as to accuracy and cost, whether the purpose be mapping or photo interpretation. Of paramount importance also is the reproduction made from this negative, since it is from this medium that the information is gleaned.

As stated on the program Mr. Pallme will read the first paper. He will be followed by the others in the order given on the program. Following the end of each paper there will be a ten-minute period for questions and discussions. Each speaker will be glad to answer, or try to answer, any question that you may have concerning some aspect or detail that was discussed in his paper.

Camera Mounting for Photogrammetric Purposes

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ABSTRACT: *When using an aerial camera for mapping purposes it must be mounted in an aircraft so that the mapping system will produce photography to meet the requirements of the contract or mission. These requirements vary according to the contract or mission, the aircraft and camera used and the flight conditions. Requirements for steadiness producing high resolution are separate from those for verticality. According to the needs different mounting methods are available, the Twinplex mount representing one of the specialized types. Future developments include improved verticality and higher resolution by techniques now under consideration.*

AERIAL mapping is the product of a complete system integrated from the initial planning through the final delivery of the map. Requirements vary for different agencies and different producers but in each case the end product or mission requirement describes the entire system needed to produce the desired result. The mission requirements are always compromised somewhat by the equipment available to perform the mission, and this equipment should be steadily improved where such improvement results in an economic gain for the using or producing agency.

In aerial mapping, photographs are required with proper orientation in roll, pitch, azimuth, altitude, transverse position, longitudinal position and time. Today any of these seven degrees of freedom can be controlled to almost any degree of the accuracy one wishes to demand of the system. The only limit to such accuracy is the cost in time, money, weight, complexity and reliability. A generalized curve is shown in Figure 1 and applies to any of the relationships in question by proper modification. In the commercial mapping field one point on the curve may apply to a particular problem or contract whereas in the military field another point may apply. The commercial mapping system has certain allowable tolerances but has the requirement that these tolerances must be met economically. In the military system the timeliness is often of a much higher degree of importance.

The seven degrees of freedom will be reviewed in their reverse order.

1. Time is a rather broad degree of freedom. The need for photography at the right time of year, the urgency of need, the politically motivated and controlled desire to obtain photography of an inaccessible area, the availability of equipment: all of these items are factors in the time domain.

2. Longitudinal position control is accomplished by an intervalometer often

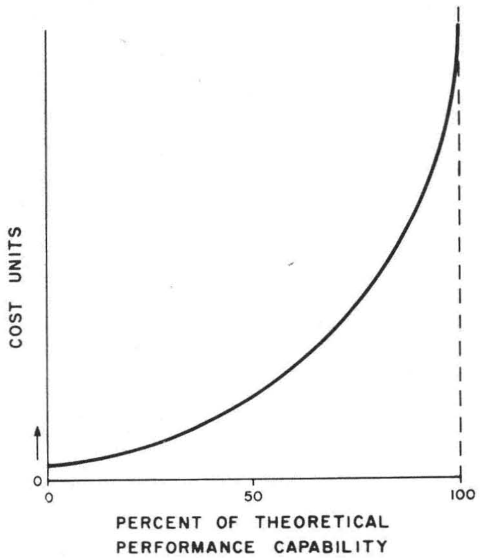

FIG. 1. Generalized relationship of performance to cost.

consisting, in its simplest form, of a man and a watch. The range of complexity varies from this simple device to radar ground speed indicators and automatic computers at the other end of the complexity scale.

3. Transverse position control requires the proper location of flight lines. Again complexity variations exist from the simple form of pilotage using visual ground check points to very elaborate automatic navigation systems.

4. Altitude is determined by an altimeter and by aircraft capability. Higher accuracy in measuring equipment and in altitude control is desired. For any given job the civilian contractor is generally restricted to an available aircraft capable of reaching the desired altitude and a simple system of control.

5. Azimuth, pitch and roll orientation are functions of the camera mounting devices. Here again almost any accuracy can be attained depending on the requirements. A wider range of versatility is readily available in this area than can be obtained in the control of most other variables.

Camera mounts fall into several categories as follows:

1. Fixed mounts
2. Vibration isolated mounts
3. Manually-operated positioning mounts
4. Remote positioning mounts
5. Automatic self-stabilizing mounts
6. Forward-motion Compensation Mounts (IMC)

Various combinations to the above are available, again, depending on the requirements. These can be listed as:

1. Verticality
2. Resolution
3. Positioning
4. Operating range
5. Reliability
6. Cost

Verticality accuracy requirements vary according to the using agency. Numbers obtained from various sources vary from 3 degrees down to 30 seconds, but 3 to 6 minutes vertical accuracy seems to be the most desirable. At this time this accuracy is being approached but at great cost.

Resolution is obtained by steadiness of the camera during the time of shutter opening. In six-inch cameras more motion is allowable than in longer focal lengths, the motion allowable being inversely proportional to focal length. The angular motion allowable is shown in Figure 2. Translatory motion is not objectionable as compared to linear motion, however. The curve of Figure 3 shows that linear motion of 60 inches would be allowable as compared to an angular motion of 1 minute of arc to obtain the same resolution under the conditions noted.

One type of mapping mount recently developed for the U.S.G.S. is the Twinplex mount utilizing two T-12 cameras. This mount, as shown in Figure 4, is designed to be operated by a camera man capable of keeping level bubbles centered to a fairly high degree of accuracy. Therefore, from a verticality point of view it is of about the same order of accuracy as any manually controlled mount except for one major advantage, namely that sudden aircraft motions and vibrations are radically reduced by the self-stabilizing effect of the mount inertia. It operates on the principle of supporting the load at one point exactly coincident with the center of gravity while the bearing friction is kept extremely low. Dr. Baker showed in 1944 that this approach was a good one when he obtained very high resolution photographs using a steel ball as a support point. This approach is successful when the ratio of camera inertia to the coercing

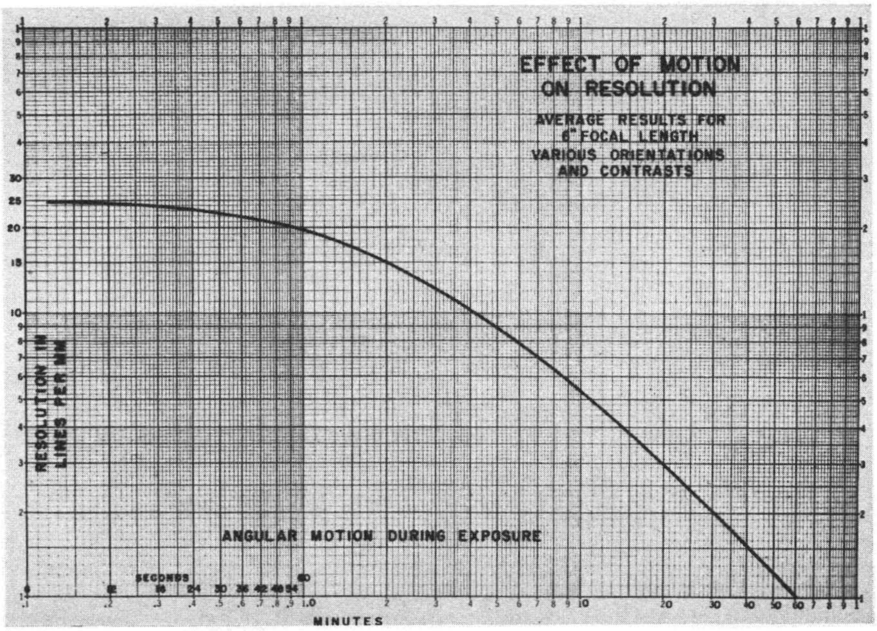

FIG. 2. Effect of motion on resolution; angular motion during exposure.

torques (bearing friction, unbalance, cable spring, and windage) is kept high. The system is then self-stabilizing and has very little response to high frequencies such as vibration and sudden aircraft motions due to gusts. Windage is a severe problem on this type of system but can be solved by use of a window or by very careful em pirical work on such aircraft installation.

In such a system light weight and low cost have been primary considerations. However, a further development of this unit will make use of a simple servo system using a highly damped pendulum for

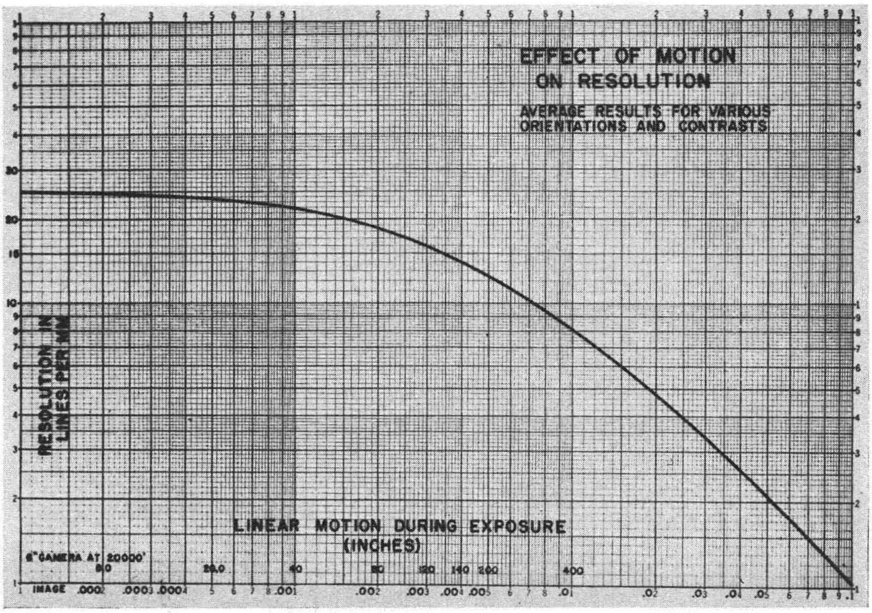

FIG. 3. Effect of motion on resolution; linear motion during exposure.

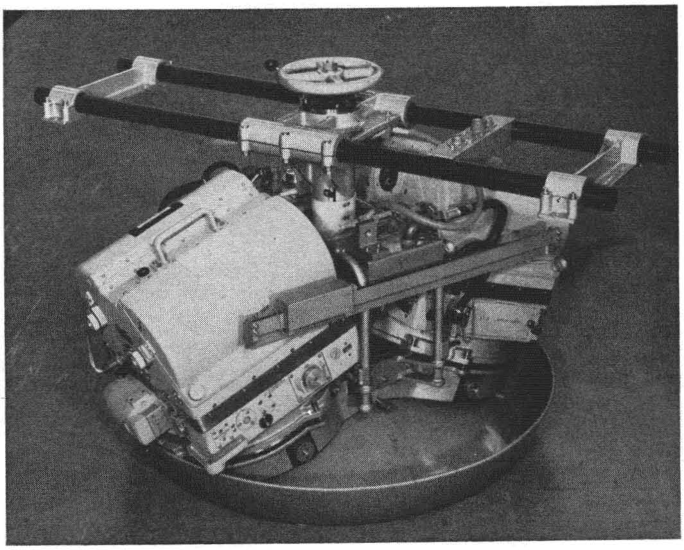

FIG. 4. U. S. Geological Survey twinplex mount.

vertical orientation to eliminate the need for the skilled operator.

A number of advantages result from the use of automatic stabilization as follows:

1. The operator may be eliminated
2. Weight of system is lower
3. Improved verticality is obtained consistently.
4. Higher resolution is obtained consistently
5. Improved operation in rough air is possible
6. Longer shutter opening times are possible
7. High altitude operation unpressurized is practical

The disadvantages are:

1. Capital investment is required
2. Complexity is increased

From the commercial user's point of view it appears to be better economy to invest a little more capital initially and eliminate the cost of an operator on each flight. To date this approach to accuracy and economy has not been exploited to the fullest by the industry. Initial steps have been made, however, and a major swing in this direction is anticipated.

Emphasis should again be made on the approach to system design that is based on determining the primary mission requirement and designing a system to meet those requirements. Such an approach is especially necessary for the commercial operator because of the economies involved. This principle has been followed by some operators in camera design, for example, and should be extended to all components of the aerial mapping system.

DISCUSSION OF MR. PALLME'S PAPER

MR. HARMAN: We have opportunity for a ten-minute discussion.

MISS NORTON (Fairchild Camera & Instrument Corp.): Is the stability a function of mass, a linear function?

MR. PALLME: Very definitely, in the Twin-Plex mount. The steadiness is the function of the inertia which in turn is the function of mass. Primarily, we wish to obtain a very low friction and high inertia system. It is one of the few systems in physics where inertia works for you instead of against you. We usually try to reduce inertia in control systems, but in this case we actually like to increase it.

MISS NORTON: My second question is about stabilization of the so-called miniature cameras. What is the possibility of such stabilization?

MR. PALLME: It is certainly possible. A mount to utilize the CA-12 70-millimeter camera is now in existence and under test. The problem is obtaining the effect of enough inertia through the control system. Miniaturizing the camera provides a greater problem from the control and steadiness point of view. One might think it would be easier to control the smaller camera; actually it is more difficult.

MR. HARMON AVERA (Naval Photographic Interpretation Center): One slide indicated that the automatic mounts to weigh less than your manual mount. Is that for the mount itself or for the mount with the electronic control?

MR. PALLME: The mount itself will not weigh less. But the system weighs less. Take out an operator and you have a lower weight system.

MR. JAMES WEBB (Army Map Service): Considerable progress has been made in obtaining a relative verticality with stabilized mounts. However, in the past there have been problems due to inertia and acceleration forces building up in the system. We have had difficulty in obtaining absolute stabilization. Has any marked progress been made in that field?

MR. PALLME: Very definitely, marked progress. The general concept of stabilization has been changed through the efforts of the Wright Air Development Center, in the direction of the use of torquer mounts, where the effect of inertia can actually work for you instead of against you.

In the A-28 mount, one of the early approaches to mounting, a fairly good control of verticality is obtained. But rapid motion has presented the problems you indicate. Presently, with the torquer mount, this is no longer a problem. Aircraft can move at any rate or any acceleration that they can develop, and the mount is not affected, because there is no gear drive that must be accelerated. Actually, the camera is trying to stand still in space.

LT. HOLMES (U. S. Coast & Geodetic Survey): How do users of automatic mounts that have eliminated the operator accomplish the changes of the magazines when more than one roll during the flight is to be exposed?

MR. PALLME: So far as my experience goes, they probably do not accomplish that. There is certainly a possibility for setting up methods of doing it. Or larger rolls of film could be used.

MR. LAYLANDER (Photogeologist): I do photographic work, and change magazines in flight. It's not very difficult if you have your camera where you can reach it.

The Role of the Airplane in Aerial Photography

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ABSTRACT: *The basic requirements of an aerial negative in engineering photography are discussed. The effect of image motion on detail and the relation of aircraft design and operation to image motion, both for large and small scale photography are described. The relationship of airplane productivity to photography cost is pointed out along with individual problems in aircraft available to commercial operators. Also discussed are the problems of crew efficiency and safety and how they are connected with the quality of photography.*

EACH year we attend this convention to exchange ideas and to learn the progress made during the year by the many engineers and authorities in the field of photogrammetry. Personally, I come away excited by new potentialites and eager to put them into operation. Then I return to my office—only to face cold, hard reality!