AIR FORCE PHOTOGRAPHY

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I. INTRODUCTION

AIR Force photography has had as its basis the same few tools which the amateur needs to accomplish photography successfully with his $1.98 camera. A lens, and except as will be noted later—a shutter, film, a light-tight box to hold these components in proper relative position, photographic chemicals, sensitized paper, and a printer; these complete his list of apparatus and material. Small wonder then that the amateur photographer is numbered in the millions. Why then any problems, any complications, any difficulties in Air Force photography? While this photography, until very recently, could be accurately described as aerial photography, it encounters, or more truthfully, produces problems, because it is forced to do things the hard way; this shall be indicated shortly.

The two main functions of photography (which term for purposes of this paper shall be used synonymously with Air Force photography) are:

First: The securing and rapid recording of large quantities of detailed information; and

Second: The summarizing and transmission of information in permanent, easily distributable and convenient form.

These two functions are accomplished within three main divisions of photographic effort. The first two of these divisions—photographic reconnaissance and photographic mapping and charting—are well-established and bear considerable resemblance to each other, both in type of instruments used and in their photographic subject matter. The third main division is a comparative newcomer, but in the language of the racetrack, "it's coming up fast on the outside." This newcomer is photographic instrumentation and instrumentation photography. These three fields will be discussed separately.

II. RECONNAISSANCE PHOTOGRAPHY

To the Air Force, photographic reconnaisance has meant a system of securing high definition—i.e., sharp photographs of targets which may range in size and interest from the barbed wire entanglements of the Normandy beaches, the first V-1's discovered at Peenemunde, and tanks proceeding under assumed cover of darkness, to bomb damage assessment or planning photographs of entire cities, airfields and industrial plants. Various official estimates have indicated that about 80 per cent of all the information secured on our enemies and their activities in this last war was obtained from photography.

To see why Air Force photography is difficult, let us first consider the requirements a photographer might set were he given the job of producing aerial photographs of an industrial area. Carefully selecting his camera and lens, he would ask for his favorite emulsion coated on a glass plate. After calculating the minimum altitude which will nicely frame his composition, he would ask for a balloon to be held in readiness to go aloft at a given time on the first clear, sunny, non-windy day. Realization of these circumstances will certainly result in a high-quality photograph of the target.

Air Force photography, on the other hand, is now prepared to photograph anything—at altitudes ranging from 40 to 40,000 feet, under light conditions ranging from darkness to bright sunlight, at airspeeds ranging up to 600 miles per hour. The problems posed by this encompassing operational range derive from the interacting requirements that first, the equipment shall operate, and second, that the detail resolved in the resulting photography shall approach the definition on photographs made in the laboratory.

Let us consider the latter requirements namely the performance goal sought in aerial photography. The detail recorded in a photograph is specified in terms of the number of equal spaced black and white lines per millimeter which are just distinguishable on the photograph. Under laboratory conditions, with one of our better lenses, on film similar to that employed in the air, and through using a collimated beam projecting a target consisting of many 3-element sets of black and white lines, the general level of obtainable definition is about 35 lines per millimeter. This means that, with an ocular, the observer can just distinguish lines at the rate of 35 black and 35 white lines per millimeter; in this case each line is 1/70 millimeter or .00056 inches in width. When the transition to airborne photography is made, numerous deteriorative effects arise—some obvious, others more subtle. The integrated effect of these deteriorative factors has been to reduce the average photographic resolving power realized during the last war to approximately 12 lines/mm. or one-third of the laboratory value, this low figure containing the effect of an upward trend, since at the beginning of the war, photographic quality averaged about 8 lines/mm.

The most obvious single effect operating to reduce the observable detail in an aerial photograph is the image motion due to the forward aircraft motion. Easily calculable, this image motion is normally reduced by using high shutter speed, which reduces the time during which the image is blurred on the film. However, the shutter speed which will successfully reduce image motion to negligible value is not practicable except under ideal illumination, and this, like many other ideals, is seldom realized and is an uncontrollable variable. One solution to this problem is afforded by continuous strip photography, which uses no shutter at all. The S-7 Continuous Strip Camera, developed by the Air Force, and used widely during the war by both the Air Force and the Navy, employs a variable-speed film drive, which moves a 200-foot roll of $9\frac{1}{2}$-inch wide film past a narrow slit in the focal plane of the camera at a speed exactly equal to the image speed, thus producing a long continuous photograph of everything below the camera as it passes over the terrain. Exposure is therefore a function of lens aperture, film speed and slit width, and can be properly varied to meet light conditions. Synchronization of film speed and image speed is done automatically by an auxiliary photo-electric ground scanner which in effect calculates the instantaneous angular velocity of the plane with respect to a ground point below. As it permits photography under the adverse conditions of little light and with extremely low altitudes, this camera has yielded remarkable photographs under very poor light conditions; on the other hand it could make on a single roll of film a continuous photograph of the United States from the Atlantic to the Pacific Coasts, covering a ground strip 10 miles wide and 2,500 miles long. The now-proven principle of image motion compensation is being extended to conventional aerial cameras, employing shutters, with similar salutary effects upon resulting definition in the photograph.

Image motion with respect to the film and resulting blur or loss of detail results also from angular vibration of the camera and the several angular motions of the aircraft—pitch, roll, and yaw. The ordinary concepts and application of instrument shock-mounting suffice to prevent or reduce vibrations which might otherwise damage the instrument, but are inadequate for camera mounting problems. An angular motion of 1,10,000 radian or $\frac{1}{3}$ of a minute of arc, during the exposure with a standard 40-inch focal length lens, will suffice to reduce definition in the direction of motion to less than 10 lines/mm. For numerous reasons, center of gravity mounts, which could transmit to the camera only non-harmful translational motions with respect to the original position of its optic axis, are impractical. Careful study and research during the war has indicated that much promise may be expected from a new type mount embodying a helical spring support and a dry friction damping system. Prevention of angular motions of the camera due to corresponding motions of the aircraft is essentially the problem of camera axis stabilization. This problem, of fundamental importance to mapping photography, will be discussed later.

The lens problem has been of the utmost importance but fortunately marked by great progress in the last few years, a progress which has carried us beyond the best photographic optics produced by the Germans. Air Force lenses used in aerial photography vary in focal lengths from $3\frac{1}{2}$ inches to 100 inches, with peculiar problems of focus arising with lenses 24 inches and greater in focal length. Early in the war, serious discrepancies were noted between laboratory focussed 40-inch lenses and their performance at altitudes of 30,000 feet. A theoretical investigation yielded the then amazing result that the change in index of refraction of air from sea level to thirty thousand feet was sufficient to shift the focus by more than a millimeter. Further extensive theoretical and experimental work established and measured the temperature and pressure effects upon the focus of aerial camera lenses, and culminated in the design, production, and use during the war of the Baker 40-inch f/5.0 telephoto lens, embodying automatic temperature and pressure compensation, and, in addition, automatic air pressure—responsive focussing at all altitudes above 2,000 feet. It is now known that neither the Germans nor Japanese were aware of these effects. As a result of improvement in lenses and techniques, the old dream of the aerial photographer—to take photographs of railroad ties from heights of 30,000 feet—is no longer a goal but is an every day actuality.

Night photography finds its origin in the desire and necessity to photograph activities and movement proceeding under cover of darkness. This is accomplished by two distinct systems. The first, older and more widely used, employs a magnesium flash bomb weighing up to 85 pounds as the illuminant. Dropped from the aircraft, this bomb is so ballistically constructed as to fall just outside the cone of vision of the special night aerial camera. In general this camera uses a 12-inch f/2.5 lens on the standard 9×9-inch format. Detonated at a predetermined altitude, this bomb reaches its peak output of three hundred million candlepower in about 15 milliseconds. The initial flash from the bomb trips a photo-electric cell circuit which in turn trips the camera shutter well before the bomb light peak is reached, thus accomplishing on a grand scale the job which is commonplace to the working news-photographer.

The Edgerton flash principle—discharge of the stored energy of a capacitor through a rare-gas filled lamp in a very short time interval—has also found considerable application to night photography. The largest presently used night spark flash assembly is the D-3 Unit. Weighing 3,500 pounds, it discharges the energy stored at 4,000 volts in a capacitance of 7,200 microfarads through a gas tube in 1/200 second and enables synchronized flash photographs to be taken from altitudes as great as 12,000 feet.

If only one photograph per mission were to be taken by an aerial camera, enormous simplification in camera construction and operation would result. The host of mechanical and electrical problems posed by operation of these cameras arises because as many as 500 photographs may be taken per camera per mission, at cycling rates varying from 2 or 3 photographs per second to one photograph every two minutes. A four hundred foot long roll of standard aerial camera film weighs 18 pounds. In making successive exposures, a new piece of film must be brought into the focal plane, accurately positioned, stopped, held flat during the exposure by application of vacuum to the back of film through a specially constructed plate, and then removed from the focal plane to make way for the next exposure. For the moving film or image motion compensating magazine, the film speed must be brought up to synchronizing speed at the time of exposure. The camera and associated electrical equipment, such as intervalometers, must be constructed so as to successfully perform this discontinuous function at least 10,000 times without breakdown. Operation and life of these cameras cannot be compared with that of an electric motor for example, but could better be compared to the action of a gun, wherein one cycle may be separated from the second by times extremely long in comparison with the minimum cycling time.

The photographic reconnaissance problem which remains is to close the already narrowing gap which exists between laboratory or theoretical performance, and actual performance. The figure earlier given for average resolving power attained in the air can now be boosted to about 20 lines/mm. by optimum use of careful techniques. Of necessity the approach to the goal must be asymptotic. Even before it is within realizable grasp, the attempt to lift our sights by continuing improvement of film emulsions and lenses may well change the goal from 40 lines/mm. to 70 or 100 lines/mm. By the standards of the Air Force's photographic engineers who have contributed much in design and technique to aerial photography, much remains to be done. Integrated, simplified, and perfected aerial photographic systems with all components of equally high quality must replace modifications, changes, and composite systems still containing relatively weak links.

Film and print processing control and equipment—the ground machinery necessary to complete a photographic mission—may not always have the glamour associated with the aerial camera, but this absence of glamour has never operated to reduce the complex engineering problems present in making equipment which must be light and capable of being easily transported by air, but rugged, simple in construction, and precise enough to handle a tremendous volume with a minimum loss of resolving power or definition in the final prints.

III. MAPPING AND CHARTING PHOTOGRAPHY

Mapping and charting photography, the second main division of Air Force photographic effort, has the simply stated job of mapping and charting the world. Its problems are those of apparatus and technique; the present trends are the replacement of arduous, painstaking, tedious technique and analysis with apparatus which will eliminate work, and the development of apparatus to accomplish tasks heretofore impossible.

Consider the requirements involved in constructing a suitable map of a given area from an aerial photograph. The camera focal plane should be parallel to the area being photographed, the lens should introduce no distortion in its representation of the view, and introduction and use of the recording medium—the photographic film—must likewise introduce minimum distortion. Techniques for using photographs so made must be devised so that an accurate map may be assembled, so that distances and directions determined from the map are correct.

The aerial cameras constructed to meet the several problems posed by mapping are fundamentally the same as reconnaissance type cameras. Differences lie in the type of lens used and the precision of manufacture and assembly. The present standard mapping lens is the 6-inch focal length Metrogon lens, which covers a plate area nine inches square. This wide-angular coverage is necessary for economy and speed, because at 40,000 feet altitude one camera equipped with a Metrogon lens will photograph 130 square miles! This lens, which has a maximum distortion of .005 inch from the center to the edge of its field, must be carefully centered, and must be mounted in the camera so that first, its optic axis is within one minute of perpendicularity to the focal plane, and second, that the optic axis intersects the focal plane at a distance less than .0005 inch from the center of the photograph.

All of the care and precision which go into the mapping camera are wasted if the recording medium does not have dimensional stability. The dimensional stability of emulsions coated on glass plates is closely approached and, in a practical sense, is reached by the special films used in topographic or mapping photography. These films have a shrinkage coefficient due to processing of approximately .06 per cent with a differential shrinkage coefficient (the difference between lengthwise and crosswise shrinkage) about one-tenth the previously stated coefficient. More important than this permanent shrinkage effect is the relative humidity expansion effect; this must be carefully controlled in all precision work.

Unless ground control—knowledge of the three-dimensional coordinates of at least three ground points in each photograph—is available, it is not possible to determine either the altitude or orientation of the camera at the moment the photograph is made, and no accurate map can be constructed. With ground control available, either tedious analytical computation, or complicated laboratory procedures such as multiplex methods are necessary before the map can be made. The tri-metrogon system of charting, wherein are used one vertical and two obliquely mounted cameras to produce a strip covering from horizon to horizon, served to produce badly needed navigational charts during the war, but this system is basically unsuitable for precision mapping and does not furnish an acceptable solution. The length of computing time per photograph, which may vary from an hour to several hours, and the difficulties and time required for the multiplex optical projection method form a bottleneck in mapping; this bottleneck may be broken by development of special mechanical computers and/or new analytical techniques. The foregoing comments apply where ground control is available, a rare situation in the presently unmapped parts of the world.

None of the foregoing problems would arise were the exact altitude of the aircraft known at the instant of exposure and the optic axis of the camera were vertical. Further intensive development of the already remarkable radio altimeters may furnish the most probable solution for the first condition. Verticality of the optic axis, however, poses a problem not yet satisfactorily solved as the best available gyroscopically-controlled camera mount will insure verticality to not more than 20 minutes of arc. The permissible maximum deviation from the vertical which will permit direct use of the photograph is of the order of 4 or 5 minutes of arc. It should be noted that, as in the case of antivibration mounting, camera stabilization requirements exceed by an approximate factor of 10 the performance characteristics found satisfactory for most other applications of gyro-controls. A great amount of work on camera stabilization has been accomplished, and, among other purposes, has served to delineate the difficulty and complexity of the problem.

The wartime development of Shoran—short-range radio navigation—has advanced mapping science tremendously within the past two years. Two ground Shoran stations, whose geographical coordinates are known, re-transmit radio impulses received from an aircraft back to the aircraft, which must be within sightline distance of both stations; the Shoran receiver in the plane then translates the inter-pulse time into distance from ground station to aircraft station. Triangulation yields the aircraft position at any instant within ±25 feet. A special instrument camera, the operation of which is synchronized with the operation of the mapping camera, photographs the mileage counters of the Shoran receivers, thus identifying the location of each aerial photograph. Several examples of the use of the line-crossing technique to measure interstation distance will serve to indicate the potentialities of Shoran methods. It is clear that if an aircraft flies a course which intersects the line joining two Shoran ground stations, the sum of the distances from plane to each station goes through a minimum when the line joining the two stations is crossed. These distances, given as distance traveled by the radiated pulse are not truly geodetic, but are rather the curved radio paths, and must be corrected for altitude and radio path to get great circle distances. During the summer of 1946, the 574 mile distance from Custer Peak, South Dakota, to Kansas City, was determined with a difference of only 21 feet from the Coast and Geodetic Survey figure. The Kansas City-Pikes Peak distance differed by only 42 feet from the 564 mile figure of the Coast and Geodetic Survey. The Custer Peak-Pikes Peak distance of 379 miles differed from the Coast and Geodetic Survey figure by 96 feet, but a spread of only 19 feet in repeated determinations throws possible suspicion on the given geodetic coordinates for Pikes Peak. The introduction and optimum exploitation of this remarkable new tool necessitates further research into velocity of propagation of electro-magnetic waves under the varying condition of humidity, temperature, and pressure, to yield the sought-for precision in distance determination.

Rapid working techniques and formulae for reduction of Shoran distances to great circle distances, taking into account the non-spherical shape of the earth, and computers to furnish a rapid least squares solution to the line crossing problem, are but several of the developments which must be undertaken.

When men walked across the country carrying transits, poles, and chains, it was relatively easy for the computers and draftsmen to maintain the pace. Now the pace that must be met is that of an aircraft flying 600 miles an hour, photographing 130 square miles in three-thousandths of a second. This is the challenge.

IV. INSTRUMENTATION PHOTOGRAPHY & PHOTOGRAPHIC INSTRUMENTATION

The third field of photographic effort—instrumentation photography and photographic instrumentation—became a vital part of Air Force photography with the advent and wide-spread use of different types of radar and the necessity of recording for future study the fleeting images formed on the radar scopes. At the start of this discussion, let us clarify our subject matter.

Instrumentation photography is the employment of photographic techniques and equipment to record the changing readings on meters, gauges, counters, radar scopes, television receivers and similar instruments. While it cannot be denied on semantic considerations that photographic apparatus so used is photographic instrumentation, it is perhaps better to reserve the latter term for the application of photography to the direct recording of phenomena in a manner suitable for subsequent detailed analysis, such as the spectrophotometry, total photometry, and photography of the atomic bomb detonations and the photography of V-2's and other missiles. These applications are marked by the absence of intermediary meters and counters. The photographic recording is direct.

Radar photography is now well developed and widely used. Photography of radar scopes was used during the war to make maps of enemy territory and cities; these radar maps were utilized in round-the-clock bombing through overcast.

Technical study of rocket flight by ground stationed phototheodolites, photographic recording of rocket characteristics by cameras mounted in the rocket itself, use of cameras to record the changing readings of instruments carried in upper air missile studies, terrestrial photography from heights never before realized, all open a new vista for photography. Accomplished now by use of modified standard equipment, these new photographic applications demand and will obtain apparatus specifically designed for the purpose at hand, permitting more positive operation under the peculiar conditions encountered.

Operation Crossroads—the Bikini atomic bomb tests conducted in the summer of 1946—furnished a preview of photographic things to come. Cameras taking 2,000 photographs per second—the longest focal-length aerial cameras, one of which weighed 250 pounds—specially built high-speed photographic photometers and spectrographs were all successfully employed. Radar recording cameras, remotely controlled cameras in uninhabited drone aircraft, television recording cameras located in mother control aircraft—recording what television cameras in drone aircraft saw of both instruments and the atomic bomb cloud—these made Crossroads the most outstanding single example of complete use of photography and, as noted before, a preview of applications to come.

V. CONCLUSION

What of the future? Not stated previously is the long-term photographic reconnaissance goal—the recording and transmission to a home station, from an uninhabited aircraft, and under all weather conditions, the ground detail below the aircraft.

Our mapping people will have no surcase from their labors until the earth is completely, accurately, and precisely mapped, and until it is possible to quickly remap any portion of the earth's surface. Speculation on the future of the new field of photography just discussed is difficult because so much of this field lies in the future, and so little is in the past. Its full import and potential when realized will make it at least coequal with the two older, more developed, branches of Air Force photography.

In closing this all too brief discussion, it may not be amiss to point out that futher developments of the very same photography so easily and successfully employed in war can be as easily, and, it is hoped, as successfully employed in the maintenance of peace, in continual and continuous inspection of large areas as required in any system of international atomic energy controls, and in all the other numerous activities of peaceful peoples.