*The KC-2—A Modern Convergent Camera System**

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ABSTRACT: *This paper describes how a modern Air Force camera system is created. The KC-2 camera was designed with the future in mind. Camera systems of the future must be smaller in size, lighter in weight and must be able to operate in an entirely new environment—heat up to 300° F. All of these conditions have been considered in the subject camera system. In addition, even more important conditions—the photogrammetric requirements—have been considered carefully. It is suggested that a modern convergent mapping camera with rigidly fixed relationships between inner cones will open up new fields for stero plotting equipment and for aerial triangulation techniques.*

IN THIS fast moving life of today where ideas and new technology are conceived and reduced to practical equipment in a very short period of time, many new techniques, processes and tools are made available to the scientific world. The purpose of this paper and the three others read today at this meeting is to introduce, to Industry and the Military, the KC-2 Convergent Mapping and Targeting Camera and its stabilized mount.

It is our sincere hope that this series of papers will give an understanding of the equipment, and provide some thought by you on what the system can make available to you in your particular area of work.

This equipment is principally a high-altitude system. The camera and mount were designed as a system because it was planned that they do a particular job in a given environment; thus, the camera and mount were made for each other, even though they were designed by different manufacturers. The first three questions that will surely come to mind about the system are, "What is it?," "How does it work?," and "When can we have it?" A fourth question is, "What can it do for the Military and Industry?" This can only be partially answered since it relies for the most part on how it is applied and the use made of it as a system. I will try to explain what the system is and when we will have it; the other papers will describe how the system works.

Delivery of the first model is expected in July of this year, even though the contract schedule calls for October, 1958. The camera contains two matched planigon lenses in a single body casting. Each of the two magazines will hold 250 feet of Super XX aerographic film or approximately 400 feet of thin base film. The camera and mount must operate satisfactorily under conventional aircraft ambient conditions, and in certain military applications for two hours in an aircraft compartment whose ambient temperature range is −100°F. to +300°F. For those who are not familiar with convergent photography, perhaps a word or two concerning it is now in order. Also there have been some fine papers in PHOTOGRAMMETRIC ENGINEERING on this subject, so a detailed explanation does not seem appropriate.

The primary justification for using convergent photographs is the increase achieved in the base-height ratio, and the savings in plotting time as the result of fewer models for equal-area coverage. For vertical photographs with a given overlap (say 60 per cent) the base-height ratio has a direct relationship to the angle of coverage

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of the lens-camera combination. For a 6″ focal-length, 9″×9″ format camera, the base-height ratio is 0.60; and for a 12″ focal-length, 9″×9″ format camera, the base-height ratio is 0.30. The base-height ratio is important, because the accuracy with which one can measure vertical heights by stereoscopic means is, generally speaking, proportional to the base-height ratio, all other things being equal. As long as we use vertical photographs made from standard wide-angle lenses (such as the Planigon, Metrogon, Topogon, Aviogon, Topon, etc.), we are limited to base-height ratios of about 0.60. This ratio can be increased only by increasing the distance between exposure stations. We can do this in vertical photography by using a wider angle single lens, such as the super aviogon, *or* we can use convergent photography.

Figure 1 shows the air base and the ground coverage for a vertical wide-angle lens camera, for a vertical super wide-angle lens camera, and for two wide-angle-lens cameras in a 20° convergent orientation. From this, it can be seen that the air base—that is, the distance between exposure stations—can be doubled in a 20° convergent installation without changing the angle of coverage of the lens.

I do not want to give the impression that by using a convergent instead of a vertical installation all plotting accuracies are doubled without any additional costs. It is true that vertical heights on convergent

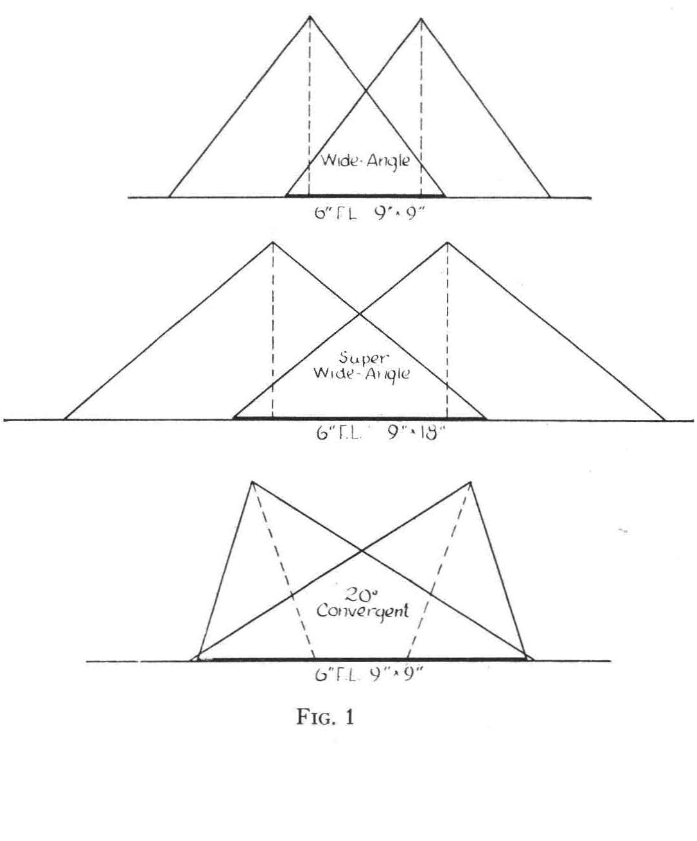

FIG. 1

photos can be measured to about twice the accuracy as from verticals, but there are new problems of control extensions, horizontal positioning, fall-off in resolution, etc., which are still being studied.

Since requirements for war-time mapping are essentially the same as 15 years ago, the Corps of Engineers has been forced to explore every possible means for increasing its plotting accuracies, because the Air Force has been forced to fly its mapping aircraft higher and higher for safety reasons.

If one analyzes a convergent camera system to determine just what characteristics in the camera influence the speed of map compilation, plotting accuracies and camera utility, the following items become apparent:

a. Lens distortion and resolution
b. Camera calibration and dimensional stability with respect to both mechanical and thermal environment
c. Platen flatness and vacuum system efficiency
d. Synchronization of shutters
e. Angular precision between the lens optical axis
f. Film resolution and dimensional stability
g. Accuracy of exposure of the aerial film
h. Size and weight of the camera system
i. Window size and quality
j. Camera verticality at time of exposure.

Most of the work to date has been on the development of techniques and equipment for evaluating the photography. This is the first time in this country that a special camera for military use has been developed for taking convergent photography. It has been the constant goal throughout the entire camera program to optimize all the above parameters in order to provide a better base to improve plotting accuracies. In particular, and this is important, it is believed that the constant and calibrated relationship between the two photographs exposed simultaneously in the KC-2 camera will provide additional benefits which will be useful in analyzing the photography.

In addition a one-inch cathode ray tube has been designed into the camera for recording, on the aerial negative, coded binary data which makes possible automatic computation of geometric data useful in compilation work or automatic film handling, sorting, titling, etc. One can easily visualize shoran, hiran or other raw positional data being recorded directly on the film. After the film processing, the digital data can be scanned automatically and absolute aircraft positions can be computed automatically. This is only one use. I will not discuss it further. You, the user, can pick it up.

For many reasons, modern, high-performance military aircraft not only fly higher, but also faster, than those used only a few years ago. Aircraft of the future will fly even faster, and a new environment will be created—that of extreme temperatures caused by thermodynamic heating or the so-called thermal barrier. The present method of providing proper environment in the camera compartment is either to utilize engine heat for warming or to provide air conditioning for cooling. These work fine but both have limitations and, in the case of the cooling, it is subject to a very expensive aircraft fuel-to-weight ratio. One can easily add over 1,000 pounds of system weight to such an aircraft. Then, logically, if this requirement can be eliminated, we have room for other more profitable payloads. If one refers to standard NACA temperature charts, it can easily be seen that the range of temperature environment of minus 100°F. to plus 300°F. is not unrealistic. Conventional cameras and films will not function properly in temperatures below 0°F. or above plus 160°F. unless properly protected. Provisions are being made in the KC-2 camera system to permit it to operate for a minimum of two hours in an ambient temperature of plus 300°F. and indefinitely at minus 100°F. I will not discuss details of this portion of the system since these will be covered in the other three papers.

Placing a camera in an aircraft of today, knowing the "status of the art," is much different from the relatively simple problems as were known in past aircraft, such as RB-17's, RB-36's, RB-47's, and the like. Today we know how to increase camera-lens-film, high-contrast resolution from previous values of 10 to 20 lines/mm. in the air to upwards of 40 to 45 lines/mm. This is made possible by improved lens and camera performances, fine-grain high-speed films such as the Kodak Aerocon on topographic base, improved stabilized mounts, and a better understanding of what is happening to the terrain image during the time the shutter is open (as the result of vibrations and angular accelerations). Most of this type of data is coming from work being conducted within the Photographic Branch of the Aerial Reconnaissance Laboratory at Wright Air Development Center.* In addition to the above, work is progressing on determination of just what happens to our higher-resolution, low-distortion image as the result of such things as shock waves, thermal gradients across the aircraft camera window, the camera lens elements, and within various components of the camera itself. Test data relative to some of the above points will be presented in the paper to follow. Other points not covered are still in the process of being solved and will surely be the subject of future papers.

One additional matter that should be included in this paper, since it is a part of the aircraft proper, is the camera window. Obviously it must be very high-grade and of mapping-quality. We go to the trouble and expense of getting a lens of less than 10 microns distortion and, unless the window is of proper quality, this benefit is lost. Because the optical axis is moved 20° off the vertical, and to this is added plus or minus 8° pitch-and-roll as the result of aircraft flight characteristics, the extreme image-forming light rays from the negative corners strike the glass at an incidence angle of approximately 73° off the vertical; with this angle of incidence, it is apparent the window flatness or lack of wedge must be the best that can possibly be obtained. Also, the thermal gradient must be nearly non-existent. In addition the flat ray angle creates another problem, and that is window size. If we consider using two standard KC-1 cameras, with plus or minus 8° pitch-and-roll and plus or minus 15° azimuth rotation, in a split mount, the window size is 34″ wide by 37″ long by $2\frac{1}{2}$″ thick. The KC-2 camera, having the lenses nearly touching, permits the window to be 25″ wide by 25″ long by $1\frac{1}{4}$″ thick, which is practical for fabrication. In some installations, this can be the limiting factor between installing a convergent system in a vehicle or not.

In closing I would like to make some acknowledgements even though there is always danger in mentioning names, because of the possibility of leaving someone out. However, it is important to mention some of the people and organizations who cooperated, encouraged and supported the KC-2 program. These include Lt. Colonel Surles and his group, Headquarters, USAF, Major Marshall's group in ARDC, Mr. Cude and Mr. Lorenz and the Engineering and Research Development Laboratories organization, Mr. Nowicki and Mr. Webb of the Army Map Service and the Operational Commands. Without this support this system would not have been ready for delivery in the immediate future.

* *Photographic Science & Engineering*, Volume 1, No. 3, January 1958, "Internal Camera Vibrations & Their Effect on Resolution."