PHOTO SYSTEM INSTALLATIONS IN AIRCRAFT*

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ABSTRACT

The fundamental concept of designing a photo system installation around the primary mission requirements is discussed. Emphasis is placed on eliminating secondary mission requirements where they jeopardize the primary mission performance of the system. Various types of camera mounts, their uses, and the basic difference between them are enumerated. The relationship of camera mount design to aircraft window installation design is established.

THE design of a photo system installation in an aircraft is important to many of those gathered here today. It is important to the aircraft designer who must install the system, the equipment designer who must design the components of the system, and the using agency, civil or military, which must use the system. After dealing with many such systems from the equipment design point of view, certain facts have been uncovered and many ideas formulated that may be of value to all of us. Most of these facts and ideas have been gleaned piecemeal from all segments of the industry, and no attempt will be made to give credit to the many individuals and groups that have been responsible for them, except to thank all of them for their help in the past.

The basic element of any photo system installation should be, *first, establish the primary mission requirement.* I will expand on that statement. What do we want the system to do? What type of photography is needed? What is the *primary* mission requirement? We have seen systems that vary in complexity from a 4×5 hand-held camera in a Piper J-3 to a very elaborate automatically-controlled system in a military aircraft. Each can be considered an excellent system if it adequately meets its primary mission requirement. It has been pointed out previously by eminent experts in the field, such as Brig. Gen. George W. Goddard, that the ideal approach would be to design an aircraft around a camera system such that the ultimate results would be obtained in the performance of a particular mission. Unfortunately, this approach is not considered a practical one in the industry today, although some projects aimed in this direction have produced encouraging results. It seems that our best approach is to first determine the primary mission requirements, and then choose an aircraft and system components that will enable us to meet, or at least approach, these requirements.

The second important factor to consider is, once the primary mission requirements have been established, the systems ability to meet those requirements should not be jeopardized by numerous *secondary mission requirements.* No attempt should be made to make a universal system at the expense of the primary mission. It is, I believe, fundamental, that the broader the requirements of *any* piece of equipment the poorer will be its performance in fulfilling any one of those requirements. An example can be cited (Figure #1). This Texas Diamond Back rattlesnake is named Herman. He was designed to strike (Figure #2). Measurements at the Bronx Zoo show that he strikes in about $\frac{1}{4}$ second once he decides to do so. Suppose he was also required to be a constrictor; like a boa. Constrictors are relatively slow by nature and this additional requirement would slow down his striking ability. The primary mission would be jeopardized in an effort to be universal.

This concept does not imply that only one mission should be designed into any one aircraft. On the contrary, many secondary missions are generally possible in the ideal system installation. However, the important point is, only those secondary missions should be included that do not jeopardize the primary mission requirements. This consideration applies to individual components as well as to the entire system, for if the performance of an individual component is deteriorated, then the

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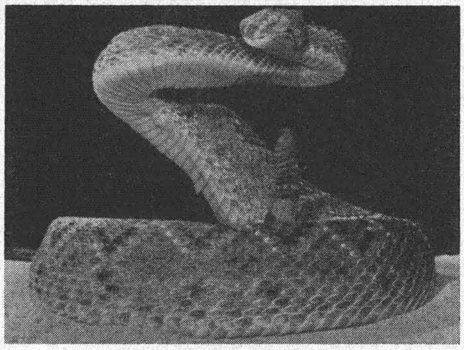

FIG. 1. "Herman" A Texas Diamond Back Rattlesnake. An example of a device designed for a primary mission. (Photo courtesy Bronx Zoo.)

performance of the entire system is likewise in jeopardy.

Now, we can discuss a number of details of system installation that apply to many systems in varying degrees. We of course cannot cover all such details in this session even if we knew enough about them. After this discussion no one person will be able to design the optimum system, unless he could do it before. But, we can cover a few points that may help us make some decisions while designing a particular system or piece of equipment. It is wisest that I restrict my discussion primarily to the field I know best, camera mounts. This is in line with the idea of not trying to be a universal engineer but, rather, to remain more specialized and thereby hope to better fulfill my primary mission.

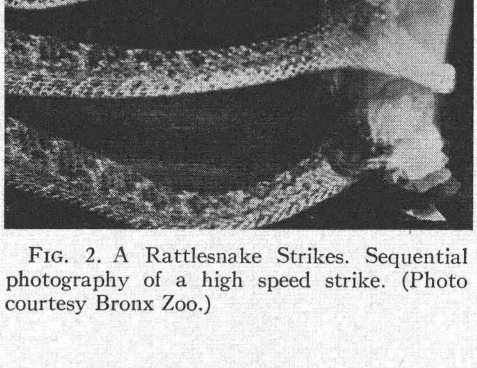

FIG. 2. A Rattlesnake Strikes. Sequential photography of a high speed strike. (Photo courtesy Bronx Zoo.)

We will consider the various categories of mounts and some of their problems and capabilities.

(1) The fixed mount, designed to rigidly couple the camera to the airframe is useful in some limited cases. It can be used on short focal length cameras in positions where vibration levels are low, and under ideal light conditions when shutter speeds are high.

(2) The fixed vibration isolated mount should be used where vibration conditions are greater and when focal lengths are longer. One type of vibration isolated mount is shown in Figure #3. Vibration isolators must be used with great care however as improper use of vibration isolators is worse than no isolators at all. As seen in Figure #4, if the center of gravity is improperly located relative to the center of support, angular motion will result from a purely translatory vibration. Proper location of the center of gravity as shown in Figure #5 will result in only translatory motion of the camera which is not objectionable. Also, improperly used vibration isolators can magnify loads many times and great care must be taken from this point of view.

(3) Azimuth positioning mounts are used to properly align the format of the photograph with the ground track of the aircraft. A typical type is shown in Figure #6. Azimuth data can be supplied from various sources ranging from pilot observation to automatic radar navigation systems. It is often automatically coupled into the mount by a servo system.

(4) The Forward Motion Compensation mount is used to provide IMC for cameras in multiple arrays or for cameras using 9 inch film with an 18 inch format across the line of flight. Figure #7 shows an example in the ARW-3 mount. This mount is very effective within the range of V/H values compatible with the K-38 camera. The accuracy is best on long focal length lenses operating near the vertical.

(5) Stabilized gear driven mounts are used to obtain improved vertical alignment in roll and pitch. The A-28 Mount is an example as shown in Figure #8. The operation is limited by the rate and acceleration capabilities of the servo system, especially in the roll axis where aircraft rates can be high. High inertia of the stabilizing components is detrimental to the system operation. Mapping and Charting missions benefit most from this mounting approach.

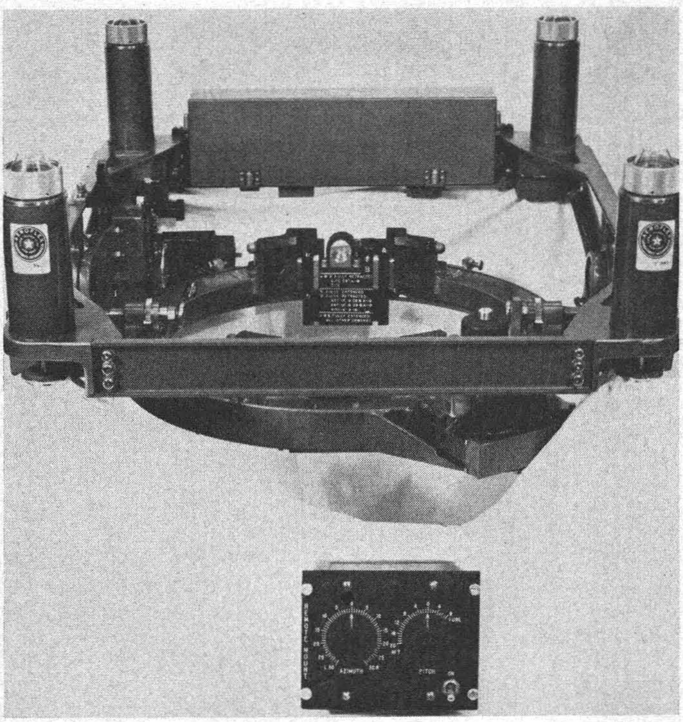

FIG. 3. U.S.A.F. Type XA-32 Camera Mount. Experimental version of a vibration isolated, remote control mount.

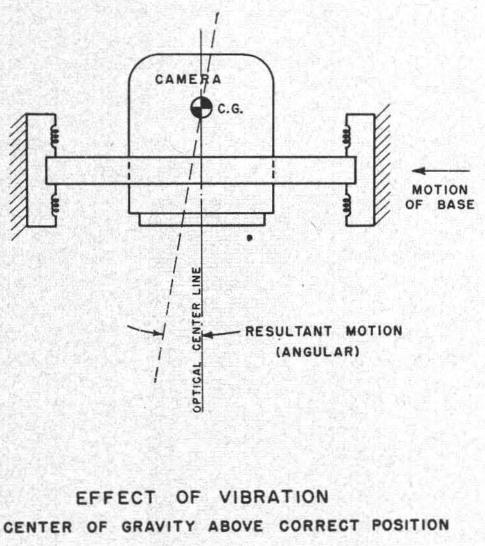

FIG. 4

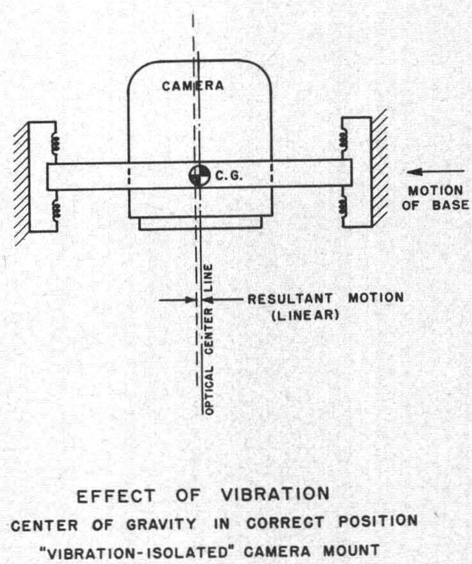

FIG. 5

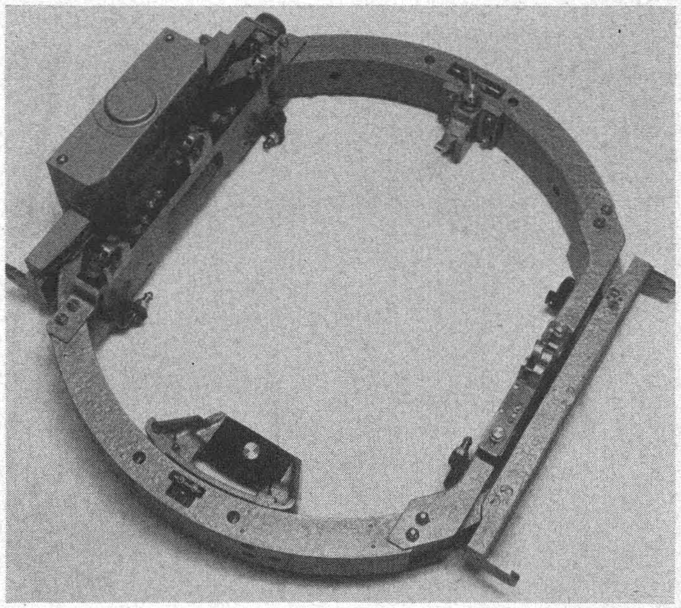

FIG. 6. U.S.N. Azimuth Positioning Camera Mount. For remote automatic operation.

(6) Stabilized torquer driven mounts are used to improve vertical alignment in roll and pitch and to obtain high resolution. One type, the LS-4, is shown in Figure #9. The improvement in resolution is especially noticeable with long focal length cameras and with low shutter speeds. Their operation is essentially independent of the rate and acceleration characteristics of the aircraft, providing good operation in rough air and under higher than normal vibration conditions. In this type of system the inertia of the stabilized element assists the operation and the higher the inertia the better. The system must be carefully balanced so that the center of gravity and the center of rotation coincide. Figure #10 shows the essential difference between gear driven and torquer driven mounts. It can be seen that when the outer frame or airframe rotates in the torquer mount design, no torque is developed unless an error exists. In a well balanced low friction system the error will always be small. When motion of the outer frame exists it is not necessary to accelerate the stabilized member but only to oppose the coercing torque. In the gear driven

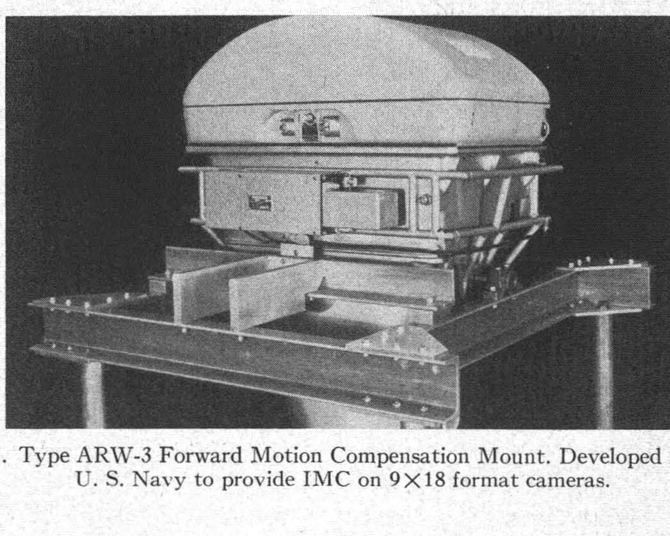

FIG. 7. Type ARW-3 Forward Motion Compensation Mount. Developed for the U. S. Navy to provide IMC on 9×18 format cameras.

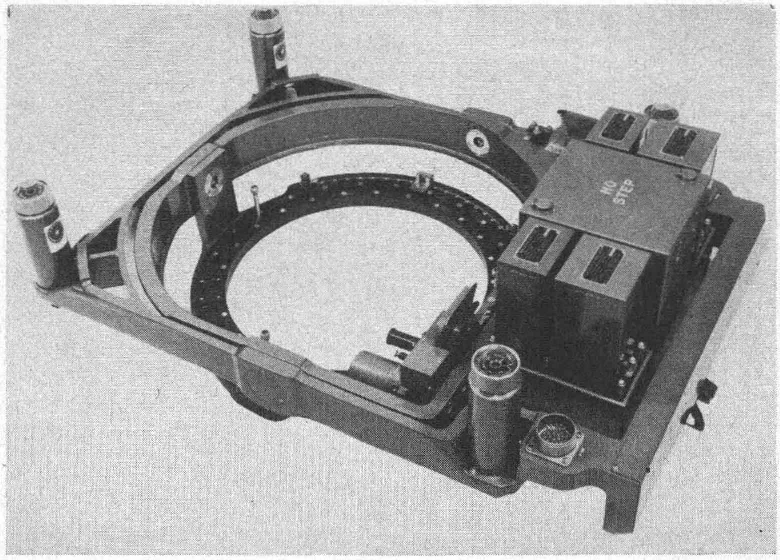

FIG. 8. U.S.A.F. Type A-28 Gear Driven Gyro Stabilized Camera Mount. To automatically improve vertical alignment accuracy.

system when such motion exists an error must develop, and the motor armature and gearing must be accelerated rapidly in order to maintain a low error. Under higher frequency inputs such as vibration, the gear driven system is effectively a solid connection whereas the torquer system is entirely free.

Combinations of the basic mounts listed above are feasible and many have been built. The LS-4 mount as pictured in Figure #9 provides torquer stabilization and Forward Motion Compensation. The A-28 mount as pictured in Figure #8 provides gear driven roll and pitch and remote azimuth control. Within limits, any combination is feasible so long as rigidity is maintained and interaction between elements is held to a minimum in the design. In all mount designs the rigidity of the

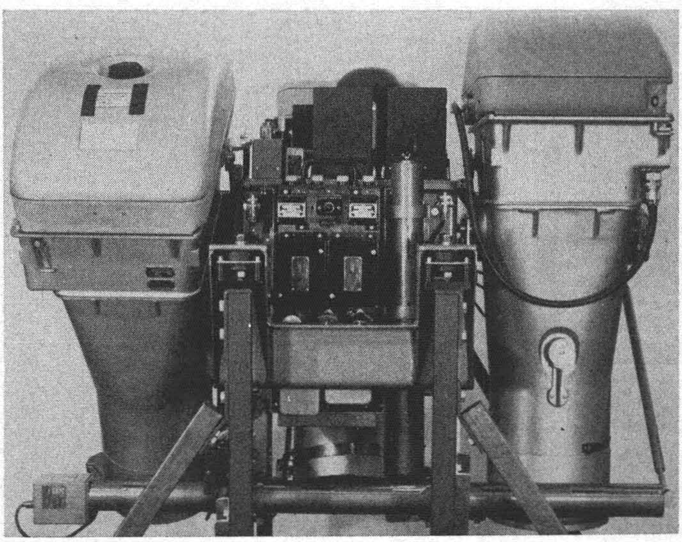

FIG. 9. U.S.A.F. Type LS-4 Torquer Stabilized Camera Mount. Provides high resolution, improved verticality and Forward Motion Compensation for a multi-camera array of 3-K-38 cameras.

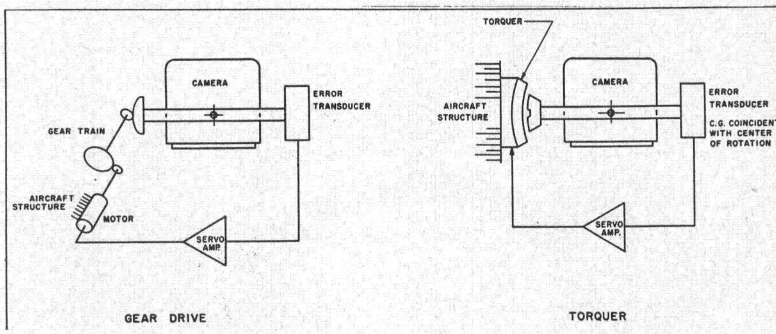

FIG. 10. Gear driven vs. torquer mounts. Schematic illustration of the difference between gear driven and torquer stabilized mounts.

connection between the camera and the mount attachment points to the aircraft is very important. The design should be such that angular motion of the camera will be within the allowable amount dictated by the mission requirements.

The location and size of camera windows in an aircraft are very closely related to the mounting problem. Many compromises are required in the design of such windows to achieve a workable system. The window should be made as small as possible so that it can be of the least possible thinness and weight. In high speed aircraft a large flat window is an aerodynamic problem, and in some aircraft a heat problem exists. In all aircraft it is difficult to install any window from a purely structural point of view.

In order to reduce window size in any particular camera installation, the angular positional requirements of the camera in roll, pitch, and azimuth should be restricted to the normally anticipated motions of the aircraft in these axes and should not be arbitrarily expanded. See Figure #11. It may be wise to allow a little extra freedom in the camera mount so that stops will not be encountered if a sudden motion should carry the aircraft beyond normally anticipated positions, but the window should not be designed to these maximum conditions. As seen in this figure the window would be appreciably larger for these maximum conditions. The center of rotation of the mount should be kept as close as possible to the window, yet it must remain consistent with rotating about the center of gravity of the stable element where this applies. Clearance between the end of the lens cone and the window should be reduced to the lowest practicable minimum. All of these items must remain compatible with aircraft structure. In the layout of camera windows the shape of the light ray bundle near the lens and the refraction of the rays passing through the thick window should be taken into account. See Figure #12.

A good example of the quality of steadiness obtainable from a torquer type mount is shown in Figure #13. The upper part is a section of a strip camera recording, unsta-

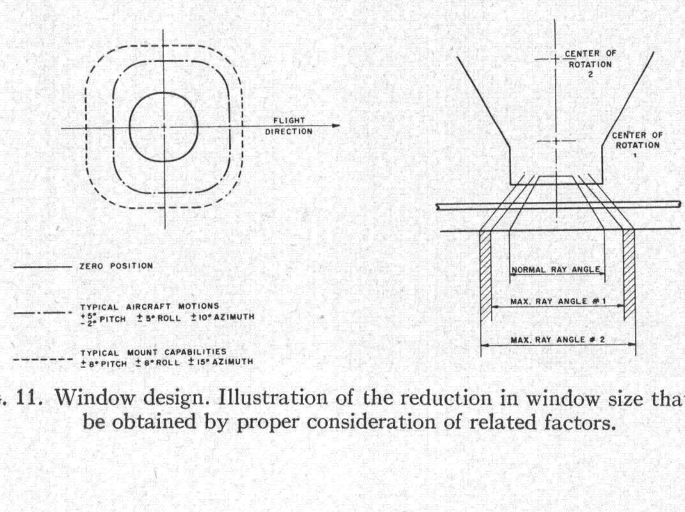

FIG. 11. Window design. Illustration of the reduction in window size that can be obtained by proper consideration of related factors.

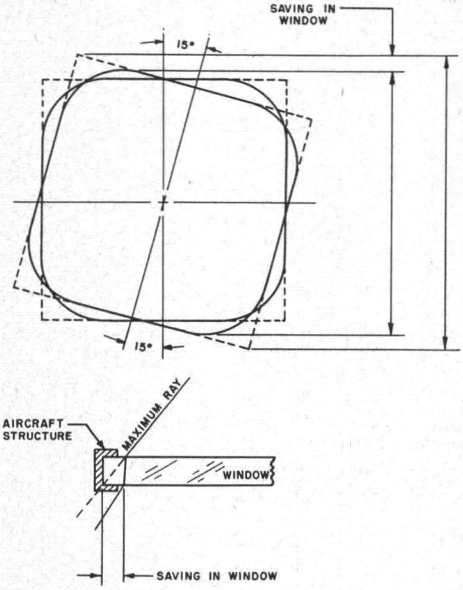

FIG. 12. Window design. Same statement applies as in Fig. 11.

bilized, which indicates very rough flight conditions. The lower portion is the same type of recording with the stabilization system operating. This was flown over a straight section of U.S. Route #1, North of Trenton, N.J., at 2,000 feet, with a 20 inch lens cone on a CAS 2a camera. This is a very effective method of taking an oscillograph of aircraft and mount roll motions if the reference line is straight and if the ground track of the aircraft is straight.

There is one further very important consideration to be remembered in a photographic system. By the very nature of photography consisting of isolated exposures, each and every exposure should meet the minimum requirements established for the mission in regard to picture orientation and quality. This is a basic difference between a photo system and, for example, a navigation system. In the navigation system the instantaneous error of the vertical is not important so long as the integrated error value over a long period of time is near zero. In the photo system the vertical error of each exposure must approach zero but the integrated value is unimportant.

This same condition exists on resolution. In almost every flight some high resolution exposures can be obtained when all conditions happen to peak favorably. But what happens when all conditions peak unfavorably? Figure #14 shows the resolution of the worst exposure for various systems of mounting and control for two typical installations.

Data for these curves was derived from the following assumptions:

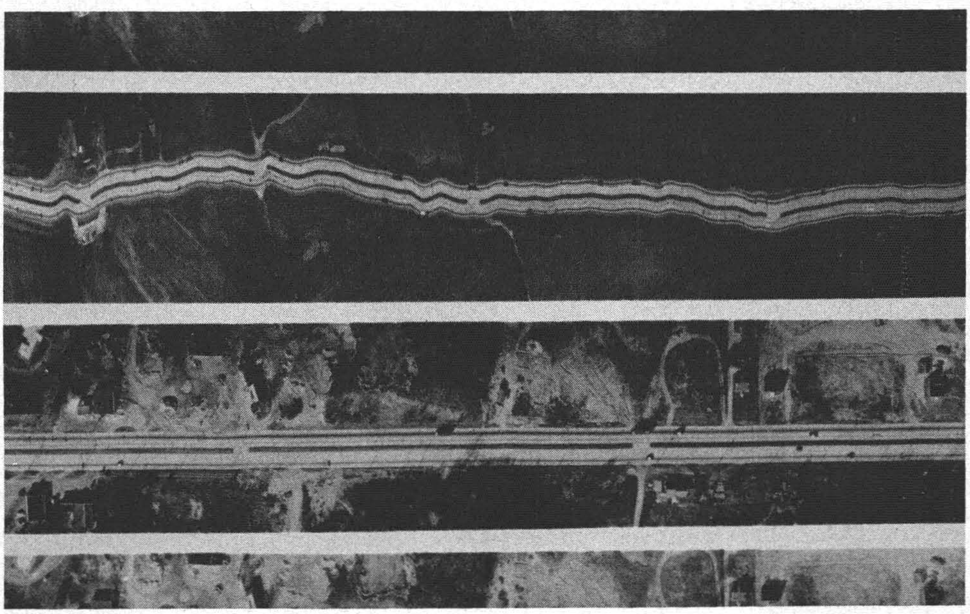

FIG. 13. Effect of stabilization on strip photography. Both strips were taken in very rough air over a straight highway by the same camera within minutes of each other.

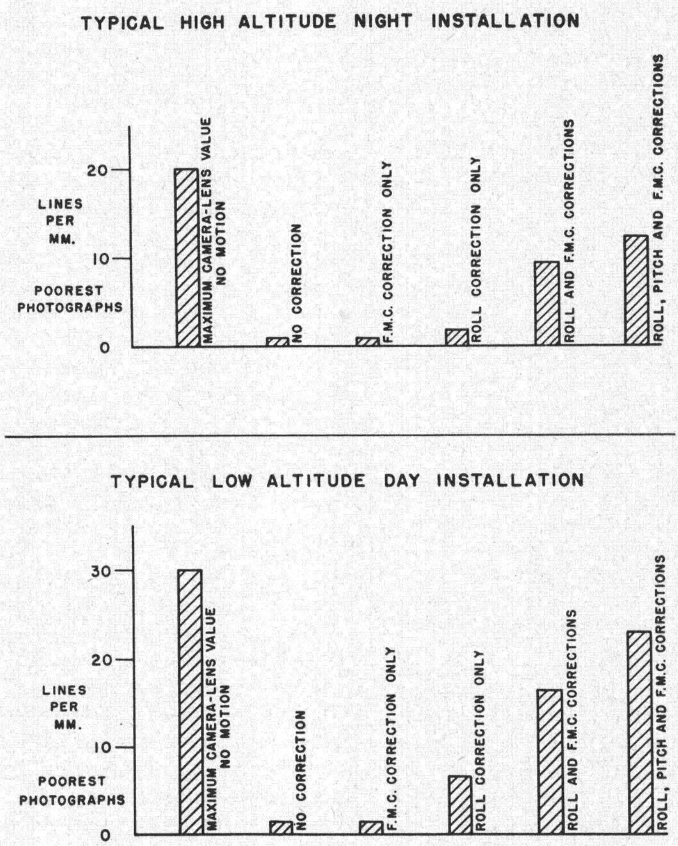

FIG. 14. Theoretical Resolution of Poorest Photographs. Data used to derive these graphs were assumed based on studies of expected aircraft motions (See Text).

1) *Day Installation:*
   a) 9×9 camera with 12″ lens cone and I.M.C. magazine with resolution capability of 30 lines per millimeter.
   b) .01 second exposure.
   c) 5,000 feet altitude.
   d) 300 knots air speed.
   e) No cross wind component.
   f) Maximum rates: Roll 30°/sec; Pitch 3°/sec.
   g) No vibration effect.
2) *Night Installation:*
   a) 9×18 camera with 24″ lens cone with resolution capability of 20 lines per millimeter.
   b) 0.1 second exposure.
   c) 40,000 feet altitude.
   d) 500 knot air speed.
   e) No cross wind component.
   f) Maximum rates: Roll −3°/sec.; Pitch −0.3°/sec.
   g) No vibration effect.

It can be seen that Forward Motion Compensation and roll stabilization provides the best combination giving the most satisfactory results with the least amount of equipment.

We could continue, covering additional detail about the location of the mount in the airframe, about the control system to provide operating signals to the camera and mount, about the type camera and incendiary lighting to use for night missions, about maintenance and serviceability and many other items, but each of these is really a subject in itself. In the discussion of any of these items, however, *the philosophy of establishing a design to meet the primary mission requirement, without this requirement being jeopardized by many secondary mission requirements, should be considered foremost.* This basic concept cannot be overemphasized.