MILITARY CAMERAS FOR HIGH SPEED AIRPLANES*

Revere G. Sanders
Liaison Engineer, Fairchild Aviation Corp.

EVERY thinking American is aware of the emphasis which is being placed upon the rapid achievement of adequate military strength in the interest of National Defense. In view of the progress and trends of the present war now being waged in Europe it is quite logical that our own Government is putting particular emphasis upon the very rapid development of the air arms of both the Army and the Navy. This emphasis upon the development of the air arms of both services goes beyond the development of an organization, beyond the development of the aircraft, into the development of every instrument and piece of equipment which is to be used by the air arms of the service. It is obviously useless to have the most up to date aircraft with the most experienced crew if the equipment which is carried is obsolete or unsuited to present day warfare. Just as the most modern combat airplane is of questionable value if it is equipped with obsolete armament, an observation airplane of most modern specifications is likewise useless if it is equipped with aerial cameras and other aides to observation which cannot take satisfactory photographs of records under modern conditions of warfare.

From the very start of the present conflict now being waged across the ocean, aerial photographs have played a tremendously important part. Because aerial photographs have proved their value the hard way, that is through actual trial under war conditions, it is no longer considered sufficient to equip observation squadrons with aerial cameras for photographic reconnaissance alone; but it is also considered imperative that practically every airplane capable of doing so carry an aerial camera of some description to record the effectiveness of bombing or the accuracy of aerial machine gunnery. Since aerial cameras definitely have their place in all types of military aircraft, it is not desirable to have the aircraft slowed down by obsolete camera equipment which can only produce good results at relatively slow air speeds. On the other hand, the cameras themselves have to be made to be suitable for photography in high speed bombers, attack planes and scouting airplanes. As if large increases in airplane speeds did not complicate the problem of aerial camera design enough, present day tactics call for operations at any altitude from the sub-stratosphere down to hedge-hopping.

It was not very long ago that a speed of two hundred miles per hour was considered the maximum at which a photographic airplane would travel regardless of whether it was engaged in aerial photographic mapping or in any one of the various types of aerial photographic reconnaissance or intelligence photography. As a matter of fact two hundred miles per hour was quite unusual and a speed of one hundred fifty miles per hour was more general. Within the last six or eight months however, the situation has changed radically. The speeding up of military airplanes has been so successful that each month it seems that the maximum speed becomes a cruising speed and a new maximum speed is established. Thus, in the space of only a few months we have seen speeds reach a proven maximum of four hundred miles per hour and reach a theoretical speed of five hundred miles per hour for airplanes now being developed.

It has often been said that the heart of an aerial camera is its shutter. The relative motion between the focal plane of the camera and the ground due to the high airplane speed combined with low altitude operation results in what is

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commonly known as "movement." This "movement" or "blurring" is a direct function of the shutter speed of the camera. Obviously, to be of value for military reconnaissance or intelligence work, a photograph must permit easy interpretation of all the details shown therein. The blurring, or image movement which could be caused under certain conditions of extremely high speed and low altitude operation might interfere with the usefulness of the resulting aerial photographs from the standpoint of military interpretation. Just how much the motion or image movement might be, just how much movement can be expected under various conditions, and just how much this movement interferes with the proper interpretation of the photographs are points on which, to date, there has been insufficient information. Opinions have been freely expressed as to the shutter speeds made necessary by the double requirements of photographing from high speed and low flying airplanes, but no one has brought forth a factual basis for the determination of shutter speeds necessary to meet the present and future military aerial camera requirements. It is the purpose of this discussion to offer a factual basis for the solution of this problem.

Before proceeding further, it is desirable to make a brief survey in a very generalized manner of the principal military camera equipment now in use. It will be soon found that the aerial camera in which the military services are primarily dependent at the present time for general mapping, reconnaissance, and intelligence photography is the standard K-3B camera equipped with a 12″ lens and a shutter having a maximum speed of 1/150th of a second. These cameras are equipped with shutters of the between-the-lens type and present day experience indicates that this type shutter is best suited to military photography. When one thinks of the problem of increasing shutter speeds, the first thought that comes into mind is the possibility of using a focal plane curtain type shutter such as is used in amateur cameras, which operate at unusually high speeds. Unfortunately the focal plane curtain type of shutter has numerous disadvantages when considered in connection with aerial cameras, which are sufficiently serious to make them of doubtful value for military aerial photography. A few of the important limitations of the focal plane shutters are as follows:

1. The distortion of shape, distances and angles due to the movement of the focal plane shutter, while minute, are nonetheless so serious that a focal plane shutter camera cannot be used for mapping or for any other purpose where it may be desired to make measurements from the resulting photographs.
2. Under present conditions of military aviation activities, it may be necessary for the airplane carrying the camera to fly at extremely high altitudes and then to descend rapidly to a low altitude. This rapid change from a very low temperature to a relatively high temperature causes a condensation of moisture within the camera which saturates every part. Moisture causes deterioration of the curtain shutter.
3. In order to protect the curtain against the moisture above mentioned, it is impregnated. When the camera is used in tropical countries this impregnation causes the shutter curtain to be somewhat sticky, impairing its operation and also leading to deterioration.
4. Single slit curtains do not permit much more than about three selective speeds. Multiple slit curtains or adjustable slit curtains are bulky and are somewhat more complex and do not stand up very well mechanically.

While the between-the-lens shutter at present on standard aerial cameras has a top speed of only 1/150th of a second, it has none of the disadvantages of the focal plane shutter. Furthermore, while it is difficult both from the standpoint of design and construction to increase the speed of the between-the-lens shutters which operate across large aperture lenses, it is nevertheless possible. Since both the Army and the Navy have a considerable number of aerial cameras having shutter speeds not in excess of 1/150th of a second, and since both services are in the process of buying new equipment for their future needs, the problem of aerial cameras for high speed airplanes breaks down into two parts.

1. To what extent and to what limits of aircraft speed and altitude does present day aerial camera equipment apply?
2. What shutter speed must be attained to make an aerial camera suitable for the present, and estimated future aircraft speed and ranges of altitude?

In order to obtain answers to the above two questions and to enable the engineers to set up a goal toward which to strive, members of the Technical Staff of the Fairchild Aviation Corp. conducted both theoretical investigations and practical air tests under average conditions. Of prime importance at the outset was the necessity of setting up one or more standards of comparison. As mentioned before, to be of any value, an aerial photograph must permit of easy interpretation. If the detail is confused or obscured by blurring or motion, the picture will be of doubtful value for military purposes. Therefore, the initial problem was to decide what constitutes objectionable blurring.

To find exactly what constitutes objectionable movement or blurring, ten separate air tests were made. A standard military camera was carried in a Company owned airplane. As you can well imagine, this Company owned airplane was not capable of speeds up to three hundred or four hundred miles per hour. As a matter of fact, with a good tailwind, it reached a speed of one hundred fifty miles per hour. However, this did not in any way interfere with the tests. A little consideration of the geometry of the problem will soon show that with the same focal length lens, an airplane flying, for example, two hundred miles per hour at an altitude of one hundred feet will attain exactly the same image movement as an airplane flying four hundred miles per hour at a two hundred foot altitude. The flight tests were made by flying the airplane at its maximum speed at ten different altitudes, each one a little higher than the previous one. The initial altitude was decided upon as a matter of experience. Each test consisted of taking a series of six to eight pictures. The purpose of this was to eliminate the possibility of the images being blurred due to an accidental sudden movement of the airplane in an airpocket. If only one picture out of a series of pictures was sharp it would indicate that the sharp picture was the standard of comparison while the others were blurred due to bumping of the airplane and not due to motion. Actually practically all the test pictures were uniform due to the fact that an effort was made not to take pictures in the midst of a bump. The following table shows the test number and the image movement measured in inches on the negatives for each of the tests.

Test Number	*Image Movement Inches*
1	.042
2	.042
3	.035
4	.022
5	.019
6	.015
7	.012
8	.009
9	.007
10	.006

The distances listed under "Image Movement" in the table above indicate the movement of each point image in the entire photograph. When one considers the actual linear distance represented by .042 inches or any other value in this table, it is hard to realize that any photographic details could be recognizable under such conditions of movement. However, the results obtained speak for themselves.

The entire range of the ten photographs was studied carefully to see the effect of blurring on them. In studying the photographs, the most important consideration at all times was to ascertain whether or not objects of military importance could be readily detected. Out of the group of ten pictures, the following classifications were made:

Test Photograph No. 2 was selected as having the maximum amount of blurring or image movement which could be tolerated. Inspection of Test Photograph No. 2 shows that its photographic quality is very bad due to the image movement, but inspection also shows that every ground object can be quickly and accurately interpreted.

It was estimated that the quality of a photograph midway between the qualities shown by Test Photographs No. 3 and No. 4 could be classed as "well useable." This quality, while not particularly good, is considerably better than that of Test Photograph No. 2. From the standpoint of accurate interpretation of military detail the photograph is quite satisfactory.

It was estimated that a photographic quality about half-way between that shown by Test Photographs No. 6 and No. 7 could be classed as being the beginning of the most desirable quality which makes photographs suitable for almost any military application.

Thus, three standards of comparison were set up on the basis of the above study and table, namely:

1. .042 inches movement, while pictorially undesirable, nonetheless permits fairly easy and accurate military interpretation.
2. An image movement of .028 inches may be classed from a military standpoint as "fair" pictorially and quite good from the standpoint of accurate interpretation.
3. An image movement of .0135 inches or less can be classed as sharp pictorially and of maximum value from the standpoint of military interpretation.

With these finite values set up to govern blurring in a quantitative fashion it was possible to analyze blurring with respect to airplane speeds and altitudes of operation.

An analysis of the image movement in a photograph resolves itself into the following factors:

1. The shutter speed of the camera.
2. The focal length of the camera.
3. The speed of the aircraft carrying the camera.
4. The altitude from which the photographs are made.

These factors can be combined into ane quation in terms of blurring as follows:

M = Image movement expressed in inches.
H = Altitude of flight expressed in feet.
F = Focal length of camera in inches.
S = Photograph scale in feet per inch.
V = Ground speed of aircraft in miles per hour.
T = Camera shutter speed in seconds.

Airplane movement over ground in feet per second $= 1.467 \times V$

Airplane movement during exposure $= 1.467 \times V \times T$

Image movement during exposure $(M) = \frac{1.467 \times V \times T}{S}$

$S = \frac{H}{F}$

In this specific case $F = 12''$ and $T = 1/150$ second

Thus $M = 1.467 \times V \times \frac{1}{150} \times \frac{12}{H} = .1172 \frac{V}{H}$

$M = .1172 \frac{V}{H}$ Equation 1

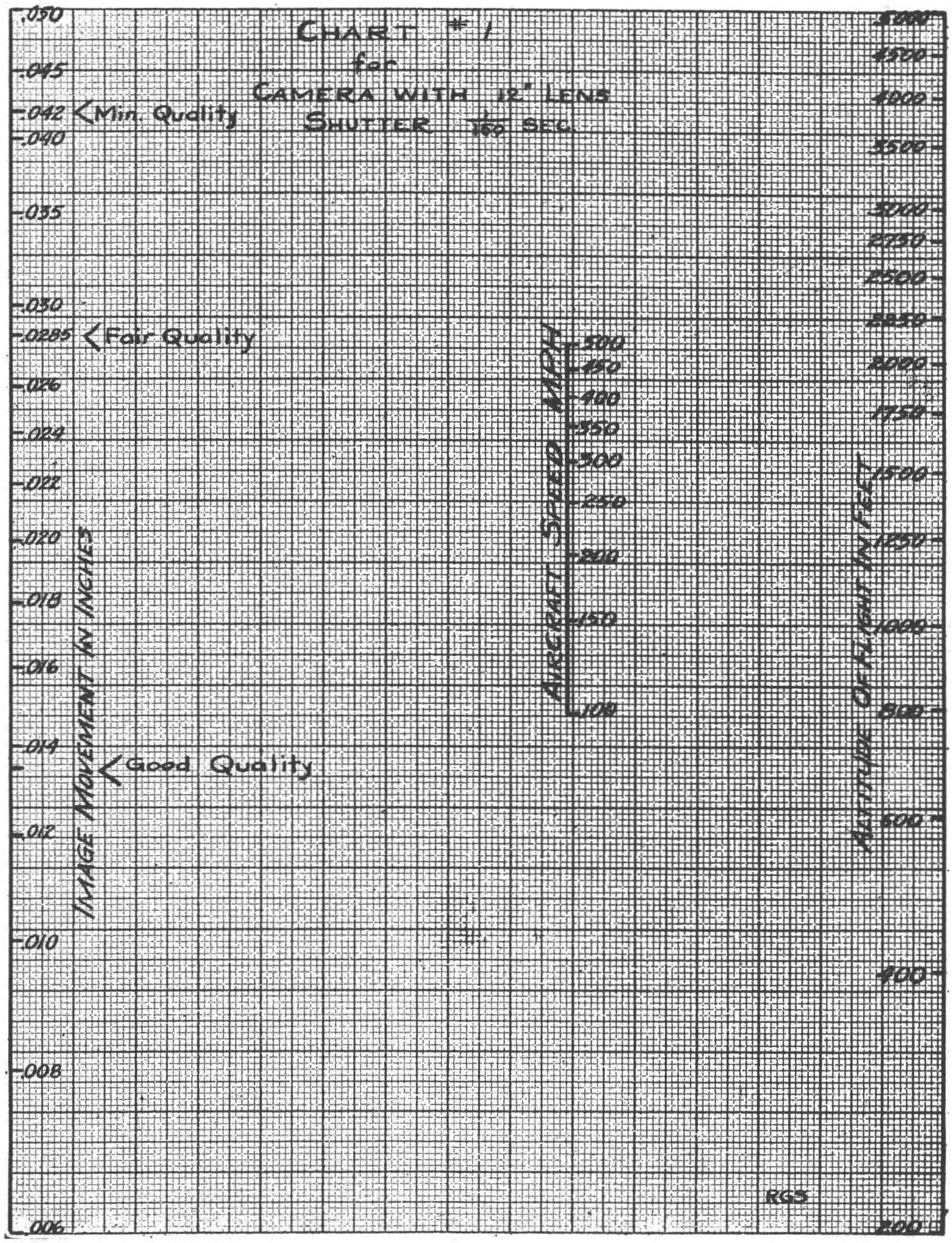

CHART NO. 1

Since the original Question No. 1 was to determine to what extent the existing aerial cameras apply to present day military aircraft, the equation $M = .1172\,V/H$ was set up to be true only for K-3B or other cameras having a 12″ focal length and a maximum shutter speed of 1/150th of a second. This type of equation can be solved graphically by the simple alignment type of diagram which is shown as Chart No. 1. The chart is used simply by laying a straight

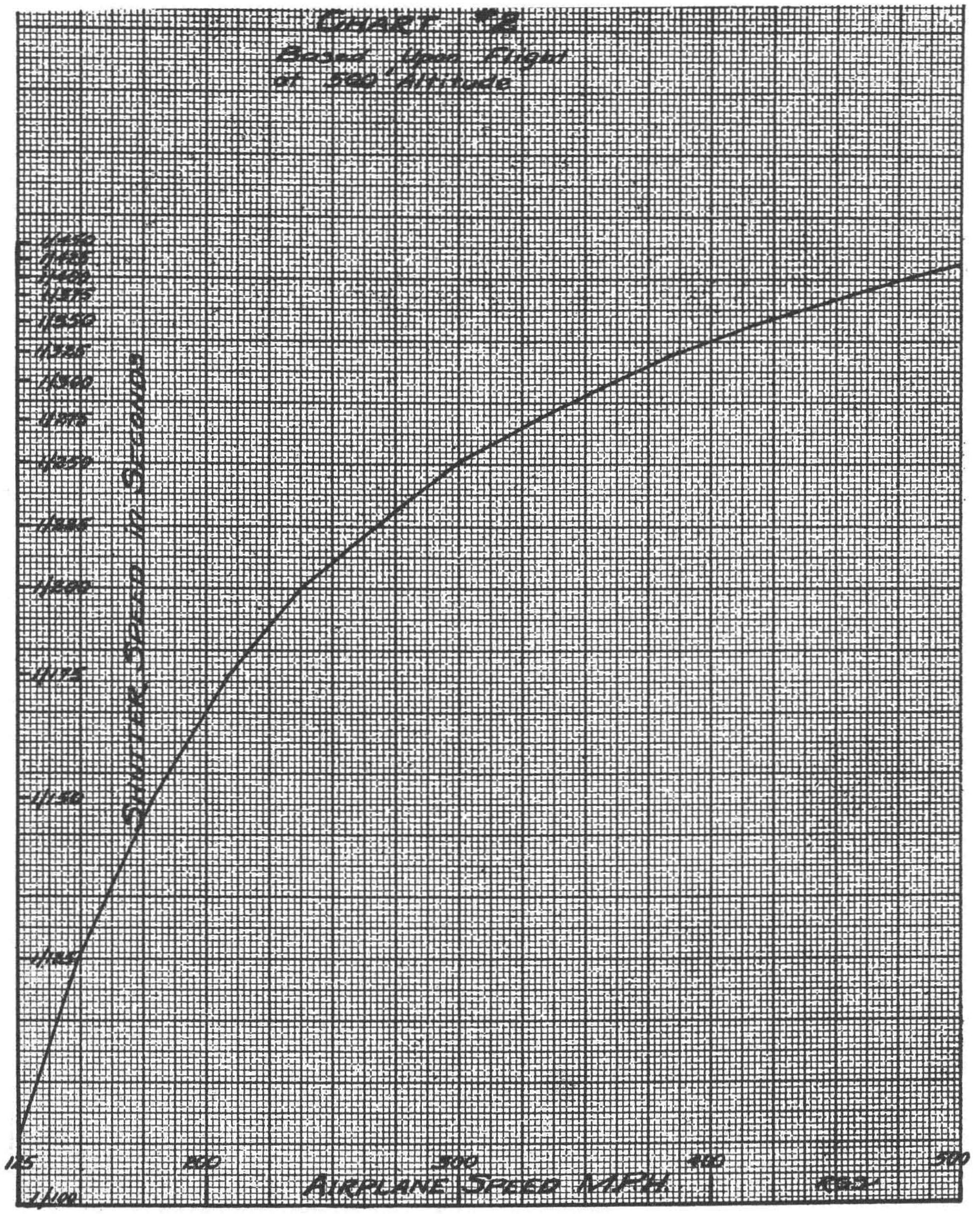

Chart No. 2

edge over any two known values and reading the answer where the straight edge intersects the third axis. Thus, if an aerial camera shutter is to be designed for use in an airplane which in a year or two may be flying at cruising speeds in the neighborhood of four hundred miles per hour, the following can be stated by reference to Chart No. 1:

Based upon the acceptance of the minimum pictorial quality, the lowest that the airplane can be permitted to fly is approximately 1200 feet. However, if it is felt necessray that the pictures obtained be sharp from a pictorial standpoint the airplane must not be flown lower than an altitude

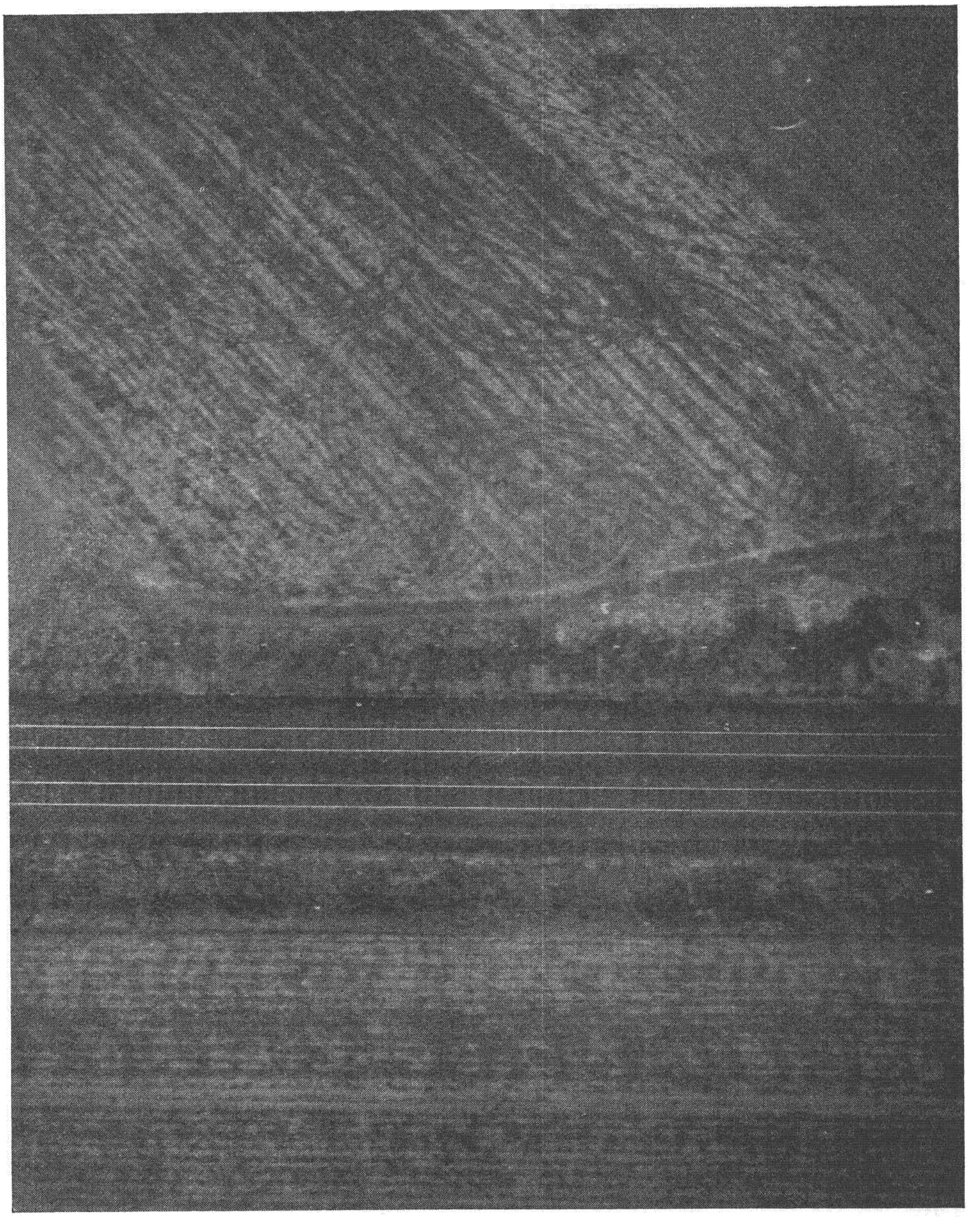

PHOTO NO. 1

of 3500 feet. In like manner the limitations of either speed or altitude can be determined from Chart No. 1 for existing camera equipment.

In order to answer the second principal question, namely what shutter speed must be selected for future military aerial cameras, an assumption had to be made. The assumption made was that the lowest altitude that military aircraft would fly under war conditions would be five hundred feet above the ground. While some experienced individuals feel that military airplanes carrying aerial cameras may fly lower than five hundred feet the majority of officers consulted

PHOTO NO. 2

subscribed to the five hundred foot minimum. Using the same general computational method as previously, but using the maximum permissable movement, namely .042 inches, using a focal length of 12 inches, using an altitude of five hundred feet and solving for shutter speed; the formula evolves as follows:

$$M=\frac{1.467\times V\times T}{S} \text{ or } M=1.647\times V\times T\times \frac{F}{H} \text{ then } T=\frac{1.193}{V} \qquad \text{Equation 2}$$

The formula $T=1.193/V$ is most easily solved graphically by the simple curve diagram as shown in Chart No. 2. By reference to this chart, it can be seen

PHOTO NO. 3

that for the maximum airplane speed estimated for the future, namely five hundred miles per hour, a shutter speed of approximately 1/425th of a second will be adequate. This then, becomes the minimum goal toward which engineers working on shutter designs must strive if aerial cameras are to be suitable for modern and future warfare.

Obviously, if shutter speeds can be increased over and above the figure mentioned it will be so much the better. However, it is not easy to increase the speed of shutters and yet retain high efficiency, reliability, and long life. The

PHOTO NO. 4

1/150th of a second maximum shutter speed has been with us for a long time and it is only within the past year that this shutter speed has been stepped up in cameras made on a quantity production basis to 1/200th of a second. However, at least one manufacturer has risen to the call to produce the seemingly impossible. Thus, now in production are cameras having shutter speeds of 1/225th of a second and 1/300th of a second. Within the past few weeks an aerial camera between-the-lens shutter has been built and tested which shows itself to be capable of a speed of 1/500th of a second or more at high efficiencies. Thus,

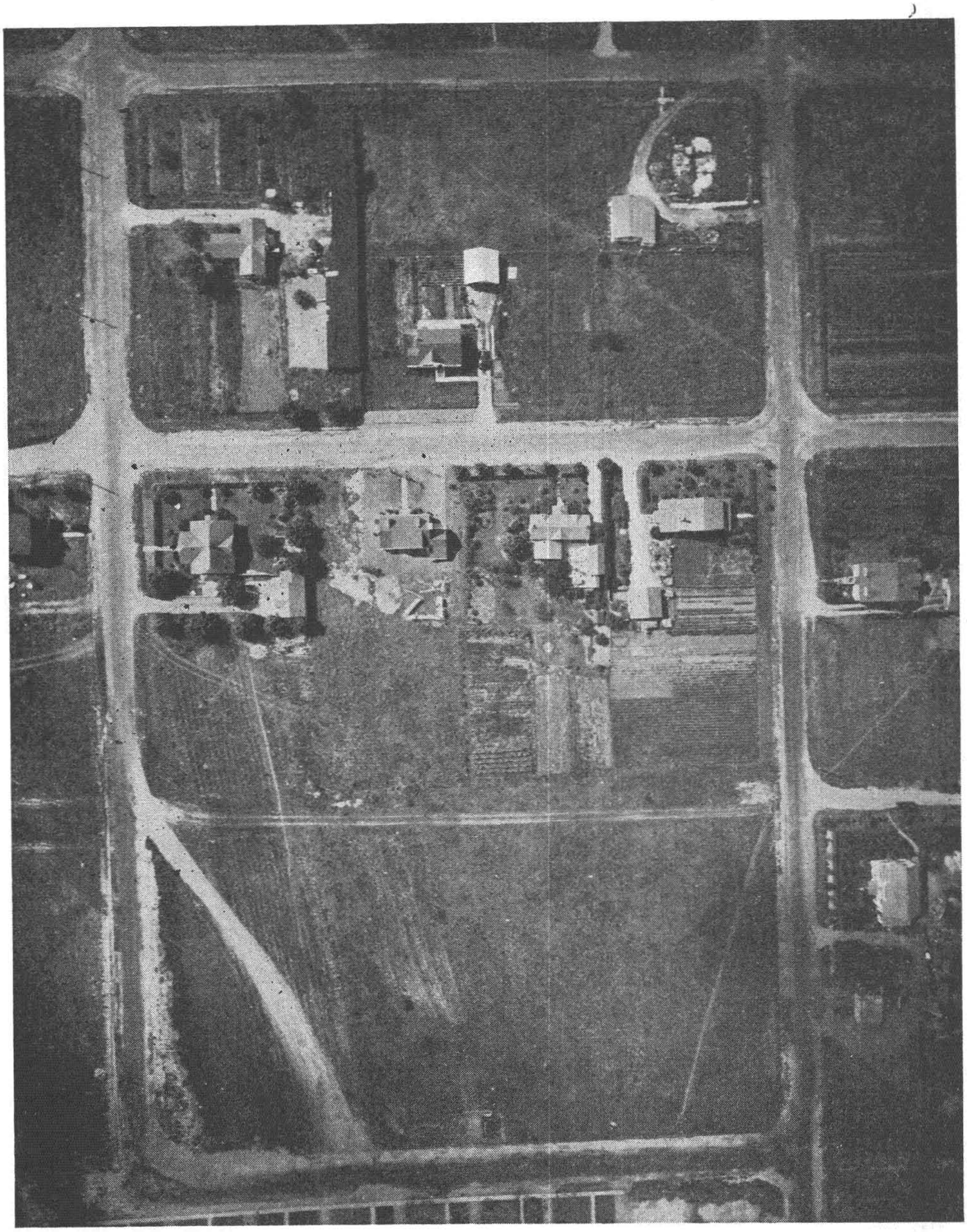

PHOTO No. 5

through the engineering, research, and production facilities of a properly balanced manufacturing concern, modern military aerial cameras are being produced which can keep up the pace set by military aircraft designers. By virtue of faster shutter speeds, the aerial cameras of the immediate future can take satisfactory pictures for all military purposes under most conditions of top speed operation and low altitude flying.

This entire discussion of shutter speeds with respect to image movement makes necessary a clarification of the term "shutter speed." "Shutter speed" has

PHOTO No. 6

been a very much misused term. Aerial camera owners for the most part naively accept the speed data printed on the nameplates of the camera shutters without question. This attitude is a carry-over from amateur ground photography. The amateur takes pictures of mountain scenes or still life with a small lens stop and with a slow shutter speed. He takes pictures of moving objects with his lens wide open and with a fast shutter speed and in both cases gets excellently sharp results. He has no reason to doubt or to question the speed of his shutter. He accepts as fact the universal belief that no good photographer photographs a

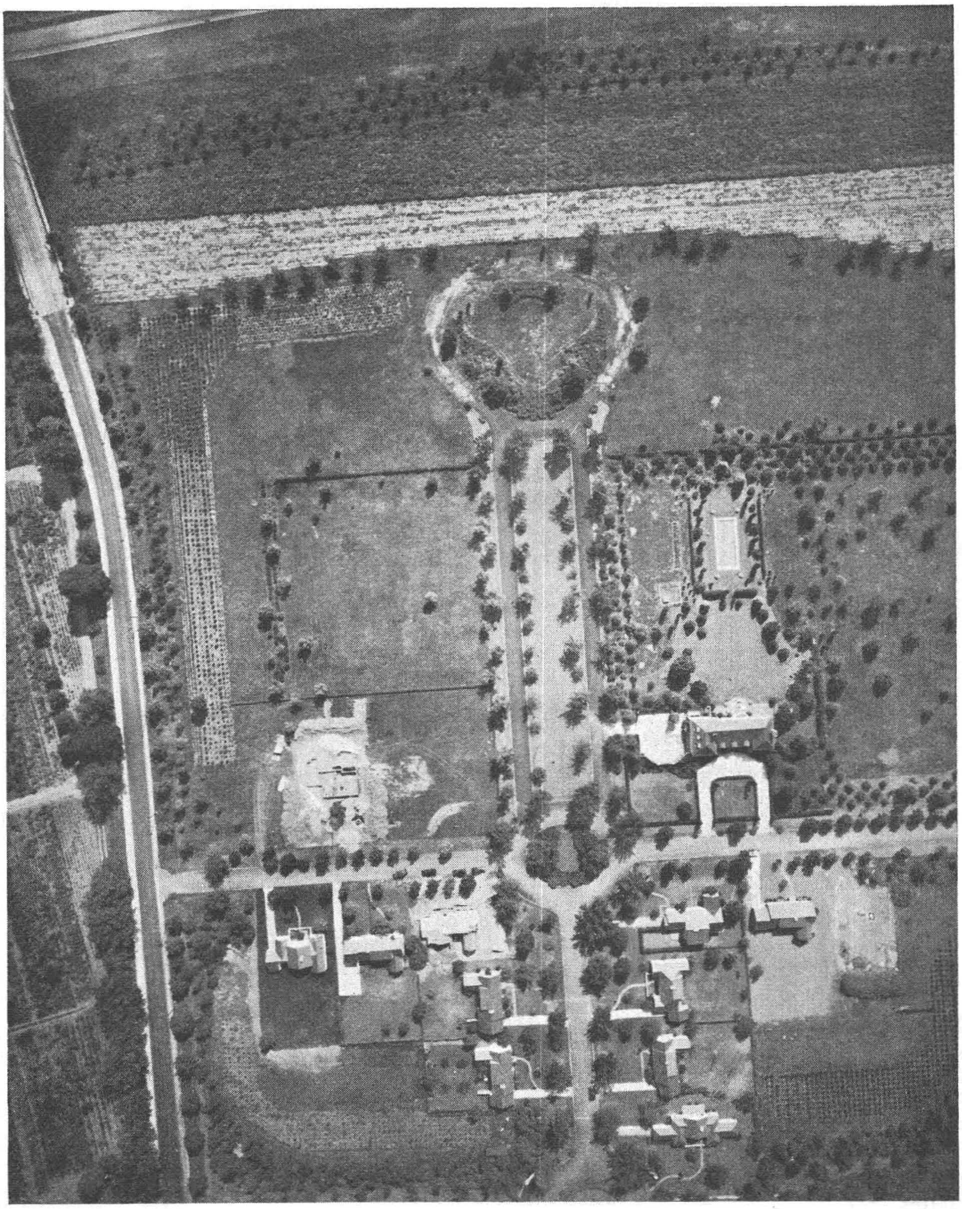

PHOTO NO. 7

moving object at right angles to its direction of motion. If an amateur with a camera having a shutter rated at 1/500th of a second takes a picture of an express train at right angles to its direction of travel and if the resulting picture is blurred, he is severely criticized for having used such a position from which to photograph the train. Few, if any, would question the rated speed of the shutter. However, in aerial photography, particularly for military purposes, it is no longer possible to define "shutter speed" in such a loose manner.

During the past several years many of the expensive and so called precision

PHOTO NO. 8

amateur ground cameras having high speed shutters have been tested. These shutters, which are plainly marked with maximum shutter speeds of 1/200th of a second or 1/400th of a second or more prove to be actually only slightly more than 50% of the rated speed. Upon first consideration, one might be tempted to call this misrepresentation on the part of the camera manufacturers. However, it can easily be seen that this definitely is not the case. Most amateur photographers use a light meter to determine their exposure. The light meter is calibrated in terms of quantity of light. Thus, under certain conditions, the light

PHOTO NO. 9

meter indicates to a photographer that he should use a certain lens opening and a shutter speed of 1/400th of a second. The light meter knows nothing about shutter inefficiency and when it indicates that a 1/400th of a second shutter speed should be used for a given lens opening, it means that a shutter of 100% efficiency should be operated for 1/400th of a second. Actually, however, if the shutter worked through a total elapsed time of 1/200th of a second and is 50% efficient at that speed, the same quantity of light is admitted to the film as would be admitted if the shutter were 100% efficient and operated through a total

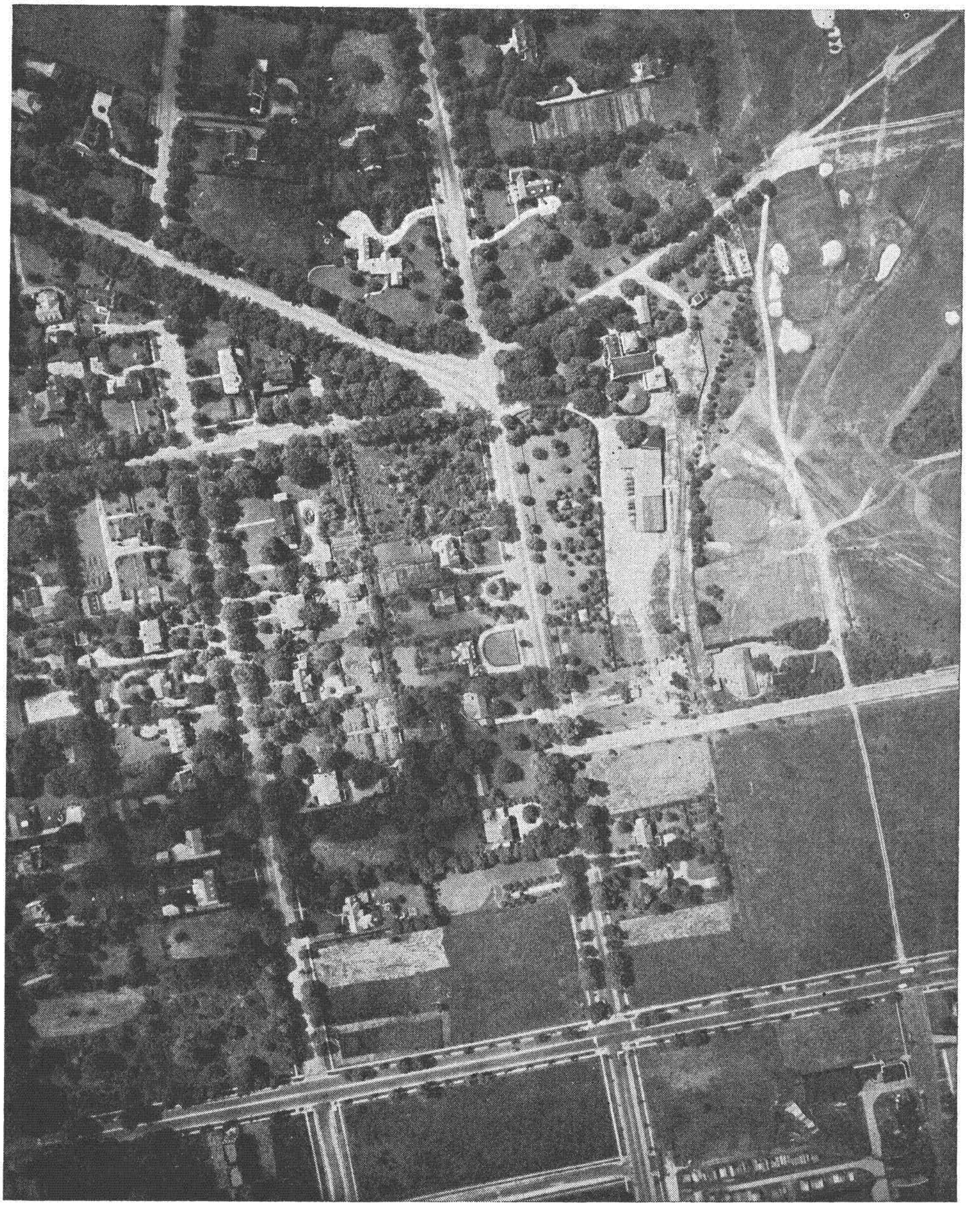

Photo No. 10

elapsed time of 1:400th of a second. As a result of his reading from his light meter the amateur photographer sets his shutter speed at 1/400th of a second and the resulting negative shows proper density. After all, the amateur photographer is much more concerned with gradations of tone, contrast and pictorial quality and seldom finds himself in a position where extreme motion is any problem.

In aerial photography and more particularly where high speed aircraft flying at low altitudes are concerned, the only definition of shutter speed that can be accepted is that the shutter speed indicated on the nameplate of the shutter must be the time interval from the start of the opening of the shutter to the final closing of the shutter. Thus, when by reference to Chart No. 1 or No. 2, it is found that a certain shutter speed must be used, the photographer must have confidence that no more than the elapsed time called for by the chart will be taken by the operation of the shutter. Any lack of efficiency in the shutter under these conditions will tend to reduce the quantity of light passing through the lens and will not at all effect the shutter speed. When an aerial photographer uses a light meter which calls for a particular lens opening at a shutter speed of 1/200th of a second for example, he will have to apply a factor based upon the known shutter efficiency to the lens aperture to arrive at the proper opening.

This entire discussion has been based upon military aerial camera requirements. From the governmental and commercial standpoints, the problem is not so serious. The commercial aerial photographers seldom make use of airplanes having speeds in excess of one hundred fifty miles per hour. Furthermore, most governmental mapping photography is carried out at considerably higher altitudes than those which have been mentioned during this discussion. The relative motion between the focal plane of the camera and the terrain is exceedingly small. However in view of the not infrequent rejections of aerial photography because of objectionable movement, it may be well for someone to carry out this study further and to investigate its application to commercial and governmental aerial photography. It might be particularly desirable to set up some standard to serve as a basis for the acceptance or rejection of aerial photographs due to the image movement.

In conclusion, as a result of the tests conducted and the studies made, image movement has been analyzed quantitatively and three military standards of comparison have been set up. Based on these standards two charts have been constructed which enable the user of present day aerial camera equipment to know the limitations of his equipment and enables the aerial camera designer to know the shutter speed which must be attained by the cameras of the future.

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