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A New Panoramic Camera Development

A continuously rotating lens and synchronously driven focal plane shutter have high reliability and favorable dynamics.

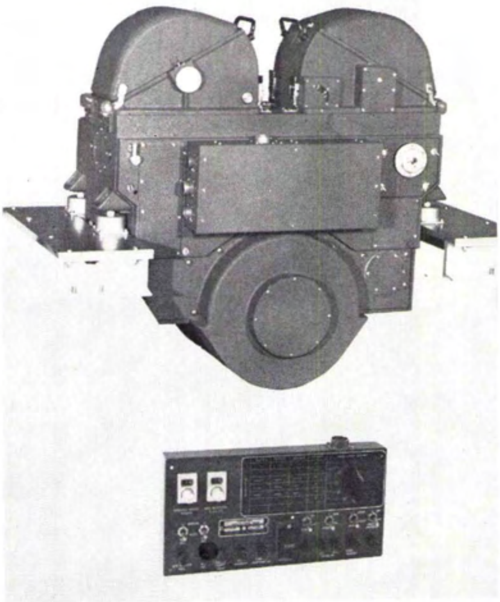

Fig. 1. The F-638-120 Panoramic Camera with Control Unit.

(*Abstract on page 170*)

Introduction

The model F-638-120 camera was conceived by Fairchild Space and Defense Systems to fill the need for higher acuity imagery during high altitude, high speed tactical reconnaissance missions as well as higher reliability under field conditions where limited service facilities are available.

Panoramic cameras currently in use for this type of reconnaissance are generally of the stationary film, reciprocating lens (stovepipe) configuration, or the rotary prism, moving film design. The reciprocating lens cameras have high resolution capability but, due to the unfavorable dynamics, have slow cycling rates and limited reliability. Rotary prism, moving film panoramics provide high cycling rates but are more generally used in low altitude applications.

The F-638-120 camera, shown in Figure 1, is a 12-inch focal length, stationary film panoramic camera which uses the principle of a continuously rotating lens together with a unique synchronously driven, focal plane shutter. This design combines the high resolution capability of the stationary film type of panoramic camera with the high reliability inherent in the favorable dynamics of continuously rotating elements.

Historical Background of Development

In 1965, Fairchild Space and Defense Systems produced a prototype version of the new panoramic camera as a company-funded development. The experience gained in the design of the KA-56 rotating prism camera for the Air Force, and the KA-54 rotating lens panoramic camera developed for the U. S. Army Electronics Command, was applied to the new design. However, the design approach was considerably different and incorporated the principle of a rotating lens in synchronization with a continuously rotating focal plane shutter. The prototype camera was test flown in February of 1965 and successfully demonstrated its higher resolution and better reliability.

In 1966, Fairchild was awarded a contract to design and fabricate a production version of this prototype camera for the Air Force.

* Presented at the Annual Convention of the American Society of Photogrammetry, Washington, D. C., in March 1967.

Flight Test Evaluation

A quantity of F-638-120 camera systems are currently undergoing extensive flight testing in the field. Flights have been flown over the Fort Huachuca Proving Ground resolution range with the camera mounted directly to the aircraft structure through its vibration isolators. No stabilized mount is provided in the installation.

Using EK 3400 film, dynamic resolution of 118 lines/mm. has been attained during these flights and is illustrated in Figure 2. No tests have been performed as yet with finer grain film, such as EK SO 206, or the high-definition aerial film EK 3404.

ABSTRACT: *The Fairchild F-638-120 panoramic camera has a focal length of 12 inches (f/3.8) and the negative size is 4.5 by 25.2 inches. This is a stationary-film camera which has a continuously rotating lens together with continuously moving shutter and capping curtains driven synchronously, allowing rapid cycle rates. The system includes forward motion compensation coupled with the velocity-altitude ratio provided from the airplane cockpit. A choice of 12 or 56 percent forward overlap is provided. Resolutions of 118 lines per mm. have been obtained at 18,000 feet altitude. The angular field coverage is 21° by 120°. Using Estar 5-inch thin-base, perforated film, the capacity is 2,000 feet or 900 frames.*

The flight test program has demonstrated the high quality of the photographic imagery produced by the F-638-120 camera system. Typical photographs taken during these tests are shown in Figure 3.

General Camera System Description

The main components of the camera are two interchangeable film cassettes, the camera body and junction box, and the camera control panel. The camera is designed to provide a photographic scan angle of 120°. A 12-inch, $f/3.8$ high acuity lens produces a photograph on 5-inch perforated film 25.2 inches long by 4.5 inches wide. The film capacity of the cassettes is 2,000 feet, which permits exposure of approximately 900 frames. The camera functions in autocycle mode, which means that the camera runs continuously at a cycling rate to permit picture taking of the ground strip to assure complete ground coverage with proper overlap. This is accomplished with a speed servo system that cycles the camera as a function of aircraft velocity and altitude in a relationship known as V/H. This V/H command can be automatically provided to the camera system by the aircraft system or manually fed into the camera from the cockpit control panel. Either 56 percent or 12 percent overlap can also be manually selected. The forward motion of the aircraft with respect to the ground during photography requires forward motion compensation (FMC) to realize maximum photographic performance. This forward motion compensation is provided in the camera system using the aircraft's velocity and altitude (V/H) command. Both manual and automatic exposure control features are included.

A summary of the camera characteristics and parameters is given in Table 1.

Lens Performance

The photographic objective utilized in the F-638-120 camera is a 12-inch, focal, length $f/3.8$ lens designed and manufactured at Fairchild Space and Defense Systems' optical facility in El Segundo, California. It is an eight-element semi-apochromat in double Gauss configuration covering a 21-degree full field of view with approximately 75 percent axial transmittance, a relative illumination substantially determined by the cosine-fourth law. The control of transmission and relative illumination in the design of the lens yields an area-weighted average T-number of 4.7.

Particular attention was directed to the rear nodal point position of the lens because of its importance in a spinning lens panoramic camera. To this end the lens was designed with the rear nodal point as close to the center of gravity as possible. The distance from the rear node to the front and rear vertices was also kept as small as possible to keep the camera compact and to minimize the lens drum inertia.

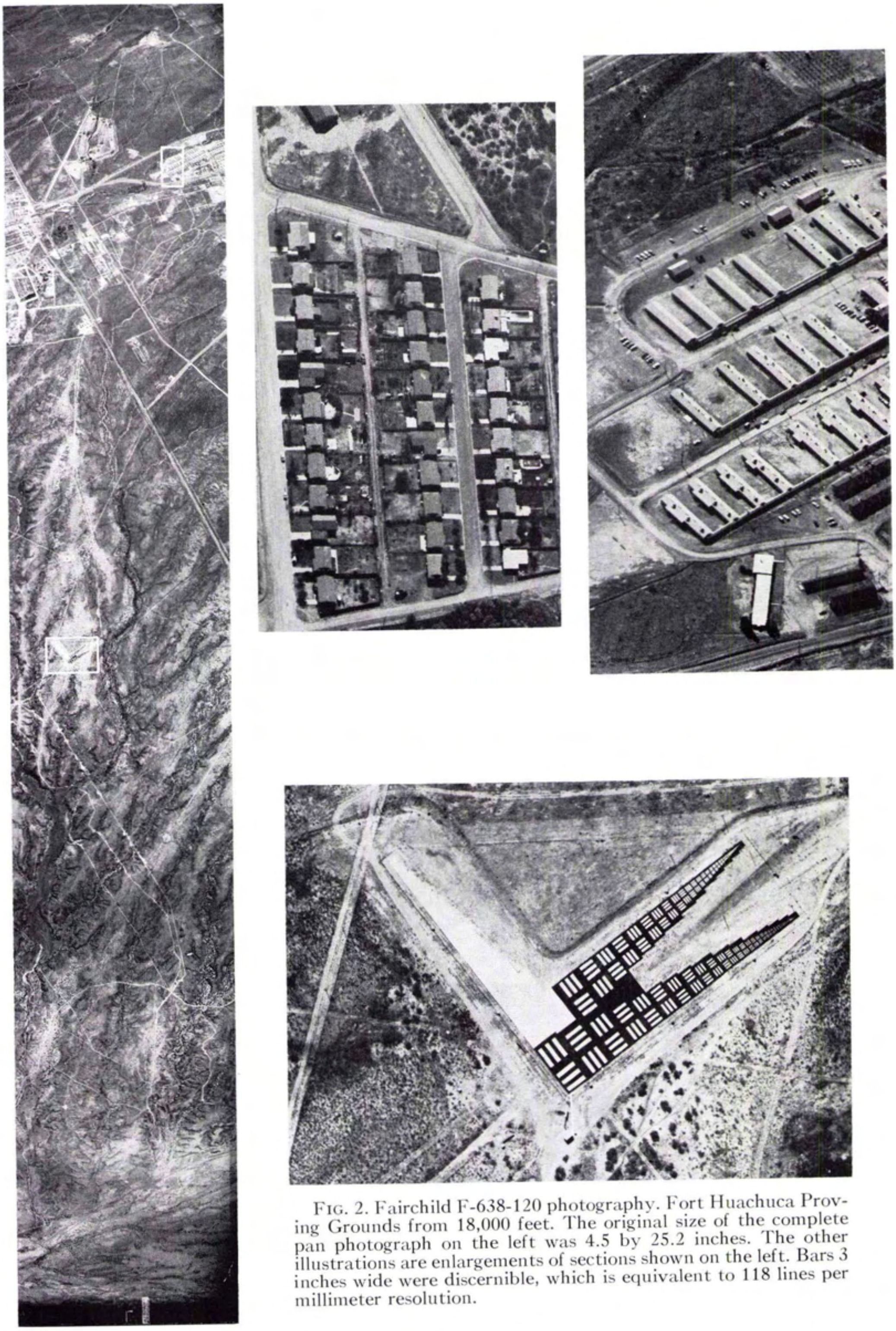

FIG. 2. Fairchild F-638-120 photography. Fort Huachuca Proving Grounds from 18,000 feet. The original size of the complete pan photograph on the left was 4.5 by 25.2 inches. The other illustrations are enlargements of sections shown on the left. Bars 3 inches wide were discernible, which is equivalent to 118 lines per millimeter resolution.

FIG. 3. Similar to Figure 2, Tucson, Arizona, is shown as taken from 18,000 feet with enlargements as indicated.

TABLE I. SUMMARY OF CAMERA PARAMETERS

Lens	12-inch $f/3.8$
Mode of operation	Autocycle
Angular coverage	21° longitudinal×120° lateral scan
Format size	4.5×25.2 inches
Film	5 inches by 2,000 feet, Estar thin base, perforated (approx. 900 frames)
Overlap	56% and 12% (selectable)
Cycle rate	0.10 to 1.17 cps (56% overlap) 0.05 to 0.58 cps (12% overlap)
Platen	Vacuum type
Aperture range capability	$f/3.8$ to $f/22$, continuous
Aperture operational range	$f/3.8$ to $f/7$, continuous
Relative shutter speed	1/30 to 1/12,000 sec (mechanical capability) 1/70 to 1/2,100 sec (operational range)
FMC range	0.2 to 2.3 inch/sec
V/H range	0.017 to 0.192 rad/sec
AEC range	300 to 5,000 foot-lamberts with Wratten No. 21 filter
Data recording	Frame counter, data card and clock
Power requirements	28 VDC; 5 amps max. 115 VAC; 5 amps max.
Camera weight	188 pounds (less film load) 8 pounds (Junction Box)

ROTATING LENS DRUM–SYNCHRONIZED-SHUTTER FEATURE

In the F-638-120 camera, panning is achieved by rotating the lens about its rear node on an axis perpendicular to the optical axis and imaging on a curved focal plane concentric to the axis of lens rotation. To accomplish shuttering, a curtain with a suitable slit opening wide enough to cover the format width is moved in synchronism with the lens rotation in an arc concentric with and close to the focal plane radius. The geometric center of the slit is intersected by the optical axis. During exposure the film is held stationary against the focal plane while the curtain carrying the exposure slit traverses the film essentially like any focal-plane shutter.

As the camera operation is autocycle, the shutter curtain and lens drum rotate at a speed proportional to the camera cycling rate. In order to permit the use of the highest possible shutter speed, regardless of cycling rate, a series of varying width slits are provided in the shutter curtain and the optimum slit is selected during photography.

All of these essential picture-taking elements are located in the camera body. The lens drum, containing lens, lens carriage, and diaphragm assembly, is mounted on pivots in two ball bearings located in the body housing. The drum construction affords a convenient means for light-sealing the rotating lens to the camera body. The lens is located so that the rear nodal point is coincident with the spin axis of the drum. The drum is driven by the main motor gear drive assembly at a speed ratio compatible with a V/H signal which controls the main drive motor RPM.

The platen assembly, which locates the film plane during the photographic portion of the camera cycle, is accurately doweled in position on the camera body so that the platen radius is concentric with the spin axis of the drum assembly.

The focal plane shutter curtain has perforations along its edges and contains a series of varying width rectangular shutter slits. The curtain is sprocket driven by the main

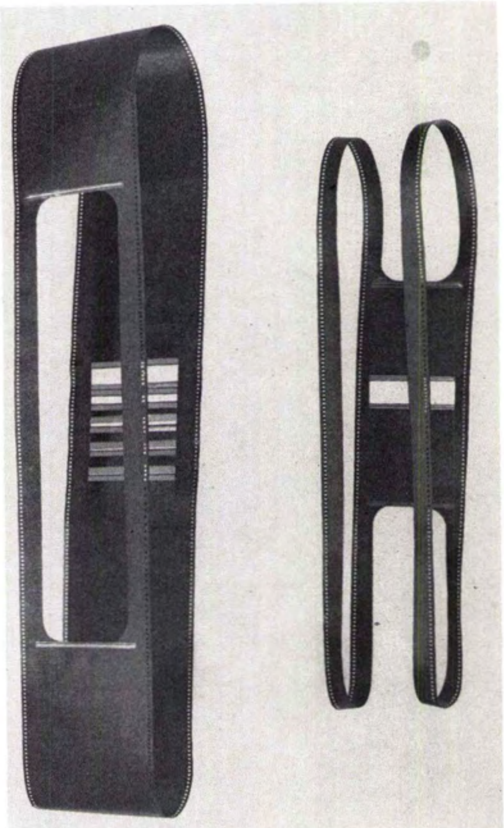

FIG. 4. Shutter curtain (left) and capping curtain.

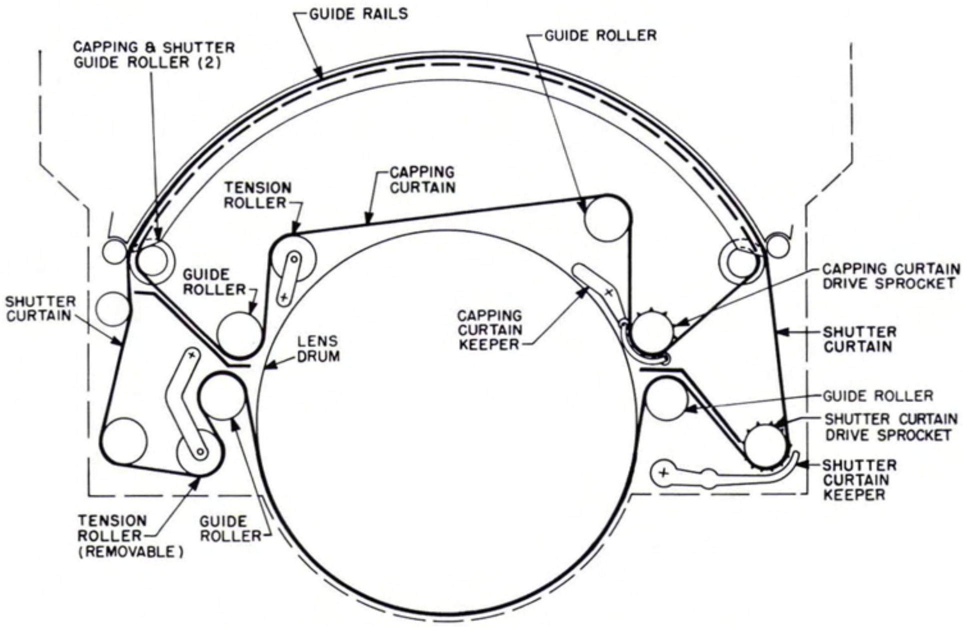

FIG. 5. Path geometry of shutter and capping curtains.

motor drive assembly. The curtain length and the gear ratio are designed so that the curtain slit transverses the format in synchronism with the lens and makes one revolution for each drum revolution. To provide the most suitable curtain path geometry, the curtain passes around the drum assembly and in front of the lens. A large opening is provided in the curtain to prevent capping of the lens during the photographic scan portion of the camera cycle.

Another continuously rotating capping curtain is located in front of the shutter curtain and its path lies between the platen and the lens drum. The capping curtain has one slit slightly wider than the largest slit in the shutter curtain, and performs the function of masking all the shutter curtain slits except the one desired for the proper exposure. A large opening is also provided in the capping curtain to avoid capping the lens opening during photography. The capping curtain has perforations along its edges and is driven by sprockets geared to the main motor scan drive at a fixed ratio with the shutter curtain. Figures 4 and 5 indicate the curtain configuration and the curtain path geometry.

In a typical camera cycle with 56 percent overlap, the photographic scan portion of the cycle occurs during every third revolution of the lens drum when the capping-curtain slit is in synchronization with the selected shutter-curtain slit and the lens optical axis. The photographic portion of the cycle occurs during every third drum and shutter curtain revolution in order to provide reasonable size shutter slits in the shutter curtain for the range of shutter speeds desired.

To prevent exposure of the film through the curtains during the two drum revolutions when camera scanning is not desired, the diaphragm assembly in the lens drum is closed by an electrical signal from a sequence-timer assembly geared to the main camera drive. Prior to the start of the scan or exposure portion of the cycle, the diaphragm is opened to a suitable aperture for proper exposure. Slip rings on the drum assembly provide the power to the diaphragm assembly for capping and diaphragm opening control.

If 12 percent overlap is desired for maximum ground strip coverage, a switch setting on the control unit electrically changes the pulse rate being generated at the sequence timer and gates the capping shutter in the lens so that an exposure can only be made every sixth rotation of the drum assembly.

FORWARD MOTION COMPENSATION

To provide forward motion compensation (FMC) during the photographic scan, a conventional technique used in other successful Fairchild camera designs has been incorporated. During the photographic scan the lens is moved in the direction opposite to the flight direction. The FMC velocity that is required must follow a trigonometric cosine wave to compensate for varying slant range as the film frame is being scanned. The lens is mounted to a carriage with motion parallel to the spin axis of the drum. Counter balance weights are mechanically linked to the carriage to eliminate torque reactions of the oscillating lens. A large bearing is mounted adjacent to and concentric with the drum assembly. The bearing is skewed so that it acts as a wobble plate on the lens, and the outer race of the bearing is fixed to the camera body. The inner race is free to rotate and is attached to a follower fixed to the lens carriage by means of a ball socket joint.

The lens rotates with the drum assembly about the flight axis and also oscillates along the flight axis because of the skew angle of the wobble bearing to which it is attached. The function generated by the oscillation along the flight axis is the same as the function required to generate an FMC velocity. The correct nominal FMC is achieved in the camera by setting the skew position of the FMC bearing to a fixed angle and varying the drum speed as a function of velocity and altitude (V/H) by a signal voltage to the variable speed camera motor.

The FMC mechanism is extremely simple and provides a high degree of reliability with exceptional accuracy due to the fact that it is mechanically linked to the rotating lens. The constant speed rotation of the lens drum assembly and the shutter curtains during camera cycling eliminates the high dynamic acceleration and load forces normally encountered with the oscillating-stovepipe type panoramic cameras. As a result, the life expectancy of the moving parts is greatly extended and higher reliability is furnished than in previous cameras. In addition, degrading effects of torque and force reactions in the camera are minimized.

The camera body is designed for simple replacement of the shutter curtains at periodic intervals to maintain the high reliability feature. To replace the curtains, the junction box and a side plate are removed exposing the curtain paths for threading. Suitable timing marks and holes are incorporated for proper phasing of the curtains during replacement. No special tools are required for this operation.

Exposure Control

The control of exposure in the camera is obtained by the selection of the slit size in the shutter curtain combined with the adjustment of the diaphragm opening in the lens. The automatic exposure control (AEC) system is designed so that the minimum possible slit width and the maximum diaphragm opening are automatically selected. This insures that all photographs are exposed at maximum shutter speed and image degradation caused by image motion is minimized.

The AEC slit motor is geared to the shutter curtain and capping curtain drive sprockets through a gear differential. When the servo commands a change in slit width, the shutter curtain is displaced through the gear differential the required amount so that the proper slit is centered above the capping-curtain slit. At the same time, a servo motor in the diaphragm control assembly drives an arm mechanism to the proper angular position to control the diaphragm blades such that the correct opening compatible with the slit selection is obtained during photographic exposure.

The AEC servo system corrections are made only in the portion of the camera cycle when the lens is capped and no exposure is being made.

Film Handling Technique

Figure 6 indicates the basic film path used in the camera. Two interchangeable film cassettes are provided for supporting the supply and take-up spools. The cassettes are designed to hold a maximum of 2,000 feet of 5-inch wide, thin base film. No film transport clutch or brake mechanisms are located in the cassettes thereby minimizing the weight and complexity. In addition, the cost of necessary spare cassettes for logistic purposes is considerably reduced.

The major portion of the film transport system is located in the camera body. The system consists of a series of guide rollers, two sprockets belted together and driven by the main drive motor, a shuttle-roller assembly, and a film-brake roller assembly. A drag brake is provided to maintain proper tension at the supply spool. The take-up spool is driven through a slip clutch located in the body and powered by the main drive motor.

A fixed length of film is threaded between the two film sprockets. The film passes from the supply cassette through the supply sprocket and around the shuttle roller assembly. The film is guided under the platen within two film guide rails. At the take-up side the film passes through the pair of brake rollers, around the shuttle roller assembly and through the take-up sprocket assembly to the take-up cassette.

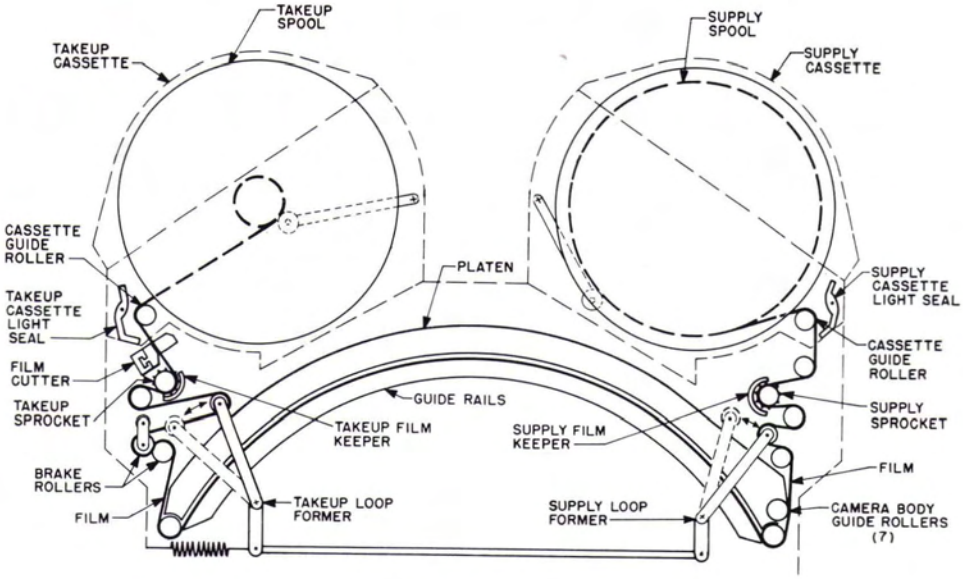

FIG. 6. Film path diagram.

During camera operation, the film sprockets drive the film from the supply cassette through the camera body to the take-up cassette. The brake-roller assembly stops the film in the platen area during the photographic scan portion of the camera cycle while the shuttle mechanism allows the film spools to run continuously during this period by automatically adjusting the loop in the film path.

A built-in vacuum pump is provided in the equipment to flatten the film against the curved platen during exposure. The film is held against the curved platen by applying vacuum through a series of slots. A high speed solenoid valve is located in the vacuum line between the pump and the platen. The valve is controlled by the sequence timer so that vacuum is applied at the platen prior to the start of the photographic scan in adequate time for flattening. The valve is de-energized at the end of photographic scan.

In order to minimize the complexity of film threading during reloading, several features have been included in the camera design.

The film cassettes are equipped with a simple tripping device linked to the film-footage indicator arm, which actuates a switch in the camera body and shuts off the camera when a minimum of approximately 10 to 20 feet of film remains on the supply spool. This prevents the film in the camera body from being wound in the take-up cassette when the film supply is exhausted. Thus, when the camera is reloaded, film from the supply spool is spliced to the film remaining in the camera body, and the necessity of rethreading film through the body is avoided.

A film cutter is built into the body to cut the film when the take-up cassette is removed. An additional splicing device is furnished with the camera to cut and splice supply film to the film threaded in the camera body.

DATA RECORDING

An Accutron* watch, frame counter, and data card are recorded in the space between frames. The recordings are imaged through two small recording lenses. Illumination is provided by incandescent lamps energized during the scan portion of the camera cycle by the sequence timer in the camera body. Sufficient space in the camera design permits the incorporation of a CRT, or the advanced Fairchild solid state data annotation system, if desired.

Small markers are recorded along the edges of the film to locate the center of scan (nadir) of the photograph and the direction of flight.

CAMERA CONTROL SUBSYSTEM

The F-638-120 controls may be divided into the following functional groups:

1. Camera timing
2. Scan velocity control servo
3. Automatic exposure controls
   a. Slit servo
   b. Aperture servo
4. Power supply

* Req. TM Bulova Watch Co., Inc.

All the controls have been modularized to the greatest extent possible to assure maintenance down-time is kept to a minimum.

During the design of the camera, the requirement for a more complex electronic subsystem in camera controls created a need for miniaturization in order to keep the size within practical physical bounds. In addition, the need for greater reliability became more important due to the large number of components involved. The development of solid state techniques and miniaturized passive elements have made considerable size reduction and performance improvements possible. Unique packaging arrangements, whereby miniaturized parts are combined into miniature circuits, have succeeded in accomplishing large size reductions.

One circuit miniaturization is the silicon integrated microcircuit. These microcircuits fulfill all the miniaturization and reliability requirements of the modern aerial camera and are produced by proven Planar methods developed by the Semiconductor Division of Fairchild Camera and Instrument Corporation and are capable of producing both linear and digital circuits.

Essentially the integrated microcircuitry consists of a compatible set of digital functional blocks in which transistors and resistors are combined via the Planar process into a single chip of silicon. They are designed to operate in a full military environment and have been employed wherever possible in the F-638-120.

Camera Timing

The primary timing component in the camera is the sequence timer. The assembly consists of a disc located in the camera body and driven by the main drive motor through gearing to provide a fixed ratio with the lens drum. Switching is accomplished by the use of one of the newly developed light-sensitive semiconductor devices which improves switching reliability over the conventional mechanical contact-type switches. Mounted on one side of the disc are lamps and on the other silicon diffused junction PNPN photocells. The disc contains a series of slots which permit light to be applied to the photocells intermittently. The angular orientation of the slit on the disc controls the timing and duration of the pulses required for the necessary camera operation.

Scan Velocity Control Servo

A simplified block diagram of the scan velocity control servo is shown in Figure 7.

The control panel V/H selector switch selects whether the V/H input voltage from an external V/H sensor or the V/H voltage produced by the ground speed control and altitude control is applied to an operational amplifier. The operational amplifier multiplies this voltage and applies it to a summing network. The summing network also receives an output voltage generated by a tachometer which is proportional to the speed of the camera drive motor. If these two voltages are not equal, an error voltage is produced. This error voltage is converted to square waves by a chopper and is applied through a phase splitter to power amplifiers. The width of the square waves is proportional to the error voltage. The amplified output of power amplifiers is applied to a pulse forming network which regulates the ac excitation

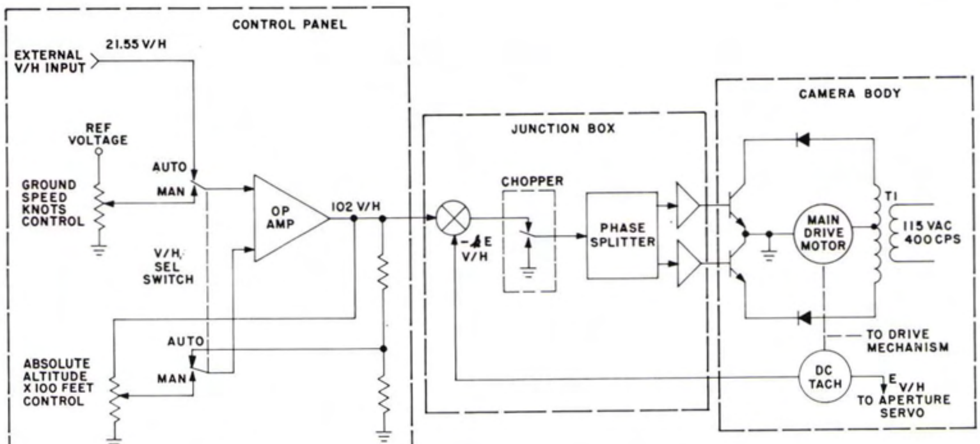

Fig. 7. Scan velocity control servo diagram.

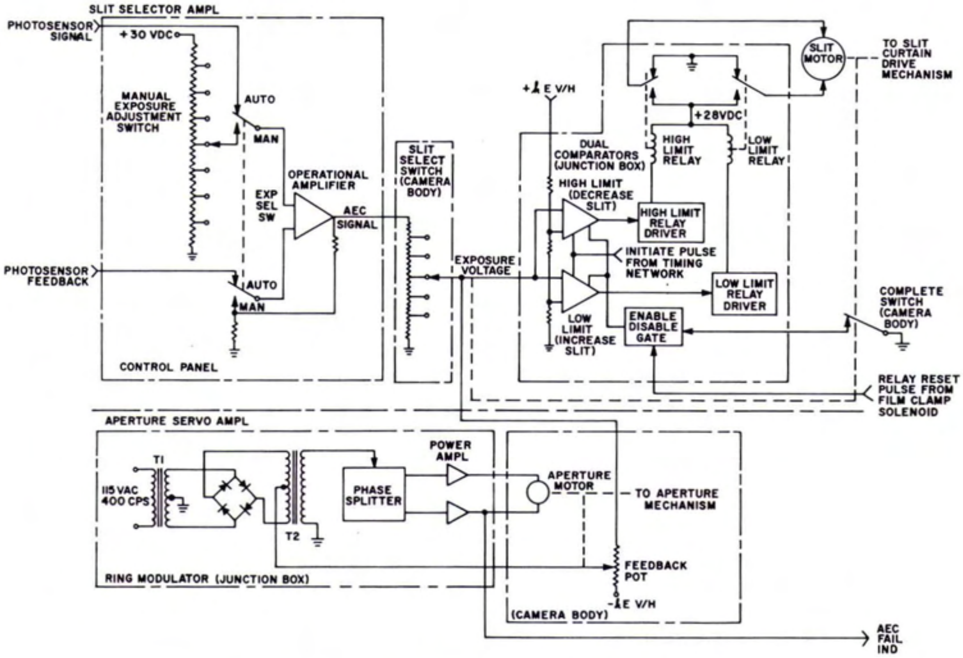

FIG. 8. Automatic exposure control circuit diagram.

coupled through transformer *T1* to the camera drive motor, thereby controlling the motor speed. When the tachometer voltage is nearly equal to the V/H voltage output of the operational amplifier, the error voltage from the summing network is small and just sufficient for the motor to be driven at a constant rate by the ac voltage coupled through transformer *T1*.

Automatic Exposure Control

The automatic exposure control (AEC) circuits, which are shown in simplified schematic form in Figure 8, provide coarse and fine adjustments for camera exposure. The coarse control is accomplished by a slit select amplifier which selects one of five slit widths located on the shutter curtain. The fine adjustment is accomplished by an aperture servo amplifier which adjusts the aperture mechanism. The slit-select amplifier compares the exposure signal from either a control-panel manual exposure adjustment switch or the camera-body photosensor to a voltage which is proportional to the aircraft's velocity and altitude (V/H). These two voltages are compared, and if they differ by a fixed ratio, an error voltage is generated which drives the slit motor in the appropriate direction to change the slit curtain position, thus selecting the proper slit width. The aperture servo amplifier also compares the exposure signal to a V/H voltage to properly position the aperture.

Power Supply

The power supply converts the aircraft power for the control elements wherein stability, regulation, and ripple tolerance are critical. This power supply is composed of replaceable modules and also includes provisions for adequately decoupling all critical amplifiers.

Conclusion

The F-638-120 panoramic camera fulfills the requirements for a high-acuity photographic system with wide-angle lateral ground coverage and fast cycling rates. It offers the additional bonus of high reliability combined with long operating life so essential to successful operation in unfavorable field environments.