run on this equipment in Italy and it was found that the error could be held to a mean of approximately 45-feet horizontally and vertically, using the equipment then available. While this accuracy would not be sufficient for some vertical operations, the results show that this equipment could have been used in the 1:250,000 program where only 200 foot contours were required. We believe that if this equipment had been used, a more accurate and economical product would have resulted in many instances. There is now being conducted in Europe, additional tests with the improved version of the 1951 equipment. The results will be made public at the International Meeting next June and it is our opinion that many of you will be amazed by the results of these experiments as regards accuracy.

There is being carried on in this country, at the present time, tests of the use of radar photography in connection with contour mapping. These experiments have not yet progressed to a completely satisfactory operational stage. However, we feel certain that in the future radar photography will be utilized in doing a considerable amount of certain types of mapping. I hope to live and work until this becomes a reality as I certainly should like to avoid having to call the weather bureau to find out whether the day will be satisfactory for photographic operations.

Of course many new techniques are being developed which are related in some way to our field. The future of photogrammetry is tied very closely to electronics in many ways and will be greatly affected by the development of new electronic devices. All engaged in this work should give full consideration to the possibilities of electronics in connection with our profession.

In conclusion I ask each of you to keep in mind at all times that the future of photogrammetry is in your hands. Photogrammetry will have a successful future if the general public and the users of our products have confidence in our ability and integrity.

INTEGRATED PHOTO RECONNAISSANCE SYSTEM FOR HIGH PERFORMANCE AIRCRAFT*

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ABSTRACT

Results of a research and development program conducted by Fairchild Camera and Instrument Corporation and directed toward evolving a photo reconnaissance system of advanced capability are presented. Emphasis has been placed on analyses of alternate approaches with final selection guided by technological factors inherent in new high performance aircraft design.

RECENTLY, Fairchild Camera and Instrument Corporation has been engaged in the development of a complete, integrated airborne photo reconnaissance system applicable to advanced high performance aircraft. As a primary capability this system was to provide military reconnaissance of large areas from high altitude, recording major detail with supplementary coverage of selected smaller areas in fine detail. As a secondary capability, in the event weather conditions precluded reconnaissance from high altitude, the system was to provide coverage of relatively small areas in fine detail from low altitude.

Before any design was attempted a careful analysis was made giving consideration to mission requirements, airframe problems and characteristics, capabilities of existing equipment and the improvement which is feasible within a reasonable time period.

Major objectives included reduction of size, weight and power consumption to a very minimum, attainment of maximum information recording ability and maximum potential reliability.

* Paper read at Society's Semiannual Convention and Trade Show, Statler Hotel, Los Angeles, Calif., Sept. 8, 1955.

Preliminary System Research

In order to guide engineering decisions, many new studies and investigations were undertaken. To attain the maximum information recording ability, studies were directed into the various factors affecting system resolution and contrast. Analyses were made of the various types of motion which could be expected, and investigations were then made into several of the more promising ways of reducing or eliminating these motions at the time exposures are made. In each case, the complexity, size and weight of all of the equipment associated with the function, and the accuracy and performance that could be predicted, were compared with similar factors in alternate methods. Laboratory tests were made of controlled moving resolution targets to determine under actual conditions the amount of image degradation. Other tests were performed to determine quantitatively the effects of different air temperatures and temperature gradients, and the rates of change of these factors on the resolution of the various cameras. Investigations were made into the relationship between accuracy of exposure control and resultant resolution and contrast. Likewise, the effects of internal reflections within the optics and cameras were investigated. Test programs were then conducted to reduce and control internal reflections and unwanted non-image forming light.

In evaluating the usefulness of several of the features, statistical analyses were compiled to determine the relationship between the magnitude of improvement or advantage provided by the feature and percentage of flight time this advantage would be realized. This information was then used, in conjunction with design analyses of weight, bulk and complexity of the apparatus required for the feature in order to reach final decisions on equipment design.

The system finally evolved represents an optimized system of considerably advanced equipment. High altitude coverage of large area is provided by a tri-camera arrangement of 6-inch focal length 9×9 inch format cameras. Detailed spot coverage of selected limited areas is provided by a multiple camera group of three 36-inch focal length 9×18 inch format cameras. In each group one of the cameras is mounted with its axis vertical, and the other two are mounted as side obliques to cover the area immediately adjacent to that of the vertical camera. The 6-inch camera group is designed for a wide range of operation so that it may be used at low and intermediate altitudes, as well as at high altitude. For supplementary use at low altitudes, a 3-inch focal length $2\frac{1}{4}\times2\frac{1}{4}$ inch format camera is mounted in a forward looking oblique position.

Each camera group may be selectively controlled. A central control system provides the means of controlling the image motion and cycling rate for each group operating from automatically generated input data representing altitude above terrain and ground speed. Similarly, the central control system senses the terrain illumination and supplies signals for automatic control of the exposure settings for all cameras of the system on the basis of this information.

The entire long focus multi-camera group and the prime vertical of the 6-inch focal length tri-camera group are mounted in stabilized mounts to hold the cameras steady during exposure to produce the highest possible resolution. A viewfinder of the closed circuit television type is also included to give the photo navigator a view of the terrain below and ahead of the aircraft.

The design of all cameras in the system is integrated and coordinated with ground based photo processing equipment, to facilitate processing of the exposed negatives in the shortest amount of time. The equipment has also been designed for use in conjunction with coordinated data recording equipment providing the basis for automatic correlation between each negative exposed and the data pertinent to it so that finally, fully titled prints can be delivered to the photo interpreter.

In the evolution of this complete system, Fairchild has worked with several other organizations. Aeroflex Laboratories have engineered the stabilized mounts; the television viewfinder has been engineered by the Norden Laboratories Corporation; and photo ground processing equipment for use with the system, by Eastman Kodak Company.

The system provides conventional camera sizes and ground coverage. However, in the various components are revealed many of the new design features and techniques associated with the meeting of the objectives.

Cameras

The 9×9 inch camera of this system is the new Fairchild F-401 General Purpose Camera. This is a combination charting and reconnaissance camera of extremely lightweight construction with a 6-inch F/6.3 Metrogon lens and a drawer type shutter. It has been designed for an extremely wide range of operating speeds to permit its use at both high and low altitudes. It has a one-piece inner cone carrying the optics which permits removal of the shutter without disturbing the lens mounting. An interchangeable lens cone equipped with a Planigon lens can be provided. Provisions have been made for fully automatic control of exposure settings, cycling rate and image motion compensation. It records directly on film code marks for correlation of data recording. The magazine is built for direct feed of the film into the processing equipment.

Principal features of the camera include the following:

- Lightweight construction—total weight of camera and magazine, but without film, is approximately 49 pounds.
- High efficiency Rapidyne shutter with continuously variable shutter speeds of 1/50 to 1/700 second.
- Servo-controlled aperture settings from F/6.3 to F/11.
- Lightweight magazine with capacity of 500 feet of standard 9½ inch aerial film.
- Image motion compensation up to 16 inches/second.
- Minimum dynamic reactions from operation of internal mechanisms.
- Integral camera drive and exposure control amplifiers.

The camera is a complete operating unit and requires only power and input intelligence for operation.

The Fairchild Model F-402 camera was designed for this system to provide detailed spot coverage with high resolution from high altitudes. This is a 9×18 inch format reconnaissance camera of extremely lightweight construction with a special lightweight 36-inch F/8.0 telephoto lens. Provisions have been made for fully automatic control of exposure settings, cycling rate and image motion compensation. It records on the film, at time of exposure, code marks for correlation of data recording. The magazine is built for direct feed of the film into the processing equipment.

Principal features include the following:

- Extremely lightweight construction—weight of camera and magazine without film is approximately 75 pounds.
- High efficiency Rapidyne shutter with continuously variable effective exposure times up to 1/550 second.
- Servo-controlled aperture settings from F/8.0 to F/22.
- Lightweight magazine with capacity of 500 feet of standard 9½ inch aerial film.
- Image motion compensation up to 3½ inches/second.
- Minimum dynamic reaction due to operation of internal mechanisms.
- Integral camera drive and exposure control amplifiers.

The camera is a complete unit and requires only power and input intelligence for operation.

A new camera, the Model F-404, has been designed for the forward looking oblique position. This camera is an impulse operated, fast cycling, lightweight reconnaissance camera using a high speed F/1.5 color corrected lens and 70 mm. film. A focal plane shutter of fixed slit width permits extremely high shutter speeds. Provisions have been made for fully automatic control of exposure and cycling rate. Code marks are recorded for data correlation. The magazine is built for direct feed of film into the processing equipment.

Principal features include the following:

- Cycling rates—up to 8 cycles/sec.
- High speed lens—3″ F/1.5
- Simplified high speed focal plane shutter with continuously variable shutter speeds 1/1,000–1/4,000 sec.
- Servo-controlled aperture and shutter speed
- Integral exposure control amplifier
- Magazine capacity of 250 feet of standard 70 mm. aerial film.

Control System

To achieve the goals of highest potential reliability and greatest reduction in weight and volume of the system components, several alternate treatments of the problem of controlling the equipment were investigated and compared. Out of this effort has evolved a system stripped down to the barest essentials. In the evolution of this equipment, emphasis on reliability has resulted in drastic reductions in the number of electronic components, such as tubes, and in the number of electrical connections and joints. The control system performs basically three control functions: (1) rate and synchronization; (2) exposure control; and (3) switching and signalling.

Control of the rates of operation of the cameras and synchronization of the cameras in each group is accomplished through the use of an input computer working in conjunction with a master synchro drive unit. The input computer is an electronic analog quotient computer taking ground speed and altitude information as inputs, and putting out a signal representing the ratio of V/H as necessary to compensate for image motion. This output information is fed simultaneously to all of the cameras of the system and to the central master rate control and synchro drive unit. This unit performs the functions of synchronizer and intervalometer and has been designated a synchrometer. It contains a variable speed drive which is made to follow the output of the V/H ratio and transmit positional or phase signals to the different cameras of each group to provide for their synchronization and simultaneous operation of their shutters. Also, tripping impulses are supplied to the pulse type cameras.

One of the new and basically different features of this system lies in the use of this synchrometer. Its use has been responsible for much of the gains realized in the direction of simplification, weight reduction and improved performance.

The exposure control function is accomplished through use of a light sensor and an exposure computer. The light sensor is mounted in the bottom of the aircraft and measures the brightness of the terrain below. The exposure computer takes the measured value, and from it provides isolated individual outputs representing light value to each camera group in the system. All of the other functions of exposure control, such as computing for film speed and filter factor and actual adjustment of the diaphragm and shutter speed setting, are handled in this system within each individual camera. The entire exposure control system has been greatly simplified and miniaturized and uses no tubes.

The functions of switching and signalling are accomplished, in a more or less conventional manner, through the use of the control panel and the junction box. Hand setting dials permit setting ground speed and altitude to permit operation of the equipment in the event of any failure in the automatic inputs. Furthermore, through the use of by-pass arrangements, emergency operation of all selected cameras is provided in the event of a failure or malfunction of any of the automatic units in the rate control system. Switches for power, and selection of camera groups, and indicator lamps to indicate correct operation of the different cameras in the groups, provide for complete operation of the system with the minimum of complexity and the minimum of attention on the part of the photo navigator.

Stabilized Mounts

As a result of studies of means of preventing serious loss of resolution in the case of 36-inch 9×18 multi-camera group, it was decided to mount the entire group in a stabilized mount. Accordingly and because of space and weight considerations, a high performance stabilized mount is provided which mounts three of these cameras together in a single mount, effectively isolating the camera equipment from airframe motions during exposure. Torquer type stabilization is used for this purpose. In order to keep performance maximum at all times, the entire stabilized assembly is kept continuously in balance through means of automatic weight shifters which compensate for transfer of the film and other unbalance effects. Maximum performance and lowest system weight have been achieved through use of the latest techniques in the art, combined with carefully coordinated design and integration with the cameras. Location and type of camera mounting points have been worked out to provide complete interchangeability and rigid stable support with minimum weight. Provisions have also been made for automatic connection of the electrical circuits and the vacuum line upon mounting of the cameras.

A stabilized mount is also used for the prime vertical 6-inch general purpose camera. Since this mount maintains a high order of vertical stabilization, it assures photography which may be used for photogrammetric purposes with minimum error due to unknown tilts. The mount stabilizes the camera throughout roll and pitch angles of ±8 degrees and compensates for drift angles up to ±15 degrees. This mount also automatically makes connection of the electrical circuits and the vacuum line when the camera is installed.

VIEWFINDER

The television type viewfinder provides the photo navigator with a view of the area below and forward of the aircraft. Two fields of view are selectively available to the operator—one a 40 degree field of view at approximately unit magnification, and the other a 10 degree field at approximately 4 times magnification. The optical system is stabilized for roll, pitch and relative azimuth. In addition, the navigator has control of line of sight and can scan from vertically downward, forward to the horizon, as well as through an angle of 45 degrees to the right or left. Use of the television type viewfinder results in maximum flexibility of installation, and also makes possible simplifications in stabilization of the line of sight.

As previously mentioned, this system was conceived to provide a solution for the requirements for high performance photo reconnaissance equipment or installation in modern, high density, high performance aircraft. The analyses have indicated a great similarity in the general characteristics of practically all of the advance aircraft and missile systems, insofar as they affect photo reconnaissance systems and equipment. It is due to this fact, and because of the high performance, light weight, low power consumption, reliability and automatic operation characteristics built into the equipment just described, that it is especially adaptable to the needs of present-day and future aerial weapons systems. The complete system, or portions, thereof, in various combinations or with slight modifications, are especially well suited for use in missiles or with the pod-mounted concept now being advanced for manned aircraft.

THE PLANIGON STORY*

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MOST of the Members of this Society have heard of the planigon lens. Many have seen it and know something about its design and capabilities. Only a few are familiar with the great effort required in the quantity production of this lens. I would like to tell you a part of the story of the organizations responsible for making the planigon lens militarily feasible. This is a success story with a happy ending, but there were many anxious moments. I will not attempt to mention the names of everyone who contributed toward the success of this lens because I fear that I might overlook someone whose efforts have equalled those with whom I am familiar.

A low distortion lens called the Topogon V was brought to this country from Germany in 1945 by an Army representative. It was turned over to the Air Force which, in turn, let a contract to the Bausch and Lomb Optical Company for study and analysis, and for determining if it could be produced in this country. Under this contract the lens was successfully analyzed and the formula determined. The formula was then modified so that standard American glasses could be used. As part of this contract, the Bausch and Lomb Optical Company made three lenses in each of three focal lengths—namely, four-inch, five-inch, and six-inch. Tests with these lenses were sufficiently convincing to cause the Air Force to negotiate with Bausch and Lomb and two other optical companies—The Curtis Laboratories of Los Angeles and The Goerz American Optical Company of New York City—for the quantity production of over seven hundred of these lenses.

* Paper read at the Society's Semiannual Convention and Trade Show held in Statler Hotel, Los Angeles, Calif., Sept. 7–10, 1955.