eliminating inertia lags and machining discrepancies inherent in a mechanical system. The electrical pulses energizing the trip magnets are obtained by means of a thyratron controlled R-C delay circuit. Discharging of two capacitors in a controlled sequence furnishes the *A* and *B* blade trip pulses. Shutter speeds are controlled by varying the delay between these pulses. This is done by manually varying the resistance values in a control box external to the camera. Changing these values varies the firing time of the thyratron circuit in the timer through which the *B* pulse capacitor discharges. A system of this type has the flexibility of not only remote control but may be coupled to an automatic exposure control servo. Precise Shoran synchronization is also made possible by obtaining output pulses simultaneously with the transmission of the *A* pulse to the trip magnet coils. A manually operated diaphragm on the camera is also provided on the shutter assembly to provide more flexibility in exposure.

Provisions are made on the inner cone assemblies for recording essential items of photographic and navigational data such as camera serial number, exposure number, time, flight altitude, fiducial marks, calibrated focal length, lens serial number, vacuum indication and a datacard. Two systems of recording have been incorporated. The first is by optical means in which the dial faces of the recording instruments are photographed on the film. The other system, which is electronic, utilizes a miniature cathode ray tube which projects a series of coded dots (binary system); this is a record of information fed into it from instrumentation located elsewhere on the vehicle. This system, therefore, contains the capability of automatic data processing from the film record. Sufficient duplication of pertinent alpha numeric data is done on both formats to provide positive correlation of the exposures in both magazines.

It is believed that the KC-2 camera is not only the finest in precision, engineered to cover the specific requirements of the convergent system, but has the basic advantage of having been developed as part of an integrated system. This system's development approach has made it possible to achieve the greatest saving in over-all weight and volume and allowed the various elements of the system to be completely compatible without compromise. Greatly improved photographic quality is expected with simplified maintenance and ease of set-up and operation.

*Torquer Stabilized Mount for Convergent Mapping Camera**

A. ROBERTS, *Staff Engineer,*
The Aeroflex Corporation,
Long Island City, N. Y.

ABSTRACT: *With the advent of high speed, high altitude and relatively small vehicles has come the requirement for light weight and compact reconnaissance equipment capable of high performance in these vehicles despite the extreme environmental conditions encountered.*

This paper presents the general design features and performance characteristics of what is believed to be the first piece of photo-reconnaissance equipment capable of operating reliably without altitude limitations and in widespread ambient temperature ranges. The basic design combines in a single package, the necessary stabilization system for high resolution and verticality, a new twinplex camera design (covered in another paper) and a specially designed thermal protector. Close liaison and agreement on camera tolerances and mount configuration has allowed

* Presented at the Society's 24th Annual Meeting, Hotel Shoreham, Washington, D. C., March 28, 1958.

thorough integration of functional unit designs into the over-all system. The tailoring of mount design to the specific camera, combined with the advanced component design and stabilizing techniques result in a system that is the ultimate in its compactness, light weight and capability of high acuity photography.

THE paper by Mr. Crouch† contains a discussion of the advantages of convergent photography, and the plans to make use of this method in a highly efficient mapping system. The details of the design and development of a new twinplex camera are covered in Mr. Levine's paper.† The author's paper discusses the development and design of the camera mount as an integral component in the over-all convergent mapping system.

In general, the camera mount performs two important functions which justify its use in any high acuity mapping system.

a) It maintains the camera in a stable position regardless of aircraft motions or vibrations, thereby allowing the camera to operate at its maximum resolution and light-gathering capability.
b) It maintains the optical axis in its designed spatial orientation, regardless of long- or short-time aircraft motions and displacements.

The achievement of the above functions provides more positive identification of control points, allows a reduction of ground-control requirements, and generally results in a more efficient mapping operation. These factors constitute important and obvious advantages for both civilian and military photogrammetry.

While the original and fundamental purposes for the use of camera mounts have not been changed, the achievement of the additional potential advantages of the convergent camera imposes a greater steadiness demand on the mount than has previously been required.

As we have seen, the use of a convergent system enables photographs to be taken at approximately twice the altitude of a single camera system, with equal vertical accuracy. However, in order to retain the same recognition and detection capability, the resolution at twice altitude must be approximately doubled, thus imposing a more stringent steadiness requirement than for lower altitude operation.

In addition, present day and contemplated environments in airborne vehicles, and the necessity for more accuracy in mapping and target location have dictated more highly developed design approaches.

Previous approaches, such as universal mounts to accommodate a series of different cameras, are no longer sufficient. The mount must be tailored to the individual camera and the vehicle. The meeting of these difficult requirements, despite the environmental conditions which are encountered in high speed, high altitude, and relatively small airborne vehicles, has necessitated a design approach with careful integration of camera, mount and other components into the over-all system.

This paper describes the features and performance of the twinplex camera mount whose design was performed under the guidance of the Air Force as system manager. Close liaison and agreement on camera tolerance and mount configuration, combined with advanced component designs and stabilizing techniques, have achieved what is expected to be the ultimate in compactness, light weight and performance capability for high acuity convergent mapping. The accompanying photograph (Figure 1) shows this mount.

DESIGN FEATURES

The camera is stabilized in the roll, pitch and yaw axes. Azimuth control is used to keep the loss of overlap at a minimum when the aircraft yaws. The freedom in the roll and pitch axis is $\pm 8°$. In azimuth the range is $\pm 15°$. When the heat barrier box is used—this would be in a supersonic vehicle—the roll freedom is $\pm 5°$, pitch $\pm 7°$, $-2°$ and azimuth is $\pm 10°$. The weight of the camera and mount is 198 lbs. The operating temperature range is $-100°$F. to $+300°$F when the heat barrier box is used, and 0° to $+120°$F. when camera and mount are used in a conventional system.

The design of the mount is based on a combined structural analysis, layout and component placement to simultaneously reduce weight, achieve compactness and

† Included in this issue.

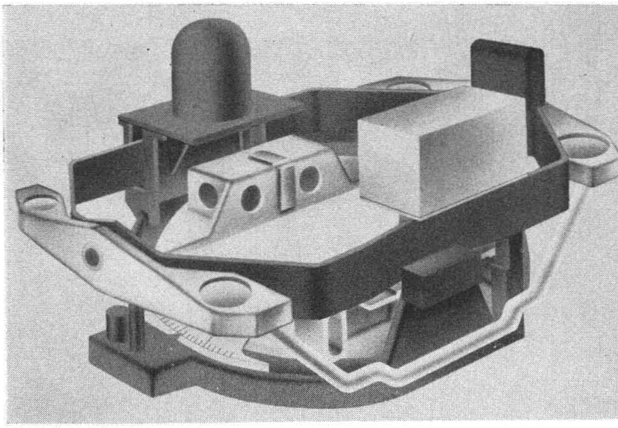

FIG. 1. The mount.

provide a structure with a minimum of mechanical displacements and resonances.

Light-weight construction has resulted from the use of hollow magnesium castings. Some consideration was given to titanium; however, fabrication techniques have not been developed enough to justify its use, and more study would be required to determine its actual value.

Compactness has been achieved by careful and experienced layout work that must effectively wrap the gimballing system around the camera, and still provide the necessary clearances for free gimbal action. Components used in the stabilization system are carefully integrated into the structure.

The thermal barrier box, now briefly described, insulates the mount and camera from ambient temperatures in the vehicle up to 300°F. At present this unit was designed as a laboratory item and is not tailored for any specific configuration.

The size of the heat barrier box is 38″×28″×44″ and it weighs 137 lbs. The pressure inside the box will be ambient at the various altitudes. A vent through a desiccant is built into the box to allow entrance and exit of air at altitude changes corresponding to 1,000 ft./min. The walls of the box will be constructed of aluminum roll bond, a commercial material fabricated with coolant openings running between two bonded surfaces. At present, the coolant will be obtained from the aircraft, and fed into the distribution system in the roll bond. A parallel system on the gimbal structure is piped through the torquer assembly, and around amplifiers and motors. In addition to the mount, camera and thermal barrier assembly, a separate box is used to house the electronic components not directly needed on the mount. This box is opened and sealed to the atmosphere before take-off. This procedure maintains one atmosphere inside the box at all altitudes. A built-in heat exchanger and the fan circulating air inside the box keep the components at less than 160°F. in outside ambients up to 300°F.

In addition to the basic design features, some of the features now discussed in more detail are the result of agreements between camera and mount deisgners.

a. For this mount, it was agreed to incorporate close tolerances on camera center-gravity variations. Ideally, it is desired to maintain the c.g. of the camera and gimballing system in each axis concident with its axis of rotation (roll, pitch and yaw). Variations in film and spool weights, as well as c.g. variations between cameras and mount structures are compensated for by balance weights or weight shifters. If the variations in c.g. can be kept very small, balancing capacities can be reduced in size or eliminated.

b. In the vertical direction, the allowable camera film c.g. variation is expected to be $\pm \frac{1}{32}''$. This close tolerance allows considerable reduction in the size and weight of a vertical weight shifter required to adjust for different cameras and rolls of film.

c. In the horizontal direction, the symmetry of two cameras allows film motion to be in opposite directions and perpendicular to the line of flight. The c.g.

tolerance in camera and film spool is expected to be $\pm\frac{1}{32}''$. These features allow the roll and pitch weight shifters to be eliminated. In addition to the weight saving, a possible source of image degradation, arising from vibrations in automatic weight shifters, is eliminated.

d. The mounting pads on the inner gimbal and the camera are maintained to close tolerance in their parallelism to the mounting plane of the vertical reference. This assures a reliable low tolerance relationship between the vertical axis of the camera and the vertical reference unit. When the camera is mounted on the azimuth gimbal, its vertical axis will be within one minute of arch in mechanical relationship to the vertical reference.

e. Synchro transmitters provide roll and pitch signals so that other equipment may be slaved to the roll and pitch gimbals of this mount. The two-speed synchro system can be adjusted for three sets of speed ratios. Caging in roll and pitch gimbals is obtained through a solenoid operated mechanism.

f. The azimuth ring is restricted by stops as well as the high reflected inertia of the azimuth drive motor. The azimuth ring has a synchro control transformer, and can be slaved to a *J2* control box or other drift computer.

Space is available on the azimuth ring to accommodate a small computer which supplies flight information to the *CRT* data recorders in the camera.

PERFORMANCE

The performance of any camera mount will be indicated by the measurement of two basic quantities: (1) *Steadiness,* (2) *Verticality.*

These quantities are directly related to, and stem from the function of the mount as indicated in the first part of this paper. They are obtained by independent measurements of mount motions taken with auto-collimators and sensitive motion recorders. Measurements are usually made in the laboratory using a rocking table or flight simulator. Any motion arising in the mount or camera will degrade the resolution. Figure 3 shows how resolution is reduced by motions acting on the lens film combination.

Although there is considerable diversity of opinion concerning the required verticality (or accuracy of optical axis orientation), most authorities will agree that achieving the ideal will result in considerable reduction in ground-control requirements. Thus in the mount design, this factor is always given special emphasis.

For a given camera, the major factors in the over-all mount design which affect these quantities of steadiness and verticality are: (1) *Structural Design,* (2) *Stabilizing System.* (Figure 2).

The structure must be designed without low-frequency resonances. Devices such as gyros must be placed on rigid structures and not placed on cantilevers. The application of torque to the gimbals must not be made through long springy shafts. The mount structure, if not carefully designed, will contribute to unsteadiness rather than help reduce disturbances. Obviously, it would be a simple matter to build a massive and enormously rigid structure without consideration to the necessity for low weight and compactness. However, present-day airborne vehicles do not allow such design luxury.

In addition to the structure itself not being a source of unsteadiness, it is desirable that it damp out motions transmitted from the aircraft structure. However, this function in large measure is performed by isolators which are used to fasten the mount frame to the aircraft.

An isolator ideally is a device which prevents one structure from transmitting its motions to another structure. Because of design limitations this function is not completely achieved with the isolator. The ideal requirement of zero stiffness contradicts the necessity for a mechanical connection between mount and aircraft. Since isolators are not ideal, there are instances where they are not helpful in attenuating motions, but in fact are instrumental in causing resonances and magnified shocks to equipment supposedly being protected. In this mount enough space is made available to use different isolators depending on the expected aircraft vibrations, and the availability of new extra-low frequency isolators.

In addition to the structure and its accompanying isolators having an important effect primarily on mount steadiness, the stabilization system is also very important in achieving both steadiness and verticality. The particular configuration and its component parts determine the accuracy in obtaining and maintaining

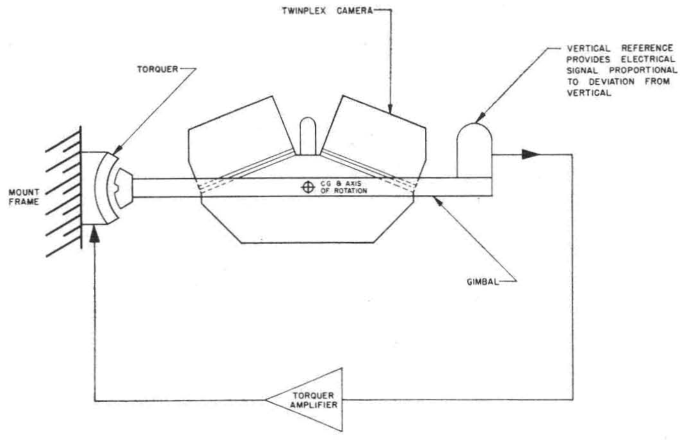

FIG. 2. Stabilizing system KC 2 twinplex mount.

optical axis positioning and reducing the response to disturbances.

Basically, the stabilization system is a means of automatic closed loop control. Figure 2 shows the basic system for KC-2 twinplex camera. In each axis, output motions are compared to a reference signal and an error signal difference is obtained. The error signal is used to apply torque to the gimbal in such manner that the output motions are caused to be equal and opposite to the reference thus resulting in a zero error signal. Within this basic configuration, there are many variations and components that may be used, depending on the desired steadiness and verticality requirements. The basic components that comprise the control loop in this mount are: (1) *Vertical Reference*, (2) *Torquer Amplifier*, (3) *Torquer*.

The vertical reference in most cases, as in this mount, is mounted on the inner gimbal. If the inner gimbal is not in a horizontal plane, the vertical reference is not level and an electrical signal is generated proportional to the deviation from vertical of gimbal vertical axis.

The accuracy of the mount stabilization system is directly related to the ability of the vertical reference to provide an accurate and steady vertical signal under various flight conditions.

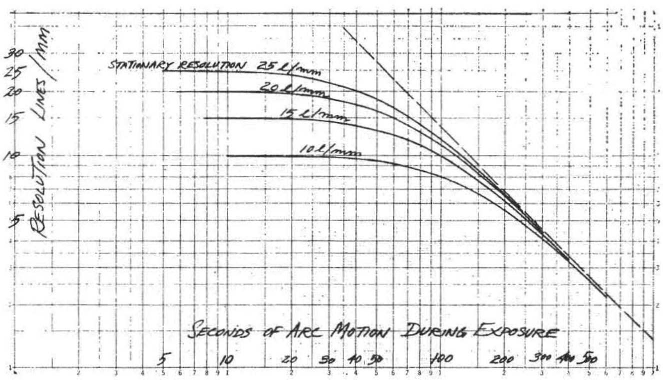

FIG. 3. Effect of angular motion on resolution of 6 inch focal-length camera.

Table 1 shows four basic types of vertical references that can be used in stabilization systems. The estimated average and peak verticality errors are shown for each type of vertical reference system. In addition, the inherent susceptibility to velocities and accelerations in causing verticality errors is summarized for each type of vertical reference system.

All of the first three systems use a physical pendulum as a basic plumb-bob reference. The pendulum, in addition to be-

TABLE 1

RELATIVE PERFORMANCE CAPABILITIES OF VARIOUS VERTICAL REFERENCES

Vertical Reference	Verticality		Susceptibility to Motions which Produce Verticality Errors			
	Average Error Minutes of Arc	Maximum Error Minutes of Arc	Earth's Rate and Profile Effects	Transla-tional Accelera-tions	Turns and Rhumb Line Flight	Coriolis
Vertical Gyro	15–30	40–90	Yes	Yes	Yes	Yes
Vert. Gyro & Integrating Erection System	12–15	20	No	Yes	Yes	Yes
True Vertical Computing System	6–12	15	No	Partly	Partly	No
Aeroflex Inertial Vertical	2	3	No	No	No	No

ing sensitive to gravity, is also sensitive to any other accelerations that result from the translation of the pendulum in space around the earth. The verticality of the various systems, as affected by these motions, is shown in the chart. The fourth system, now under design and development at Aeroflex, produces a precise electromechanical analogy of the so-called earth's radius. 84 minute or Schuler pendulum. This type of system is based on purely inertial principles and provides a vertical not affected by translational motions.

At present, the system being used with this mount is the vertical gyro and integrating erection system. Although the *TVCS* system has somewhat better performance capability, it is felt that the added complexity does not warrant its use in this case. This opinion is reinforced by the conviction that the inertial vertical, when available, will supersede both *TVCS* and the vertical gyro integrating erection system, and will be usable on this mount.

Before leaving the subject of vertical references, another method should be mentioned. The aircraft navigation system is sometimes used as a vertical reference. Some of the highly sophisticated and complicated navigation systems can provide a vertical reference to 1–3 minute accuracy. However, this reference is usually remote from the camera mount, and due to flexure of the aircraft, the vertical reference signal when transmitted to the mount is usually considerably degraded in accuracy. In addition, navigation systems usually do not emphasize a vertical reference signal that is also steady, as is done in vertical references specifically designed for photogrammetric work.

Another important component in the stabilization system is the means of actuating the gimbals, so that they remain slaved to the vertical reference. The object is to transmit torque from the mount frame to the gimbal, but still have the gimbal free to move in space without any reaction with the frame. A servo motor with gearing can transmit torque from frame to gimbal; however, the gimbal attempting to move in space will see the reflected inertial of the motor. In addition, gearing, though it be extremely fine, is essentially a non-continuous motion and can affect mount steadiness. However, the torquer used in this mount is practically ideal for the job. Torque is transmitted by electro-magnetic coupling. No gearing, exists between gimbal and frame. The circuitry is designed such that negligible reaction torque occurs in the frame when the gimbal moves in space. The new model of torquer used here provides extremely smooth relative motion between gimbal and frame.

The transistorized amplifiers used in the stabilization system must also be designed with the requirements for steadiness and verticality in mind. These amplifiers must have low electrical noise characteristics, especially in the low-frequency range. The electrical noise can be the origin of signals that drive the torquer and gimbals, causing unsteadiness. The amplifiers must not be susceptible to supply voltage fluctuations which would be reflected to the mount as unwanted motions. There must be no long-term drifts in the amplifier since these would be reflected as verticality errors.

Now, after the stabilizing system is put together, it constitutes the closed-loop control required to keep the camera oriented and steady. In addition to inherent sources of error in each loop component, care must be exercised in reducing factors that are always acting against the capabilities of the control system.

Deviation of the camera and mount c.g. from the axes of rotation will cause an unbalanced torque. This torque causes a verticality error.

Gimbal restraints such as bearing-friction and cabling-jumping gimbals constitute sources of torque disturbances and verticality errors, and must be given careful consideration.

In essence, we have the requirement to obtain instrument servo accuracy in a relatively massive structure, a job that requires careful analysis of the many factors involved that affect mount performance.

SUMMARY

To summarize briefly, there has been discussed the basic function of the KC-2 camera mount and the criteria involved in designing for maximum geometric and resolution performance. The general design features and the performance as related to the mount structure and stabilization system have been analyzed.

This mount and camera system provides the mapping and charting industry with a tool to obtain new advances in compilation techniques and performance. Along with the increase in performance capability, equipment has been provided which is considerably reduced in size and with less than half the weight of previous systems.

In the near future, with the advent of new lenses, fine-grain films and the photogrammetric vertical reference, the KC-2 camera and mount system should represent a major step forward in the instrumentation and implementation of high-performance mapping systems.

However, like all previous engineering and scientific achievements, this development stimulates challenges for further progress in other areas of the system chain, from the photograph to the finished map or manuscript. For a look into a portion of the immediate future, Dr. Baker's paper* discusses the T-11 lens which is directly applicable to this system.

* This paper is not yet available. When received, it probably will be printed in an issue of this JOURNAL—*Editor.*

CORPORATE MEMBERSHIP ON JULY 1, 1958

The following statistics were obtained from recent studies of the business associations:

	No.	%
7 Federal Agencies—principally engaged in mapping	763	25.2
State, Foreign and other Federal Agencies	611	20.2
Colleges	229	7.5
Non-Government or Commercial		
Retired and Self Employed	31	1.1
In companies selling photogrammetric products or service. Sure 490. Probable 72	562	18.7
In companies possibly so engaged	84	2.8
Reason for interest in photogrammetry not known	334	11.0
Unknown	413	13.5
Total	3,027	100.0