PERFORMANCE OF AIR FORCE MAPPING CAMERAS*

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ABSTRACT

The paper presents a review of past mapping cameras which have been used operationally by the Air Force for mapping purposes. The relative merits and deficiencies of the cameras are presented. Other components of the photo mapping system are discussed relative to their deficiencies when compared to the mapping cameras. These components consist of the aerial film and the aircraft camera window. It is concluded that in order to utilize the mapping camera effectively, extreme care must be used in selecting and installing the windows and in the handling of the aerial film.

THE purpose of this paper is to review briefly the performance of past and present Air Force cameras used for mapping purposes. This review will consider the metric aspects of the cameras and how they compare with other components of the complete camera system.

Previous cameras were basically of the 6-inch focal length, 9×9 inch format variety, with several variations of other focal lengths and format sizes being present during the earlier years of the aerial map making industry. Some of the camera variations just mentioned are still used by commercial mapping organizations, and are doing the job for which they were designed. These cameras for various reasons, are unsuitable for Air Force use. They included a three lens camera, and the T-3A mapping camera with 5 lenses, which was used both singly and in tandem. The first camera having a 6-inch wide-angle lens and a 9 by 9 inch format, and which was used extensively for photogrammetric purposes, was the K-17 camera. This was designed basically for reconnaissance purposes. It utilized a 6-inch metrogon reconnaissance lens and had a film capacity of approximately 250 exposures. This camera was a major milestone along the road of photogrammetric progress. It presented the photogrammetrist with a single aerial negative showing 32.5 square miles of the earth's surface from 20,000 feet altitude. This was very satisfactory as far as it went. For charting purposes the camera was adequate, as it was used in a tri-camera installation which provided a 180 degree angle of photographic coverage. However, when attempt was made to adapt the camera for precision mapping purposes, much was left to be desired. First, specifications permitted the lens to have a total of 0.240 millimeters of radial distortion. Next, there existed 6 pairs of mating surfaces between the lens and the magazine platen or focal plane. Assuming conventional manufacturing tolerances of ±0.001 inch per mating surface, there could be up to 0.012 inch displacement of the platen with respect to the lens. This was increased by 0.003 inch full indicator reading for variation in flatness of the magazine platen which, with age, usually became greater. Also, the camera fiducial markers were contained in the magazine base casting. These indicated the center of the aerial negative and had no particular relationship to the optical axis or point of symmetry of the lens distortions, except as given by the element of chance when the magazine was installed on the camera body. Even this relationship was changed with each different magazine that was installed on a given camera body. The main selling point for using the camera for mapping was that it was reliable and that it was available; in the middle of World War II, K-17 photography was the only photography available from which to make the urgently needed maps.

Following recognition of the shortcomings of the K-17 camera, a new precision mapping camera came into being. This was the type T-5 mapping camera. It was equipped with a 6-inch metrogon lens, which had been hand selected for controlled distortion. A special group of lenses, having similar distortion curves were selected for use in the T-5. The similarity of these lenses enabled the optical industry to design a reduction printer lens

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which would remove most of the radial distortions while reducing the T-5 camera's 9×9 inch aerial negatives to 54×54 mm. glass plate diapositives for use in the Multiplex equipment. Having reached a satisfactory solution to the lens problem, the next step was the design of the focal plane and fiducial markers into the camera body along with the data recordings. Upon completion, the T-5 camera represented the first Air Force mapping camera as it is known today. Unfortunately there were camera maintenance problems which limited its operational use in general to the continental limits of the United States. The next logical step was to utilize the good points of the T-5 mapping camera, to improve on them, and to design a new camera.

Next to reach operational use was the T-11 mapping camera; this currently is in extensive use. Briefly, it has the same handpicked 6-inch metrogon lens as the T-5 camera. This lens is designed into the inner lens cone of the camera and, once the lens cone is assembled and calibrated at the factory, it is never disassembled during service use. The cone contains all the geometric precision components of the camera which affect the mapping photography except the magazine platen, or vacuum back, which positions the film in the focal plane. Extreme care is also exercised while fabricating the camera to maintain the focal plane parallel to the lens seat to 0.0005 inch. The fiducial markers indicate the point of symmetry of the lens radial distortion to ± 0.05 mm.; the platen of the magazine is flat to a full indicator reading of 0.001 inch. This means that the mechanics of the camera have been eliminated from contributing any significant errors in the mapping photography. However, a lens problem remains because the ultimate mapping camera is one which introduces no significant optical distortion into the aerial mapping photography and therefore does not require the introduction of any corrective devices into the map compilation equipment.

The Planigon Lens can fulfill the "no optical distortion" requirement for precision mapping photography and has been designed into a new Air Force camera called the KC-1 mapping camera. It is identical mechanically and electrically with the T-11 camera. At this point, when using the Planigon Lens, the mapping camera can be eliminated from the complete system as one of the variables which contributes significantly to the geometric distortion of the aerial negative's terrain detail.

Some of the other more tangible items which can be considered as part of the system are the film and aircraft camera windows. The standard window used in a military aircraft for mapping purposes is called a Group M window. This is at least ¾ inch thick. The surfaces of the glass are parallel and have a wedge angle of less than 4 seconds and a wedge angle differential of less than 4 seconds of arc. This means that with glass having an index of 1.5 and the 4-second differential wedge angle, a light ray striking the surface of the glass at 35 degrees off the camera axis will be displaced approximately 18 microns on the focal plane of the camera. This figure assumes ideal conditions with no temperature or pressure differential on the window surfaces. Since the camera compartment of a mapping aircraft is usually pressurized and temperature controlled, these conditions to some extent influence the resultant image displacement due to the window deflection. As the aircraft pressurizes with altitude, the window tends to deflect outward, the amount of deflection being proportional to (1) the pressure differential exerted upon the glass, (2) the size of window opening and (3) the thickness of the glass. In turn, as the heat of the aircraft is increased on the inside and the defrosting airflow is turned on, a temperature differential is established between the surfaces of the glass. The created effect is to deflect the window toward the warm air due to the expansion coefficient of the glass. The deflection is proportional to the thickness of the glass and is inversely proportional to the effect of pressure on the window. This means that under a certain set of conditions, the temperature and pressure effects compensate for each other, and at other conditions, the window will deflect either to the inside or outside of the aircraft, the amount of deflection being dependent on the severity of the conditions. Compounded with these effects are stresses and deflections created by the mounting of the window in the aircraft and fluctuations within the airframe. Unfortunately, data on exact distortions resulting from the above would be all but impossible to obtain, and the best that can be done is to minimize the effects consistent with military operational equipment requirements. One additional point on the subject of camera windows is that the Group M type glass windows are very costly and difficult to obtain. This results in only the mapping camera station in the aircraft being equipped with the Group M windows. Other windows may have 30 seconds and greater wedge angles present. In general, if cameras such as the KC-1 are to be effective and yield the accuracy designed into them, only the Group M windows must be utilized, or better yet, no window at all.

The remaining major contributing factor to image distortion that will be discussed herein is the aerial film. The film records the terrain image in the camera under various temperature and humidity conditions. After exposure, the film is processed and dried, is placed in storage and, at some later date, is used by the photogrammetrist in compiling maps. Once the can of film is opened prior to exposure, the dimensions of the film are in a continuous state of change from then on. The environmental conditions encountered by the film base affect the dimensional stability of the base in four different ways: (1) processing results in shrinkage; (2) with an increase in humidity, the film base is expanded; (3) with a decrease in humidity, it is contracted; and (4) with age, the film base tends to contraction. During the changes in environmental conditions, the resulting change in dimension will be greater per unit of length across the film than along its length. There is an ever-continuing effort being made to improve film bases; as improvements are realized the film specifications are corrected accordingly. This insures that the very best material possible is used in the aerial film. Current specifications on mapping film, designated Type 1A film base, permit the following approximate dimensional characteristics when the film is processed and handled under normal conditions:

a. Humidity effect—a 50 per cent change in relative humidity will result in a nominal change of 0.045 inch per 9 inches of film, with 0.0045 inch differential shrinkage between the 9-inch length and width dimensions of the film.

b. Processing effect—As the result of processing, film base will shrink a nominal 0.009 inch per 9 inches of film, with 0.0027 inch differential shrinkage between the 9-inch length and width dimensions of the film.

c. Storage effect—When the processed film is stored under given temperature and humidity conditions, the film continues to shrink with age. If the film is not processed or dried at proper temperatures and drying rates, the above dimensional changes can become much larger and more unpredictable. This necessitates constant vigilance over film processing and drying techniques, in order to minimize their effects. In addition to the preceding, if by some chance the Reconnaissance Type 1B film is used for mapping, the dimensional instability can be expected to increase by a factor of two.

In summarizing briefly, the entire system will be considered and the "precision" capabilities of the various components compared. The mapping camera before leaving the factory has proven itself through calibration and testing, to be a precision instrument. In the case of the T-11 camera, the lens seating plane, focal plane and platen are controlled to the point where no significant radial or tangential distortion results therefrom. The precision of the camera is limited by the optical characteristics of the Class T Metrogon Lens. The KC-1 camera, having identical mechanical design with the T-11 and using the Planigon Lens, is capable of producing mapping photography with no significant distortion. Use of the Group M windows, which are (1) clean, (2) installed in the aircraft in such a way as not to introduce warpage of the glass, and (3) not under the influence of temperature and pressure, can be expected to introduce up to approximately 18 microns distortion at the focal plane at 35 degrees off axis. If other than the above windows are utilized, the distortion can be much greater. If the film used in the camera is Type 1A topographic base and if it is processed and dried according to instructions, a differential distortion with a 50 per cent change in relative humidity can result in 0.0045 of an inch or 115 microns distortion. Added to this will be approximately 0.0027 of an inch or 69 microns differential shrinkage. Any deviation from the use of type 1A topographic film and proper processing and drying procedures can result in even greater distortion being present in the aerial photography.

From the preceding one might be led to believe that it is all but impossible to make precision maps from aerial photography. On the other hand, acceptable photographs have been made over vast areas of the earth's surface. Also there are instances, when photography is taken over controlled areas, that local disturbances occur in the stereo model. This being true, it must also be assumed that these disturbances occur over the uncontrolled areas. These disturbances are explained by (1) differential shrinkage or distortion of the film; (2) window deformations; (3) possible air turbulence; and (4) in the future high-speed aircraft, the cause may be shock waves.

In weighing the various component's capabilities to produce the degree of precision desired of mapping photography, the camera apparently has neared its goal. The windows and film bases, however, are under outside influences, which are very difficult to control by man; and, as such, are somewhat difficult to predict at the present time. The making of aerial negatives is the result of the entire operation of the system. Any part being deficient will result in an inferior product. In the correction of the weak points of a system, care must be exercised not to lose sight of any single part of the system, and all effort must not be expended on just one part.

In the future, when more data on the window problem are obtained, and with the advent of improved film bases, the photogrammetrist will receive the type of mapping photography which will make compilation of maps much easier.

ESTIMATION OF VERTICAL EXAGGERATION IN STEREOSCOPIC VIEWING OF AERIAL PHOTOGRAPHS

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PUBLISHED articles on this topic give such different results that one is left wondering in what way they are related and what is really correct. Some writers have tried to give a simple working method without explanation, while others have tried to give mathematical proof for statements made. Some made only qualitative evaluation, while others made quantitative studies. Aschenbrenner[1] reviewed the literature in December, 1952, pointing out conflicts which were largely a result of differences in the points of view of the photo interpreter and of the multiplex operator. Under the circumstances of different points of view and varying purposes, it is not surprising that the results look quite different. It is much more surprising to find conflicting statements about the qualitative effects of different factors. Conflicts are to be found even among three articles published in a single issue of PHOTOGRAMMETRIC ENGINEERING (Sept., 1953), only a few months after Aschenbrenner presumably clarified the situation.

It is the purpose of this paper to examine certain published articles on vertical exaggeration as experienced by an air photo interpreter (or "relief stretching" as Aschenbrenner calls it) to determine the strong and weak points of each, and to evaluate them for accuracy and practicality for use. In conclusion, it is proposed to offer a formula which has general application, but one which is still accurate enough for most purposes and simple enough for easy application. Field testing of different formulas is invited.

I. A REVIEW OF SELECTED ARTICLES

Kirk H. Stone[2] chose to call vertical exaggeration, "Appearance Ratio, or ApR." He gives an empirical formula, with no mathematical development, for the ratio of the "apparent height of objects in stereovision to the way they ought to look through the stereoscope."[3]

[1] Aschenbrenner, Claus M., "A Review of Facts and Terms Concerning the Stereoscopic Effect," PHOTOGRAMMETRIC ENGINEERING, Dec., 1952, pp. 818–823.

[2] Stone, Kirk H., "Geographical Air-Photo-Interpretation," PHOTOGRAMMETRIC ENGINEERING, Dec., 1951, pp. 754–759.

[3] *Ibid.*, p. 757.