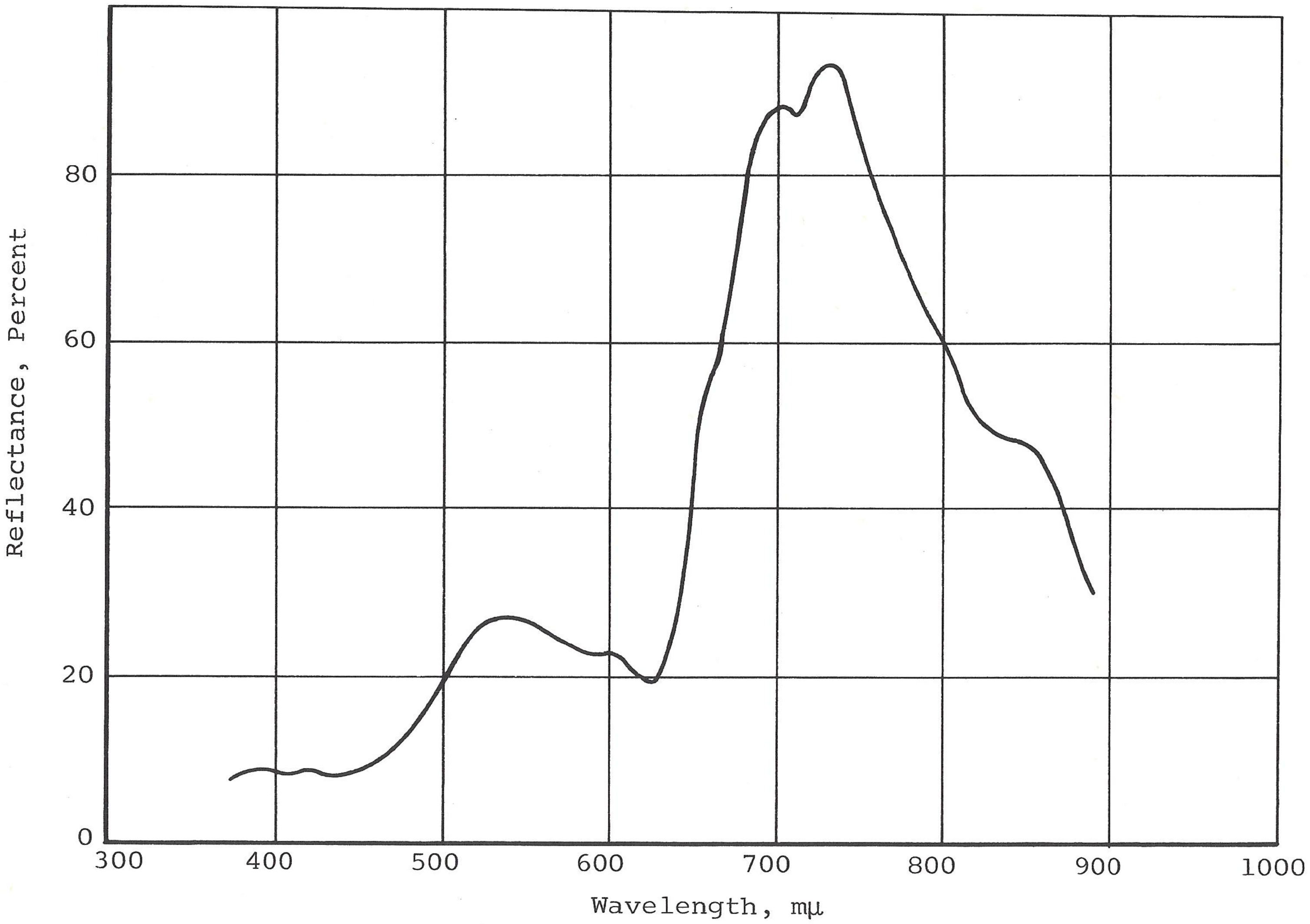


Figure E-3.-Curve showing spectral reflectance of freshly laid raisin grapes. Peak reflectance at about 730 mμ in the infrared range; the highest reflectance in the visible spectrum falls at about 530 mμ.