JOSEPH J. ULLIMAN*
ROBERT P. LATHAM
MERLE P. MEYER
School of Forestry
University of Minnesota
St. Paul, Minn. 55101

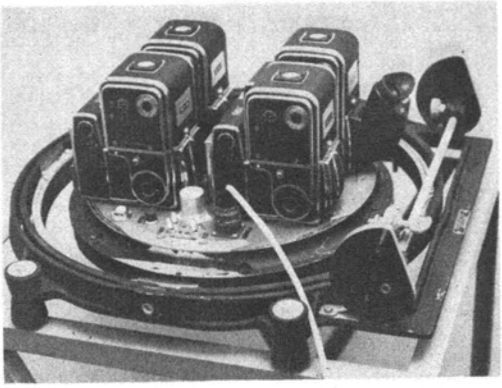

FIG. 1. Quadricamera assembly. Four Hasselblad 500 EL cameras are oriented in the same direction on the mounting plate bolted within the Robinson mount.

70-mm. Quadricamera System

Offers many capabilities over the standard mapping camera and has proven to be a very useful resource analysis tool.

INTRODUCTION

CONTINUING RESEARCH by many investigators in the applications of aerial photography to wildland and agricultural resource analysis has inevitably produced a need for a multicamera assembly capable of simultaneous exposure of a variety of film-filter-focal length combinations. The multispectral system to be described here was patterned after the basic four-camera assembly designed by Marlar and Rinker (1967) of the U. S. Army Cold Regions Research and Engineering Laboratory (CRREL). Marlar and Rinker paired two Hasselblad 500EL cameras with the film advancing in the same direction as the flight path with another camera pair having the film advancing in the opposite direction. Although films from one camera pair could be viewed stereoscopically in the uncut film strip, film from the opposite-facing cameras had to be cut and position-transposed for stereoscopic viewing.

Inasmuch as an ability to view stereoscopically all film strips side-by-side was considered a necessity, a mount assembly was needed which would permit all cameras to face in the same direction. An additional necessary characteristic of the mounting assembly was adaptability to a variety of conventional aerial mapping camera mounts (e.g., Hurd, Wild and Robinson). This requirement was defined by the fact that a number of different operators, and associated flight equipment types,

ABSTRACT: *An aircraft mounting plate for a multiple assembly of 70-mm. cameras was designed and fabricated by the University of Minnesota School of Forestry with the assistance of Mark Hurd Aerial Surveys, Inc. The basic idea and inspiration for the plate assembly was provided by the CRREL four-camera system. The assembly permits up to four simultaneous exposures which can be stereoscopically viewed and compared at the same time in the uncut film strips. Development, calibration and operation of the system is discussed.*

* Published as Paper No. 6916, Scientific Journal Series, Minnesota Agricultural Experiment Station, St. Paul, Minn.

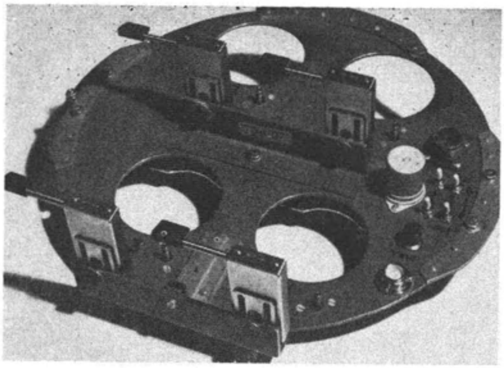

FIG. 2. The standard mounting plate contains the four quick-coupling tripod adapters, four lens-barrel holes, a fish-eye level, power input receptacle, relay, and trip switch with individual on-off buttons. Wiring is on the underside of the plate.

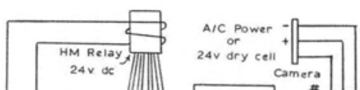

FIG. 3. Mounting plate wiring diagram.

must be depended on to accomplish the School of Forestry's aerial photography missions.

Once the initial design requirement of the unit had been agreed on, the School of Forestry contracted with Mark Hurd Aerial Surveys, Inc., to fabricate the assembly and, in the process, initiate any useful design changes or innovations—which they did to a considerable degree. The resulting quadricamera assembly is shown in Figure 1.

FIG. 4. The Lear Jet mounting plate is smaller than the standard plate and therefore has cameras oriented in opposite directions. Components are the same as the standard plate.

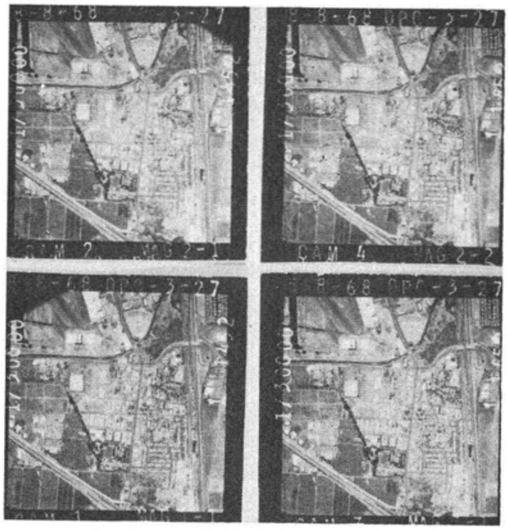

FIG. 5. Four-exposure set demonstrating the quadricamera ground cover registration. The cameras are essentially parallel and provide identical ground coverage in the final print.

DESIGN OF THE STANDARD MOUNTING PLATE

The standard mounting plate to be used in conventional low-to-medium altitude aircraft is shown in Figure 2. The plate is constructed out of light alloy metal, weighs 4.4 pounds without cameras, and is 14.3 inches in diameter and 5.4 inches in height. Four Hasselblad quick-coupling tripod adapters are mounted on the plate in the same orientation. The lens

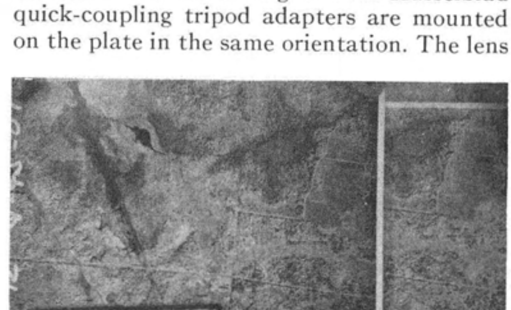

FIG. 6. Enlarged portion of a small-scale photo. A 4.2× enlargement of an original 1:45,000 nominal scale 70-mm. photo of the Cloquet Forest Research Center. A 9×9-inch enlargement provides good resolution and ease of handling.

TABLE 1. ALTITUDE CHART
70-mm. Hasselblad Camera; 55×55-mm. Format
Flying Heights (H-h in feet) by Various Focal Lengths

Scale	*50 mm.*	*80 mm.*	*120 mm.*	*150 mm.*	*250 mm.*	*500 mm.*
1:1,584	260	420	620	780	1,300	2,600
1:2,000	330	520	790	980	1,640	3,280
1:3,168	520	830	1,250	1,560	2,600	5,200
1:4,000	660	1,050	1,570	1,970	3,280	6,560
1:5,000	820	1,310	1,970	2,460	4,100	8,200
1:6,000	980	1,570	2,360	2,950	4,920	9,840
1:6,336	1,040	1,660	2,490	3,120	5,200	10,390
1:7,000	1,150	1,840	2,760	3,440	5,740	11,480
1:7,920	1,300	2,080	3,120	3,900	6,490	12,990
1:8,000	1,310	2,100	3,150	3,940	6,560	13,120
1:9,000	1,480	2,360	3,540	4,430	7,380	14,760
1:9,600	1,570	2,520	3,780	4,720	7,870	15,700
1:10,000	1,640	2,620	3,940	4,920	8,200	16,400
1:12,000	1,970	3,150	4,720	5,900	9,840	19,680
1:15,000	2,460	3,940	5,900	7,380	12,300	24,600
1:15,840	2,600	4,160	6,230	7,790	12,990	25,980
1:20,000	3,280	5,250	7,870	9,840	16,400	32,800
1:24,000	3,940	6,300	9,450	11,810	19,680	39,360
1:30,000	4,920	7,870	11,810	14,760	24,600	49,200
1:31,680	5,200	8,310	12,470	15,590	25,980	51,960
1:40,000	6,560	10,500	15,740	19,680	32,800	65,600
1:45,000	7,380	11,810	17,710	22,140	36,900	73,800
1:50,000	8,200	13,120	19,680	24,600	41,000	82,000
1:55,000	9,020	14,430	21,650	27,060	45,100	90,200
1:60,000	9,840	15,740	23,620	29,520	49,200	98,400
1:63,360	10,390	16,630	24,940	31,170	51,960	103,910
1:75,000	12,300	19,680	29,520	36,900	61,500	123,000
1:90,000	14,760	23,620	35,420	44,280	73,800	147,600
1:100,000	16,400	26,240	39,360	49,200	82,000	164,000
1:125,000	20,500	32,800	49,200	61,500	102,500	205,000
1:126,720	20,780	33,250	49,880	62,350	103,910	207,820
1:150,000	24,600	39,360	59,040	73,800	123,000	246,000
1:200,000	32,800	52,480	78,720	98,400	164,000	328,000
1:250,000	41,000	65,600	98,400	123,000	205,000	410,000

release buttons protrude through the plate next to the 3.2-inch diameter lens barrel holes. On the right side are located a fish-eye level, power input receptacle, relay and a trip switch with individual camera on-off switches. All wiring is on the underside of the plate, the diagram for which is shown in Figure 3.

DESIGN OF THE LEAR JET MOUNTING PLATE

Simultaneous with the development of the standard mounting plate, Mark Hurd Aerial Surveys was experimenting with ultra-high altitude aerial photography using the Lear Jet. As there was also a desire to use the quadricamera unit at high altitudes to simulate space photography, the contract was extended to include design and development of a unit to fit Mark Hurd's door assembly (Bock, 1968). The Lear Jet plate (see Figure 4) is necessarily somewhat smaller than the standard plate (i.e., 2.8 lbs., 12.3×5.6 inches) and, consequently, has the camera pairs oriented in opposite directions.

INITIAL FLIGHT TESTS

The mounting plates were completed in June 1968, and the initial flight tests accomplished in July along a test line over Santa Barbara, California. Both 50-mm. and 80-mm. lenses were tested with panchromatic film and yellow filters. Ground coverage registration for the four cameras was found to be very acceptable (Figure 5) for all test scales flown (1:4,000; 1:6,000; 1:8,000; 1:10,000; 1:15,840; 1:30,000; 1:45,000; 1:75,000; and 1:90,000). There was no perceptible vibration in the cameras and resolution was good (Figure 6).

One-second cycling was found to be attainable with a Nikon intervalometer. However, both the test flight photographer and photographers for subsequent flights indicated better

TABLE 2. INTERVAL TABLE
70-mm. Hasselblad Camera; 55×55-mm. Format: 40% Forward Gain
Interval Between Exposures for Various Ground Speeds and Scales

Scale	Ground Speed (mph)								
	500	400	300	150	135	120	100	90	80
1:1,584	0.16	0.19	0.26	0.52	0.58	0.65	0.78	0.87	0.97
1:2,000	0.20	0.25	0.33	0.66	0.73	0.82	0.98	1.09	1.23
1:3,168	0.31	0.39	0.52	1.04	1.15	1.30	1.56	1.73	1.95
1:4,000	0.39	0.49	0.66	1.31	1.46	1.64	1.97	2.2	2.5
1:5,000	0.49	0.62	0.82	1.64	1.82	2.1	2.5	2.7	3.1
1:6,000	0.59	0.74	0.98	1.97	2.2	2.5	3.0	3.3	3.7
1:6,336	0.62	0.78	1.04	2.1	2.3	2.6	3.1	3.5	3.9
1:7,000	0.69	0.86	1.15	2.3	2.5	2.9	3.4	3.8	4.3
1:7,920	0.78	0.97	1.30	2.6	2.9	3.2	3.9	4.3	4.9
1:8,000	0.79	0.98	1.31	2.6	2.9	3.3	3.9	4.4	4.9
1:9,000	0.89	1.11	1.48	3.0	3.2	3.7	4.4	4.9	5.5
1:9,600	0.94	1.18	1.57	3.1	3.5	3.9	4.7	5.2	5.9
1:10,000	0.98	1.23	1.64	3.3	3.6	4.1	4.9	5.5	6.2
1:12,000	1.18	1.48	1.97	3.9	4.4	4.9	5.9	6.6	7.4
1:15,000	1.48	1.85	2.5	4.9	5.5	6.2	7.4	8.2	9.2
1:15,840	1.56	1.95	2.6	5.2	5.8	6.5	7.8	8.7	9.7
1:20,000	1.97	2.5	3.3	6.6	7.3	8.2	9.8	10.9	12.3
1:24,000	2.4	3.0	3.9	7.9	8.7	9.8	11.8	13.1	14.8
1:30,000	3.0	3.7	4.9	9.8	10.9	12.3	14.8	16.4	18.5
1:31,680	3.1	3.9	5.2	10.4	11.5	13.0	15.6	17.3	19.5
1:40,000	3.9	4.9	6.6	13.1	14.6	16.4	19.7	21.9	24.6
1:45,000	4.4	5.5	7.4	14.8	16.4	18.5	22.1	24.6	27.7
1:50,000	4.9	6.2	8.2	16.4	18.2	20.5	24.6	27.3	30.8
1:55,000	5.4	6.8	9.0	18.0	20.0	22.6	27.1	30.1	33.8
1:60,000	5.9	7.4	9.8	19.7	21.9	24.6	29.5	32.8	36.9
1:63,360	6.2	7.8	10.4	20.8	23.1	26.0	31.2	34.6	39.0
1:75,000	7.4	9.2	12.3	24.6	27.3	30.8	36.9	41.0	46.1
1:90,000	8.9	11.1	14.8	29.5	32.8	36.9	44.3	49.2	55.4
1:100,000	9.8	12.3	16.4	32.8	36.5	41.0	49.2	54.7	61.5
1:125,000	12.3	15.4	20.5	41.0	45.6	51.3	61.5	68.3	76.9
1:126,720	12.5	15.6	20.8	41.6	46.2	52.0	62.4	69.3	77.9
1:150,000	14.8	18.5	24.6	49.2	54.7	61.5	73.8	82.0	92.3
1:200,000	19.7	24.6	32.8	65.6	72.9	82.0	98.4	109.4	123.0
1:250,000	24.6	30.8	41.0	82.0	91.1	102.5	123.0	136.7	153.8

For combinations not shown, interval (seconds) $= \dfrac{\text{PSR } (0.04921)}{\text{ground speed in mph}}$.

results could be obtained using manual release in conjunction with a view-finder for cycling intervals slower than five seconds.

EQUIPMENT CAPABILITIES AND OPERATIONAL PROBLEMS

As a result of the initial calibration test flight and subsequent operational photographic missions, the following equipment capability limitations and operational problems have been noted:

- *Due to the relatively slow camera cycling speed, synchronized stereoscopic coverage at scales exceeding 1:1,800 is not generally attainable with a fixed wing aircraft.* A Nikon intervalometer permits operational cycling intervals as short as 1.0 second. The internal automatic cycling mode on each camera permits cycles of 0.9 or slightly less but synchronization between cameras is quickly lost.
- *Limited camera shutter speeds and f/stop maximums may sometimes limit the conditions under which satisfactory photography can be accomplished.* Maximum shutter speeds and aperature openings are, respectively, 1/500th of a second and $f/4.0$ for the 50-mm. and 150-mm. lenses and $f/2.8$ for the 80-mm. lens, lenses which the School of Forestry has on hand.
- *If the quadricamera is used in a variety of aircraft, viewfinder facilities may not always be available.* Attempts are being made to fabricate a viewfinder to be installed in the mounting plate. Use of the Hasselblad eyelevel viewfinder is not feasible because the photographer has to virtually stand on his head to use it.
- *Static marks became a major problem on infrared B&W film, especially at high altitudes.* Upon

TABLE 3. COVERAGE TABLES
Hasselblad; 55×55-mm. format; 60% endlap; 30% sidelap

Scale	*1 in. =Ft.*	*Side of Sq. (ft.) Entire Format*	*40% Forward Gain (Ft.)*	*70% Lateral Gain (Ft.)*	*Sq. Mi. Coverage Entire Format*	*Sq. Mi. Coverage Gain*	*Acres, Entire Format*	*Acres, Gain*	*Photos per Lineal Mile*	*Photos per Square Mile*
1:1,584	132	285	114	200	0.0029	0.0008	1.9	0.5	47	1269
1:2,000	167	360	144	252	0.0046	0.0013	2.9	0.8	37	777
1:3,168	264	570	228	399	0.0117	0.0033	7.5	2.1	24	336
1:4,000	333	720	288	504	0.0186	0.0052	11.9	3.3	19	209
1:5,000	417	900	360	630	0.0291	0.0081	18.6	5.2	15	135
1:6,000	500	1,080	432	756	0.0419	0.0117	26.8	7.5	13	91
1:6,336	528	1,140	456	798	0.0466	0.0131	29.8	8.4	12	84
1:7,000	583	1,260	504	882	0.0569	0.0159	36.4	10.2	11	66
1:7,920	660	1,426	570	998	0.0730	0.0204	46.7	13.1	10	60
1:8,000	667	1,440	576	1,008	0.0744	0.0208	47.6	13.3	10	60
1:9,000	750	1,620	648	1,134	0.0941	0.0264	60.2	16.9	9	45
1:9,600	800	1,728	691	1,210	0.1071	0.0300	68.5	19.2	8	40
1:10,000	833	1,800	720	1,260	0.1162	0.0325	74.4	20.8	8	40
1:12,000	1,000	2,160	864	1,512	0.1674	0.0469	107.1	30.0	7	28
1:15,000	1,250	2,700	1,080	1,890	0.2615	0.0732	167.4	46.8	5	15
1:15,840	1,320	2,851	1,140	1,996	0.2916	0.0816	186.6	52.2	5	15
1:20,000	1,667	3,600	1,440	2,520	0.4648	0.1302	297.5	83.3	4	12
1:24,000	2,000	4,320	1,728	3,024	0.6694	0.1874	428.4	119.9	4	8
1:30,000	2,500	5,400	2,160	3,780	1.0459	0.2929	669.4	187.5	3	6
1:31,680	2,640	5,702	2,281	3,991	1.1664	0.3265	746.5	209.0	3	6
1:40,000	3,333	7,200	2,880	5,040	1.8597	0.5207	1,190.2	333.2	2	4
1:45,000	3,750	8,100	3,240	5,670	2.3535	0.6591	1,506.2	421.8	2	2
1:50,000	4,167	9,000	3,600	6,300	2.9057	0.8135	1,859.6	520.6	2	2
1:55,000	4,583	9,900	3,960	6,930	3.5160	0.9844	2,250.2	630.0	2	2
1:60,000	5,000	10,800	4,320	7,560	4.1841	1.1716	2,677.8	749.8	2	2
1:63,360	5,280	11,405	4,562	7,984	4.6660	1.3065	2,986.2	836.2	2	2
1:75,000	6,250	13,500	5,400	9,450	6.5377	1.8306	4,184.1	1,171.6	1	1
1:90,000	7,500	16,200	6,480	11,340	9.4145	2.6360	6,025.3	1,687.0	1	1
1:100,000	8,333	18,000	7,200	12,600	11.6226	3.2543	7,438.5	2,082.8	1	1
1:125,000	10,417	22,500	9,000	15,750	18.1604	5.0848	11,622.7	3,254.3	1	1
1:126,720	10,560	22,810	9,124	15,967	18.6641	5.2259	11,945.0	3,344.6	1	1
1:150,000	12,500	27,000	10,800	18,900	26.1510	7.3223	16,736.6	4,686.3	1	1
1:200,000	16,667	36,000	14,400	25,200	46.4906	13.0176	29,754.0	8,331.3	1	1
1:250,000	20,833	45,000	18,000	31,500	72.6415	20.3396	46,490.6	13,017.3	1	1

recommendation of the Mark Hurd engineering department, a small moist sponge is placed in each magazine to raise the humidity.

- *Identification of the various lens-camera body-magazine-plate position combinations was necessary.* Each lens, camera body, magazine and plate position was numbered. Each magazine format was notched to identify the camera and magazine on the negatives and each camera body has specific lenses and magazines permanently assigned to it.
- *Streaking sometimes occurred throughout the length of the 60-exposure roll.* These were traced to physical damage inflicted by a number of faulty cassetts. The cassetts were also found to have serious light leaks, thereby precluding the loading and unloading of magazines while airborne.
- *Although the cameras are internally powered, 24-volt direct current was required for tripping the relay.* This can be provided either from the aircraft's electrical system or a series of 6-volt lantern batteries. It should be noted that since this unit was developed, Hasselblad has begun marketing a centrally-controlled multiple shutter release system relying only upon the batteries of one of the cameras for power.
- *The lenses were not calibrated for B&W infrared film.* A preliminary bench test indicates that the optimum focus setting for B&W infrared, depending upon the lens-filter combination, may be anywhere from one to 16 millimeters circumferentially removed from the visible infinity mark.
- *Considerable calculation is required to determine scale, flying height, exposure intervals and area coverage.* Tables 1, 2 and 3 provide the solutions for most situations.
- *The camera focus ring may move off the desired setting due to aircraft vibration.* To prevent this, the ring is taped before takeoff.
- *Magazine malfunctions are not uncommon.* Occasionally during a run, a magazine will malfunction for no apparent reason and during a rerun it may suddenly, and just as mysteriously, begin to function properly again. This is a characteristic of some particular magazines more than others and no amount of care and precautionary measures with regard to electrical contacts, dust, latches, etc., seems to prevent it completely. Magazines having this tendency receive the *lemon* label and are placed in a standby category—a painful solution, to say the least, in view of the very substantial initial cost per magazine.
- Film processing was initially accomplished with individual channel-feed load 70-mm. developing reels. Threading the reels was very slow and the film sometimes inadvertently slipped out of the channels and was improperly developed as a consequence. A four-roll tank and flat-load reel assembly is now being fabricated by Mark Hurd Aerial Surveys.
- *Because there was a need to view stereoscopically*

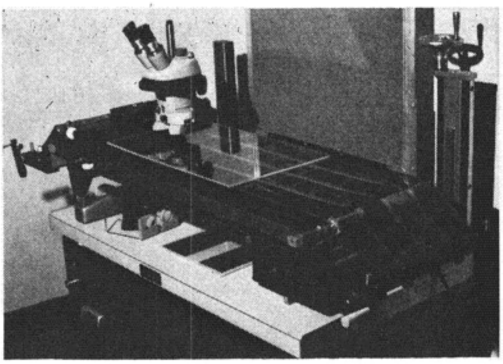

FIG. 7. Light table with four films displayed on a four-reel spool. Four spools of 70-mm. film can be viewed and compared effectively with this setup.

and compare four film strips in a side-by-side situation, a special light table was needed. The available Richards GFL 940 MC table normally accommodated only two 70-mm. reels simultaneously. To remedy this, a four-reel spool was built from $\frac{3}{8}$-inch galvanized pipe and $1\frac{3}{4}$-inch outside-diameter fender washers. The pipe was cut into 12-inch lengths and both ends notched to fit the roller pivots. The $\frac{3}{8}$-inch inside diameter washer centers were drilled out to $\frac{1}{2}$-inch diameter, spaced $2\frac{7}{8}$-inches apart, and soldered onto the pipe. Although the table width is minimal, acceptable comparison and interpretation of four films can be accomplished (Figure 7).

- *Neither magnitude of camera component prices nor brand name constitutes an absolute guarantee of mechanical or optical functionality upon delivery.* Every lens, camera body and magazine should be tested upon receipt. In the case of the School of Forestry camera components, one camera body was delivered in mechanically defective, unserviceable condition—a situation not discovered until the calibration run had been set up and contracted. Weeks of expensive waiting, frequent telephone calls and a blizzard of frantic correspondence were required to finally get the unit back into service.

CONCLUSION

Many research workers in the remote sensing field will probably agree that a below-$10,000 development cost of a 70-mm. quadricamera system is not unreasonable. Nevertheless, this represents a considerable sum and it is important for those who possess both the inclination and the necessary budget, to realize at the outset precisely what it is they are, and are not, getting for their money. Such a unit is no multispectral reconaissance panacea but it does offer many capabilities over the standard mapping camera and has proven to be a very useful resource analysis tool.

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