# HIGH ALTITUDE STEREO TECHNIQUES*

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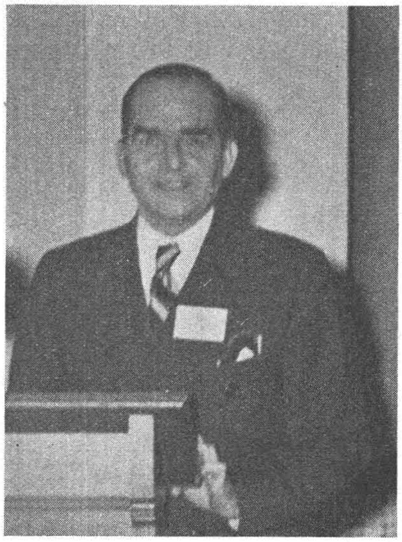
HIGH altitude is an obvious operational necessity in military aerial photography, especially in pinpoint reconnaissance.

Stereoscopy is a necessity, if one attempts to find and to interpret the small, mostly man-made objects of interest in photographs of this type.



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High altitudes are those altitudes which have just recently been made available for routine aerial photography,—more specifically altitudes of about 40,000 ft. This is twice as high as the routine altitude of 20,000 ft. which was common practice in World War II.

It is obvious that this increase in distance from our objects of interest can be counteracted to some extent by increasing the focal length of our aerial cameras proportionally, thus maintaining the required image scale and therewith the apparent size of our objects in the photographs. But the question arises: How will the stereoscopic effect and the perception of the tridimensional structure of our objects be affected?

Figure 1 outlines the basic geometric relations. In these sketches the size of the image, or at least its breadth in the direction of flight, is held constant, according to the fact that, in almost all aerial cameras, film of constant width (9 inches) is used. The film width is the most conservative constant in aerial camera design because it must fit so much other equipment (e.g., spools, processing, viewing, printing and storing equipment). As can be readily derived from Figure 1, the basic problem in high altitude pinpoint photography may be formulated as follows:

Will the simple technique of 60% overlapping verticals (or obliques with parallel axes), although implying a reduced base/height ratio, still give adequate stereo effect for exhaustive interpretation, or will it be necessary to use the more complicated technique of convergent stereo pairs in order to convey to the interpreter all useful stereoscopic information which might be obtainable from photographs of a given scale?

The manner in which this problem was attacked at the Boston University Optical Research Laboratory is illustrated by Figure 2. With stereo pairs of different base/height ratio, composed of pictures from one stereo fan and showing the same object under otherwise identical conditions, it was attempted to isolate the effect of the base/height ratio on the interpretability of small objects.

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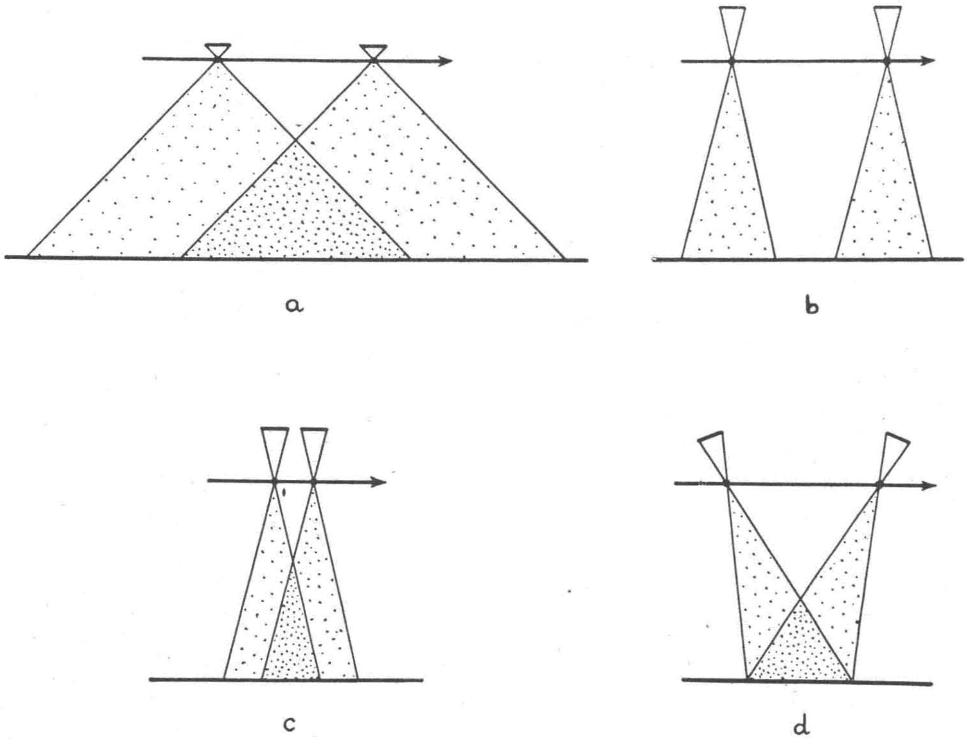


FIG. 1. Basic geometric relations. a—Verticals, 60% overlap, focal length too short for high altitude. b—Focal length increased, film width and air base same, overlap lost. c—Remedy 1: Vertical axes maintained, air base shortened. d—Remedy 2: Air base maintained, axes convergent.

It is known that photo-interpretation is a very complex process—a combination of observation, previous training and experience, expectation and interest in the object. Therefore, a fair judgment of factors affecting interpretation can only be expected if experimental targets and conditions closely resemble such actual targets and conditions, with which a photo-interpreter is trained and accustomed to deal. Experiments with artificial targets or on a model scale would involve so many unknown conversion factors for components such as experience, expectation, interest and others of similar complexity, that results would hardly be significant at all.

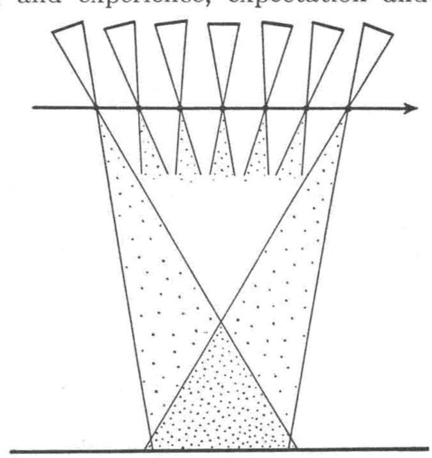

FIG. 2. Stereo Fan. Pictures are taken at short intervals with camera pointing at same target area. Any two pictures may be combined to form a stereo pair with air base equal to 1, 2, 3 . . . intervals.

Therefore, in order to obtain suitable experimental material, stereo fans as described in Figure 2 were taken at the highest altitude the aircraft could reach, i.e., about 32,000 ft. The camera used had a 40-inch f/5 telephonto lens and 9″×9″ format. Thus, the image scale of the pictures is slightly larger than 1:10,000, in accordance with conventional scale requirements for pinpoint reconnaissance.

The camera was mounted in a special swing mount which could be cranked by hand in such a manner as to keep the camera axis pointed at a particular chosen target on the ground. For this purpose, a view finder was rigidly attached to the camera body (*see Figure 3*).

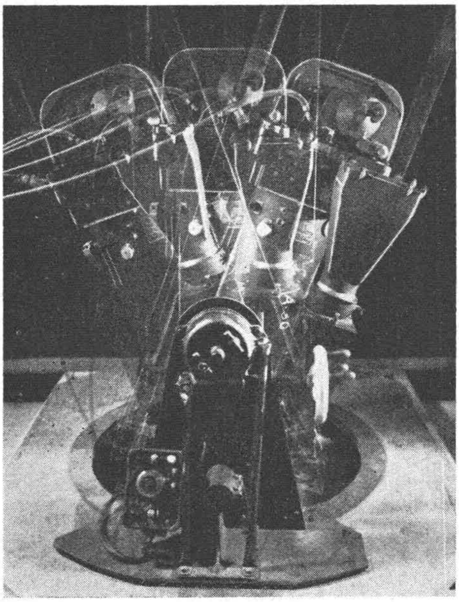

FIG. 3. Camera in swing mount. Multi-flash exposure shows camera and view finder in three different positions during the run of a stereo fan.

Let us now analyze the conditions and limits for the perception of small tri-dimensional detail in a stereoscopic picture.

Let a stereoscopic pair of verticals (or near verticals) be taken at an altitude $A$ over terrain of elevation $h$, with air base $B$ and focal length $f$. Then it follows from the fundamental equation of stereoscopy:

$$H = (A - h) = \frac{Bf}{p}, \tag{1}$$

that

$$\Delta h = \frac{1}{B/H \times f/H} \Delta p = \frac{1}{\Theta M} \Delta p \tag{2}$$

($H$ = flying height; $p$ = parallax; $M = f/H$ = image scale; $\Theta = B/H$ = base/height) ratio.

The smallest just recognizable increment $\Delta h_{min.}$) of the relief (or object) height $h$ is the limit of stereoscopic depth perception, which we want to find. It is, according to equation (2), proportional to the smallest just recognizable differential parallax $\Delta p_{min.}$).

At first thought we are inclined to set this latter equal to the smallest just resolved detail on the negative, commonly expressed as the reciprocal of the resolving power $R$. But experience has shown that the smallest just recognizable differential parallax in stereoscopic vision is much smaller than the smallest just resolved detail. This is quite understandable, because in stereoscopic vision we perceive the shift of a group of detail, representing a particular object element, against another group of detail, representing the back-ground of the object detail in question, which is separated from it by the increment in height $\Delta h$.

The ratio of smallest resolved detail $1/R$ to smallest differential parallax $\Delta p$ has been found to be about 2 to 4. Let us assume for the purpose of this survey an intermediate value of this ratio, say 2.5. Then we can set:

$$\Delta p_{min} = \frac{1}{2.5R} \tag{3}$$

The resolving power $R$ may, according to usage, be expressed in lines per millimeter on the negative. From equations (2) and (3) we find for the smallest stereoscopically resolved increment in object height:

$$\Delta h_{min} = \frac{1}{2.5\Theta MR} \tag{4}$$

If we take verticals with $p\%$ overlap, focal length $f$ and film width, $w$ then the base/height ratio will be:

$$\Theta_{p\%} = \frac{B}{H} = \frac{w(100 - p)\%}{f} \tag{5}$$

For 60% overlap we get:

$$\Theta_{60\%} = \frac{w(100 - 60)\%}{f} \equiv \frac{0.4w}{f} \tag{6}$$

combining of equations (4) and (6) gives:

$$(\Delta h_{\min})_{60\%} = \frac{H}{Rw} \tag{7}$$

Equation (7) shows that the smallest just recognizable height increment increases proportionally with the flying height, and does not depend on the focal

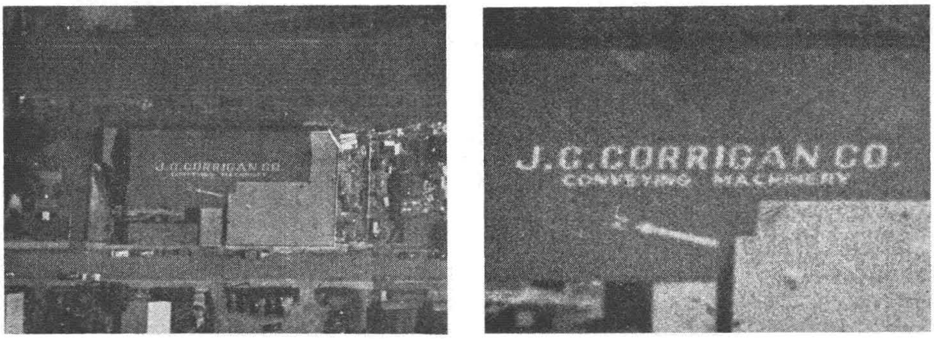


FIG. 4. Section of aerial photograph taken at 32,000′ with 40″ camera. Left—magnification 5×. Right—magnification 15×. Note amount of detail revealed by high magnification, e.g., improper spacing of letter I in MACHINERY.

length. In other words, the "stereoscopic resolution of depth" becomes proportionally worse with higher altitude if we use the same film width, no matter what focal length we choose in order to compensate or even overcompensate for image scale. Unfortunately, the resolving power $R$ is also likely to shrink with increasing focal length, impairing the stereoscopic resolution of depth still more, and increasing the film width involves too many inconveniences to be attractive. So the obvious solution of obtaining higher stereoscopic resolution of depths is, according to equation (5), the choice of a higher base/height ratio $\Theta$, i.e., the use of convergent stereo pairs.

The same reasoning applies to oblique stereo pairs with parallel or convergent camera axes. We only have to replace the flying height $H$ by the oblique distance $D$, and the increment $\Delta h$ of the relief or object height $h$ by the increment $\Delta D$ along the oblique direction lens-object.

The just discussed stereoscopic resolution of depth has nothing to do with the question, whether the stereoscopically perceived object appears similar to the real object, or whether its dimensions along the line of sight seem exaggerated or compressed. Small objects will appear similar to their true form if, and only if, in stereoscopic viewing the rays left image—left eye and right image—right eye subtend the same angle as the respective rays object-camera did when the pictures were taken. In other words, the convergence of the two lines of sight toward the object must be preserved in stereoscopic viewing, if we want to see the object without exaggeration or compression of depth. If we make the object appear nearer to the eye base (e.g., by pushing left and right picture toward each other under the stereoscope), it will appear flatter and vice versa.

After this theoretical analysis of the problem, some typical results of the test flights shall be discussed.

Within the area covered by one of the stereo fans, an excellent object was found to illustrate the amount of detail recorded in a high altitude photograph (Figure 4). It shows that if we want to be sure of ascertaining all the information

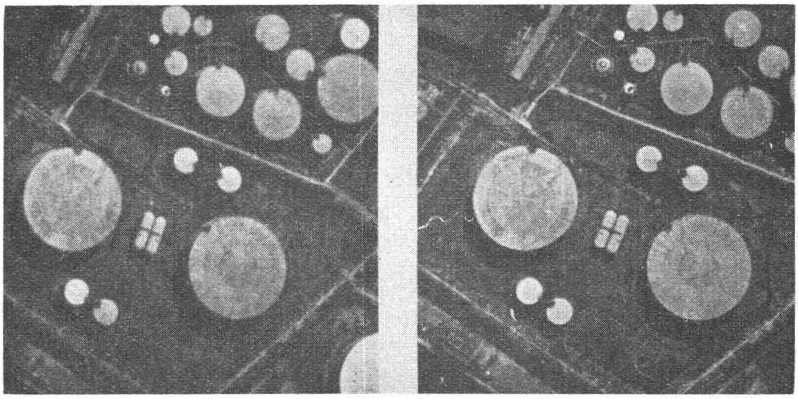

FIG. 5. Group of gasoline tanks, magnification 4×. Triple air base (see text).

a picture contains, we must offer it to the eye with a rather high magnification, about 10X or even higher. Although under such a magnification any aerial photograph will appear fuzzy, it will nevertheless reveal more information than if presented with low magnification, under which it may still appear reasonably "sharp." Certainly, in photo-topographic practice, a low power stereoscope may be an expedient compromise, but in pinpoint reconnaissance we cannot afford to preclude by inadequate techniques a great amount of available information from being perceived and used at all.

With the following stereoscopic pictures (Figures 5–9) an attempt is made to demonstrate the effect of various factors on the interpretation of small object detail from high altitude photographs. These stereoscopic pictures are arranged in such a way, that they can be viewed easily with or without the use of a low power pocket stereoscope. In order to overcome the limits of detail reproduction inherent to the half-tone printing process, some of the objects are reproduced with two different magnifications. The lower magnification enables the reader to see the whole object and understand its general structure, whereas the higher magnification is intended to show conditions near the limit of resolution in the original negative.

All these stereo pairs are taken from stereo fans with an interval of 2,000 ft., corresponding to a base/height ratio of:

$$\Theta_i = \frac{2{,}000'}{32{,}000'} = \frac{1}{16} \tag{8}$$

Using equations (4) and (5) we find, that this interval corresponds to an overlap of 72% of verticals taken under the same conditions, and that the same resolu-

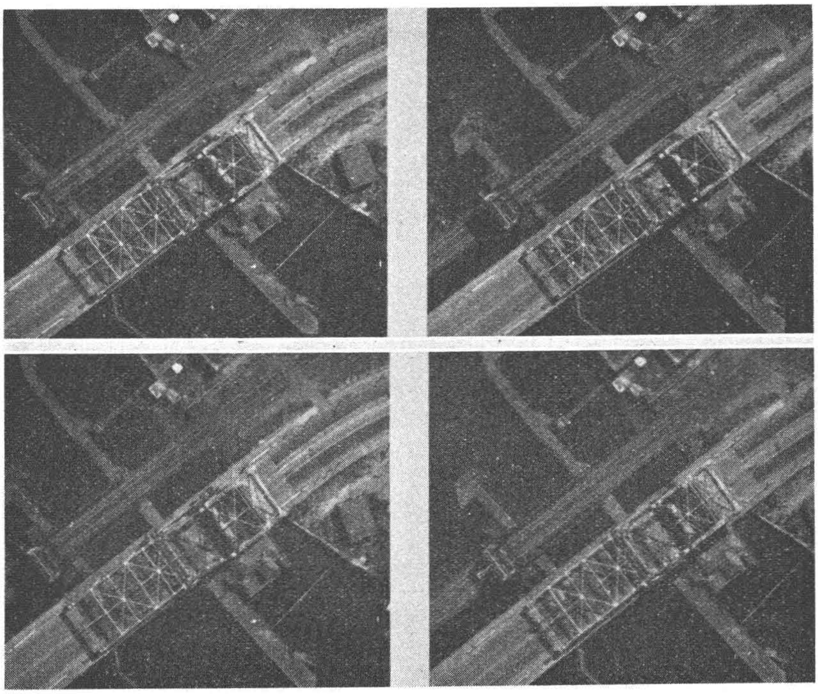

FIG. 6. Bascule bridge, magnification 4×. Top—normal air base (see text). Bottom—triple air base.

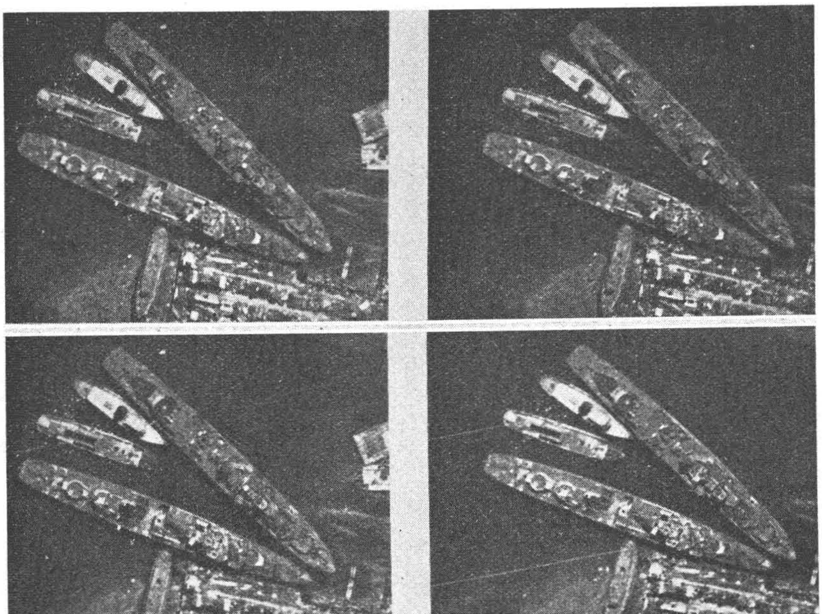

FIG. 8. Two destroyers, partly scrapped, in salvaging yard, magnification 4×. Top—normal air base. Bottom—triple air base.

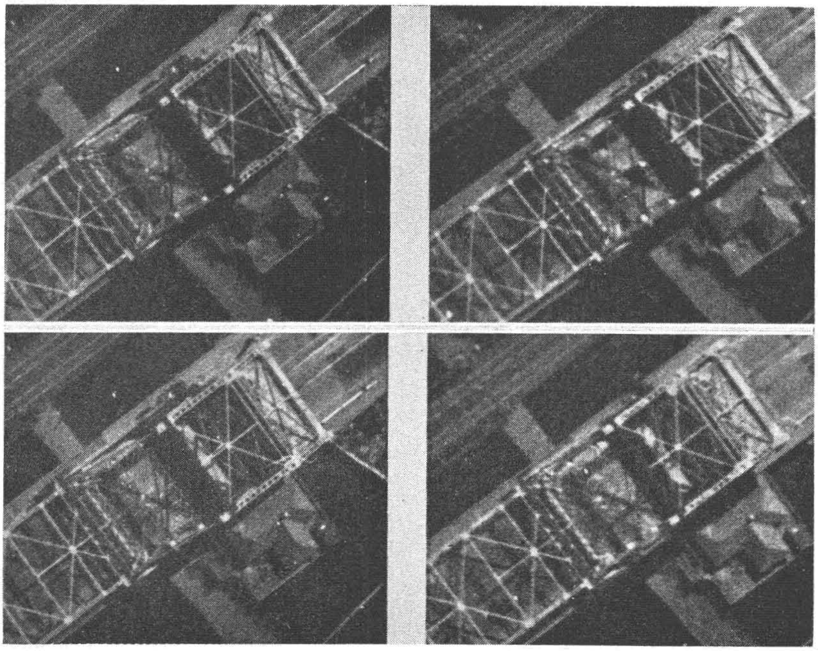

FIG. 7. Part of bascule bridge in Figure 6 enlarged. Total magnification 8×. Top—normal air base. Bottom—triple air base. Note difference in representation of structural detail.

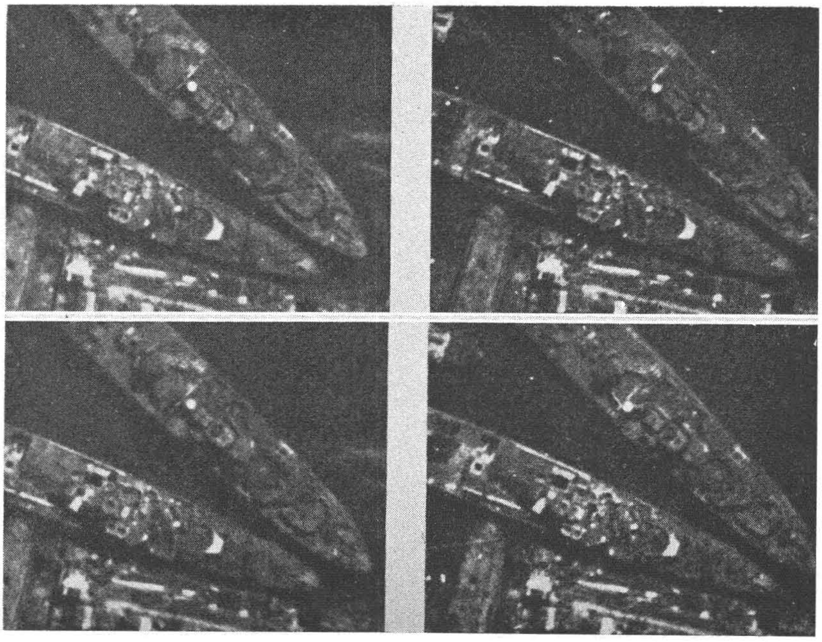

FIG. 9. Central part of ships in Figure 8 enlarged. Total magnification 8×. Top—normal air base. Bottom—triple air base. Note difference in clarifying tridimensional arrangement of structures on deck.

tion of stereoscopic depth would be attained by verticals taken with a focal length of 48″ at 40,000′, with 65% overlap. Thus, stereo pairs taken from our test flight, and having a one interval air base, are fairly representative of typical high altitude conditions. We are therefore justified in calling this one-interval air base further on the "normal air base."

From the stereo fans already mentioned, stereo pairs were selected having either normal or triple air base (or base/height ratio $\Theta$). According to equation (4) we should expect the triple base stereo pairs to reveal detail in depth about three times as small as could be seen in a normal stereo pair.

However, with respect to the complexity of the interpretation process, a statement of such geometrical strictness does not seem proper. We would rather expect the test pictures to verify that a triple air base will improve interpretation accordingly with respect to amount, clarity and reliability of information.

Figure 5 shows that objects as bulky in size, simple in structure, and familiar in appearance as this group of gasoline tanks, can easily be recognized as such even without making use of stereoscopy. Their relative height, however, and other detail of their structure and arrangement could hardly be deduced with satisfying ease and certainty from shadows, reflections and similar hints, when using a single picture only. The superiority of a stereoscopic picture is self-evident.

Figures 6 and 7 show a more complicated object—a bascule bridge. In this case a single picture gives hardly more information than that the object is a bridge, whereas the stereo picture shows immediately the general features of a bascule bridge. Significant details, however, need higher magnification to be fully understood. The reader is invited to compare the normal and triple base stereo carefully, with regard to their respective value as a source of information. He should also try to regard himself faced not with the problem of understanding the structure of a bascule bridge, but with the problem of understanding a structure composed of similar structural elements, but of unknown nature or purpose, say a construction which might be a launching device for an unknown weapon. He will then appreciate every additional bit of information made available by an improved stereo technique.

The object shown in Figures 8 and 9 is still more complicated and less familiar. Therefore, the advantages of the triple base stereos in clarifying the tri-dimensional arrangement of crow's-nests, platforms and similar small detail on deck will be even more convincing.

The results of this investigation and demonstration may be summarized as follows:

1. The application of stereoscopy is a mandatory requirement in high altitude photography, if small targets are to be recognized and functionally understood, clearly and reliably.
2. High magnification, about 10X, is necessary to make the full amount of information contained in high altitude photographs readily available to the interpreter. A stereoscope of power 10 to 15 is desirable.
3. The stereoscopic effect as obtained by the conventional technique of taking verticals with 60% overlap is barely sufficient in high altitude photography under present conditions. Convergent stereo pairs with a three times larger base/height ratio are definitely superior for the interpretation of small, complicated and unfamiliar objects.