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The use of convergent photography in high altitude reconnaissance.

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GRADUATE SCHOOL

Thesis

THE USE OF CONVERGENT PHOTOGRAPHY IN HIGH ALTITUDE RECONNAISSANCE

by

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(B.S.,Villanova College,1949)

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First Reader ....
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OUTLINE

ILLUSTRATIONS

INTRODUCTION

The introduction of jet propelled aircraft into the field of photographic reconnaissance greatly increased the height at which missions could be flown. This increase in altitude permitted greater coverage on a single mission, but the reduced scale of photography made photo-interpretation more difficult and less accurate. The obvious solution was to increase the camera focal length in order to maintain sufficient image size for ease and accuracy for photo-interpretation. This means could be used to maintain the original desired scale of photography. Other problems are introduced such as the loss in resolution due to increased focal length, but the principal difficulty exist in the jet aircraft itself. Very strict space and weight limitations are placed upon high speed aircraft. The installation of a larger and heavier camera would necessitate the removal of other equipment in order to meet the weight requirements. Also the increased size of the camera would require structual changesin the camera compartment and the outside configuration of the aircraft. Any change in the configuration is prohibited since it would affect the aerodynamic characteristics of the aircraft.

In order to overcome the focal length limitations and still increase photographic detail, a method was proposed which will use a convergent system of photography. This consists of using two cameras of moderate focal length. The optical axes of the cameras would be tilted along the line of flight in opposite directions. With the cameras in this orientation and utilizing longer airbases between photographs, greater stereoscopic effect can be achieved.

The basis for the proposed method is that the third dimensional view, provided by a strip of aerial photographs taken at intervals, is extremely valuable for recognition and detection of detail. The stereoscopic view is available in the overlapping parts of two photographs. The stereoscopic resolution (smallest increment of depth perceptible) is not only inversely proportional to the quality of the photograph in lines per mm., but is directly proportional to the scale (image size/object size) and the angle of stereoscopic view(parallactic angle) between the two lines connecting the object with the two points from which the photograph were made. The parallactic angle is proportional to the base/height ratio; where the base is the distance between positions where the photographs were made.

High altitude photography with long focal length cameras (24 in. or better) flown with normal air base (60% overlap) on present film (9 in. width) reduces the depth perception beyond usable limits because of the small parallactic angle and scale. The resolution limit for the third dimension (depth) in vertical photos is considerably out of proportion to the plan view.

> From 60,000 feet with 36 in. focal lengthat 25 lines/mm. resolution, one should be able to recognize dimensions of 2.5 feet in the ground view or a square of less than 3 by 3 feet in a single photograph. The supposition that one of the dimensions considerably exceeds the minimum increment of resolution on the ground diminishes very considerably (by a factor of 2 to 4) the minimum increment resolved by the second dimension. This well known phenomena mainly accounts for recognizability of small ditches, paths, pipelines, or even rails and high voltage lines at very small scales way beyond the resolution shown by regular resoluton

> targets. Taking this phenomena into consideration under the stated conditions of 60,000 feet, 36" focal length, 25 lines/mm., one can safely say that, if there is continuity in one direction, the other dimension shown in a single picture may be recognized to less than one foot, in cases of high contrast to less than one foot.
>
> The same phenomena which increases the resolution of the second dimension also applies to the third dimension because generally there is a continuity in three dimensional patterns. When taking into account an improvement factor due to continuity of the third dimension of 2.5 the smallest increment of depth recognizable is 10 feet (60,000 ft.,36" F.L.,25 l/mm.) which is a discrepancy of 1:10 as compared to at least one of the other dimensions. This is certainly an unbalanced system as far as recognizability of three dimensional objects is concerned IIn such a system stereoscopic viewing contributes very little to recognition since it's resolution is far below what can be recognized from the other two dimensions shown in single pictures. This short coming of conventional photography can and must be corrected by taking photography with convergent views which allow regaining of any desirable scale of the third dimension. Convergent photography by increasing the parallactic angle, will provide a stereoscopic resolution similar to that of the other two dimensions.[1]

The information stated above indicates the need for a new system of reconnaissance which will produce more information from photos taken at very high altitudes. The need for the system is urgent since Air Force photography is presently being flown at altitudes above 40,000 feet. The aim of this study is therefore to determine if convergent photography is the answer to the problem. An attempt will be made to arrive at figures comparing normal to convergent photography so that these figures can be applied to actual use. Laboratory tests simulating actual conditions will be performed in order to obtain data on extra information obtainable by convergent photography.

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[1] The Development of Photo Reconnaissance Systems (Confidential) Photo Reconnaissance Lab., Wright Air Development Center. (Quoted material is unclassified)

I. CONDITIONS AND LIMITS FOR PERCEPTION OF SMALL TRIDIMENSIONAL DETAIL IN A STEREOSCOPIC PICTURE.

Dr. C.M. Aschenbrenner has investigated the principle of convergent photography and his calculations prove that a longer air-base will provide better stereoscopic resolution.

Let a stereoscopic pair of vertical pictures be taken at an altitude "A" over terrain of elevation "h" with an air base "B" and focal length "f". Then it follows from the fundamental equation of stereoscopy,

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

that $$\Delta h = \frac{1}{B/H \times f/H} \Delta p = \frac{1}{\theta M} \Delta p \qquad (2)$$

H-Flying height
p-Parallax

$\theta = \frac{B}{H}$ Base height ratio

$M = \frac{f}{H}$ Image scale

The smallest just recognizable increment (Δh min.) of the 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 (Δp 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". Experience has shown us 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 background of the object detail in question, which is separated from it by the increment in height (Δh).

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

$$p \; \frac{1}{2.5\, R} \qquad (3)$$

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

$$\Delta h \text{ min.} = \frac{1}{2.5\, \Theta\, R} \qquad (4)$$

If we take verticals with p% overlap, focal length "f", and film width "w" then base/height ratio willbe:

$$\Theta\, p\% = \frac{B}{H} = \frac{w(100-p)\%}{f} \qquad (5)$$

For 60% overlap we get:

$$\Theta\, 60\% = \frac{w(100-60)\%}{f} = \frac{0.4w}{f} \qquad (6)$$

Combining equations (4) and (6) gives:

$$(\Delta h \text{ min.})60\% = \frac{H}{Rw} \qquad (7)$$

Equation (7) shows that the smallest just recognizable height increment increases proportionally with the flying height, and does not depend on the focal 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 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 . The obvious solution to obtaining higher stereoscopic resolution of depth is, according to equation (5), the choice of a higher base/height ratio "Θ", ie. the use of convergent photography.[2]

This Mathematical proof then illustrates the advantage of using longer airbases. It is necessary, now, to determine the mechanics of operation of convergent photography since the overlap will be decreased

[2] C.M. Aschenbrenner, "High Altitude Stereo Techniques", Photogrammetric Engineering, XVI (1950), Pp.712-19.

when a larger base height ratio is used. The loss of the overlap will decrease stereoscopic coverage, thus defeating the purpose of the proposed method. The addition of a second camera into the system and the rotation of both cameras along the line of flight will solve this problem.

II. CALCULATION OF THE ANGLE OF CONVERGENCE.

The use of the term "angle of convergence" will be defined as the angle formed by the optical axes of the two cameras when the stereoscopic pictures are taken. The "divergent angle" will be the angle between the optical axes of the two cameras as they are mounted in the aircraft.

The following assumptions will be made for the calculations:

Flight Altitude H = 40,000 Feet
Focal Length f = 24 inches
Format w = 9X9 inches
Normal Overlap = 60%
Increased Airbase = Three times normal

Under these conditions:

Scale = 1:20,000
Coverage = 15000 Feet
Overlap = 60% X 15,000 = 9000 feet
Airbase(Normal) = 15,000-9000 = 6000 feet
Angular Coverage = 21° 14.6' ½ angle 10° 37.3'
Triple Airbase = 18,000 feet

Figure I shows the camera coverage at normal and triple airbase. From this it can be seen that to maintain stereoscopic effect and overlap of the triple airbase that the cameras will have to be rotated along the line of flight. In order to maintain coverage a second camera has to be introduced into the system and rotated the same amount along the line of flight, but in the opposite direction. The angle of rotation of the cameras is limited by the half angle of the optical system which is 10° 37.3'. This limits the rotation to 10° so photographic coverage will be maintained at the nadir point. Rotation beyond the half angle would leave a gap directly below the aircraft.

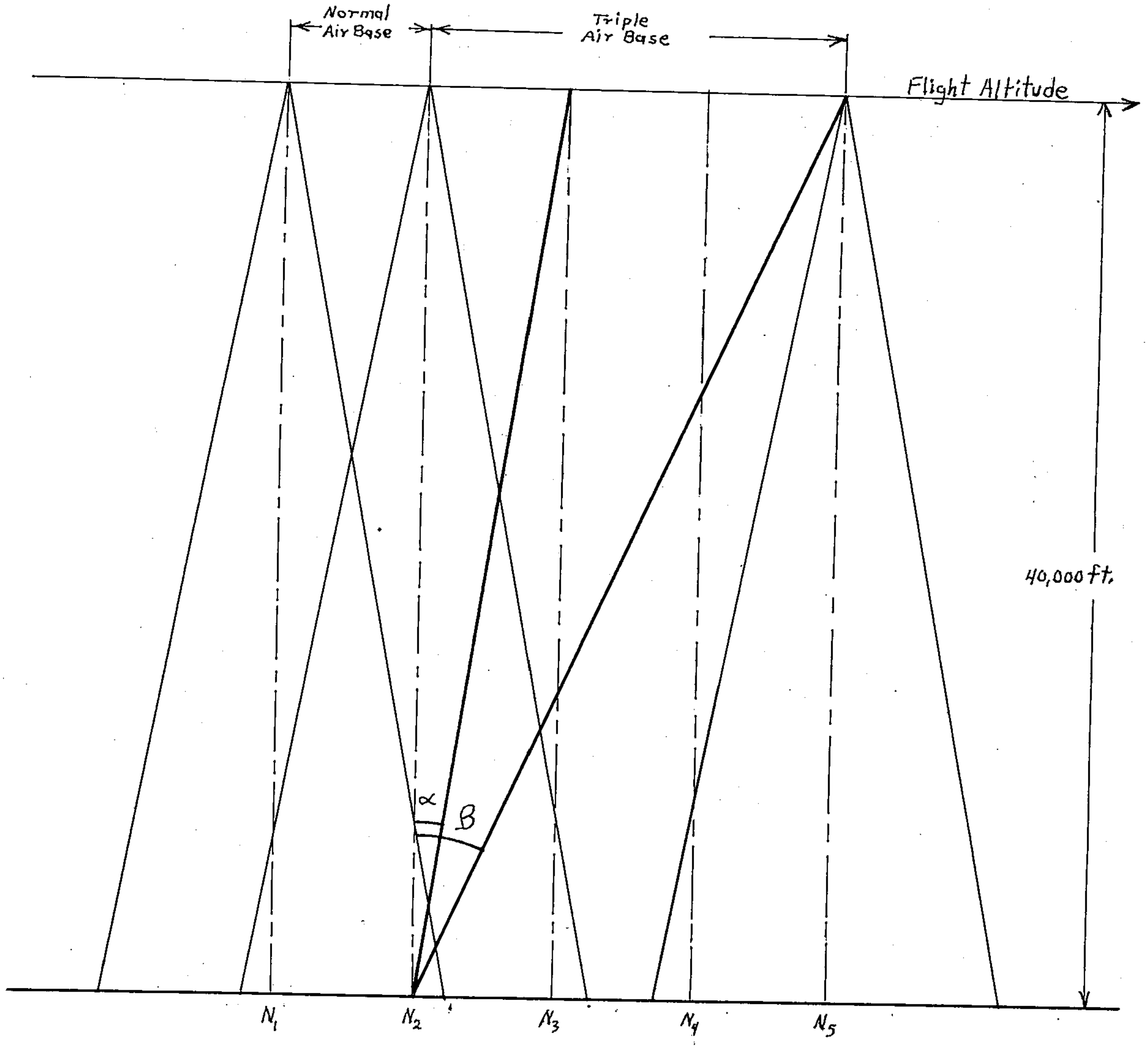


Figure I STANDARD 60% OVERLAP SYSTEM

Under the conditions of 10° rotation the distance from the nadir point to the intersection of the optical axis with the ground plane is:

$$D_1 = 40{,}000 \tan 10^\circ = 7052 \text{ feet}$$

and the distance to the extreme point of camera coverage from the nadir point is:

$$D_2 \doteq 40{,}000 \tan 20^\circ\ 37.3' = 15056 \text{ feet}$$

The coverage on the opposite side of the nadir point is:

$$D_3 \doteq 40{,}000 \tan 37.3' = 436 \text{ feet}$$

Total coverage of both cameras is 30,112 feet along the line of flight.

Figure II shows the coverage of the convergent photography system. The coverage is shown for a triple airbase, but photographs would be made at the usual 60% overlap so that complete stereo scopic coverage will be maintained.

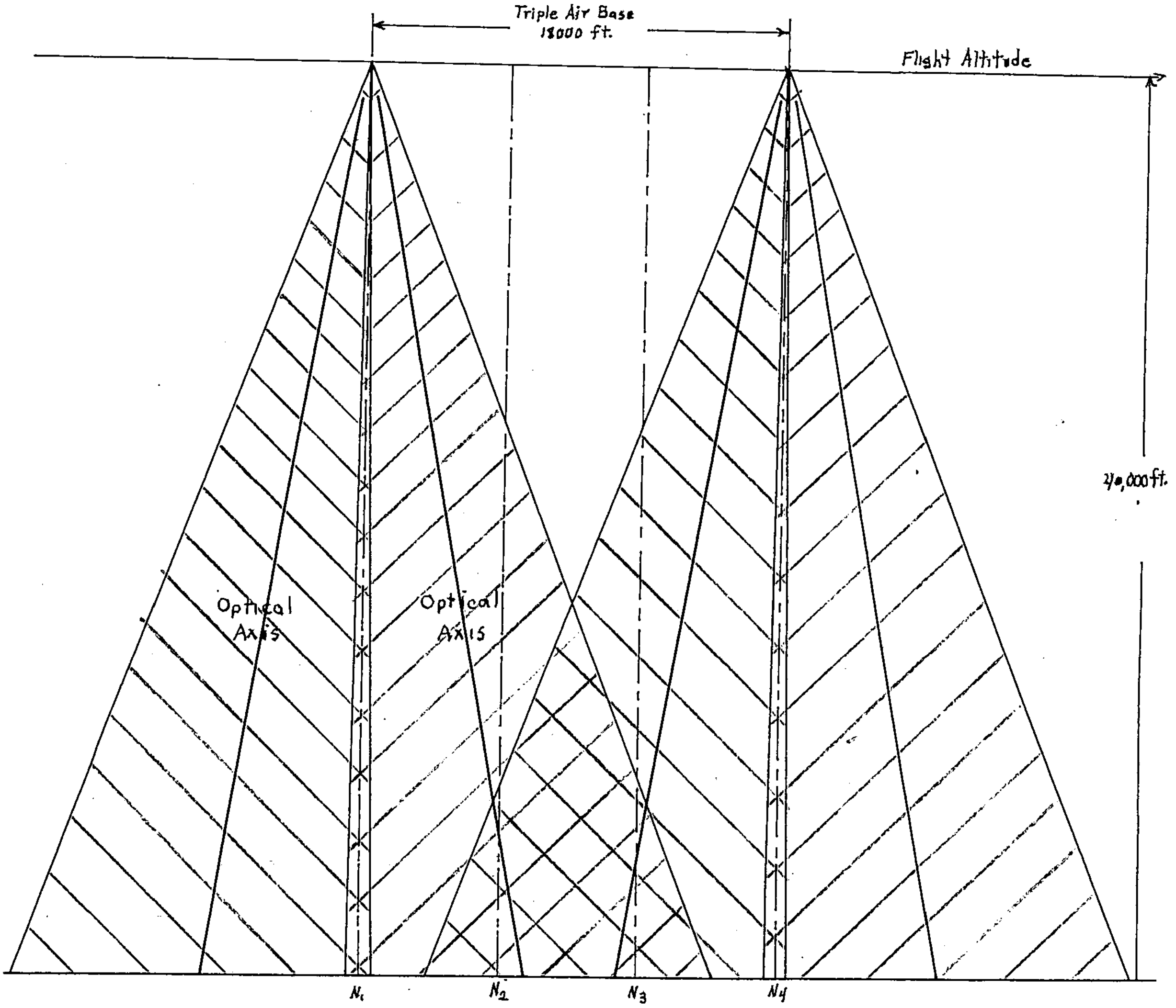


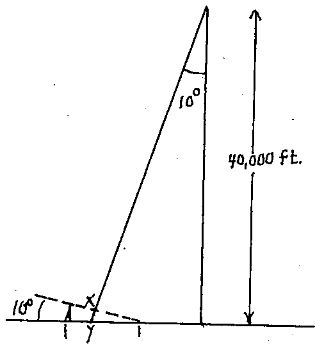
Figure II CONVERGENT CAMERA SYSTEM

III. EFFECT OF CAMERA TILT ON PROJECTED OBJECTED DIMENSIONS

The effect of increased object distances is negligible and will not be included in the calculations.

1. Horizontal Dimensions- (on optical axis)

a. Along Line of Flight.



$x = y \cos 10^\circ = 0.9848y$

$x = 98.5\% y$

Figure III

The decrease in horizontal dimensions is only 1.5% along the line of flight and this loss is practically negligible. At 20° the decrease amounts to 6.6% which could conceivably be enough to put the image below the resolution limit.

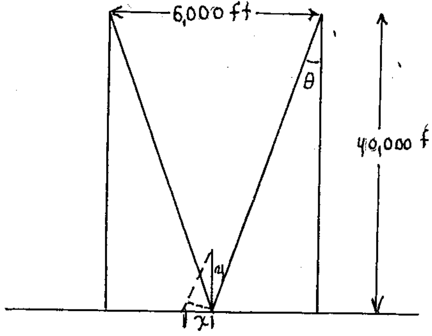
b. Across The Line of Flight

There will be no change in projected object dimensions across the line of flight

2. Vertical Dimensions

Comparision will be made at the midpoint of both systems.

a. Normal Airbase 60% Overlap



$\tan \theta = \frac{3000}{40,000} = 0.0750$

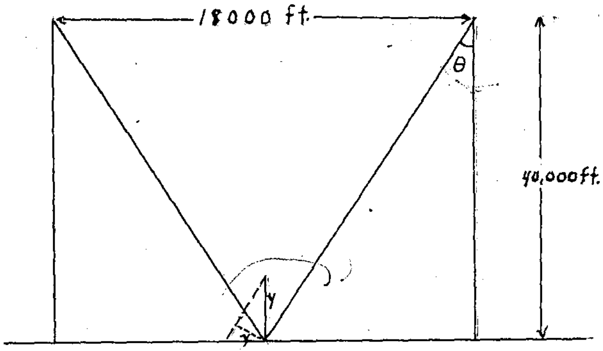
$\theta = 4^\circ \; 17.3'$

$x = y \sin \theta = 0.0747y$

$x = 7.5\% \, y$

Figure IV

b. Triple Air Base



$$\tan \theta \cong \frac{9000}{40,000} = 0.225$$

$$\theta = 12^{\circ}\ 40.25'$$

$$x = y \sin \theta = 0.2194y$$

$$x = 21.94\%\ y$$

Figure V

The comparison of figures between single and triple airbases shows that the increase in projected dimensions of a vertical dimension for a triple airbase is three times that with normal airbase. This is the significant figure to be used as a criteria for evalution of stereo photography. The 1.5% loss in horizontal dimension can be n neglected. If the camera tilt is increased then it would be necessary to arrive at optimum conditions for the relation of the increase in vertical dimensions to the decrease in horozontal dimensions .

The same results can be shown from the formula;

$$H = (A - h) = \frac{B\ f}{p}$$

$$p = \frac{B\ f}{H}$$

1. Normal Airbase

$$p = \frac{6,000 \times 2}{40,000} = 0.3$$

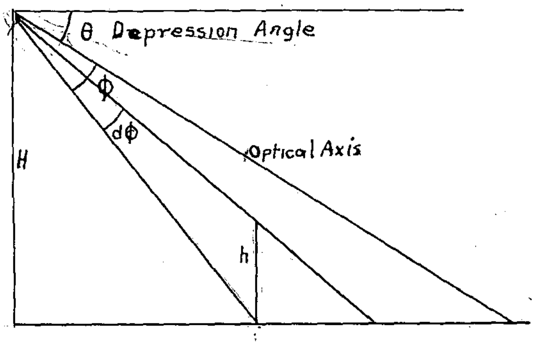
2. Triple Airbase

$$p = \frac{18,600 \times 2}{40,000} \cong 0.9$$

IV HEIGHT MEASUREMENTS IN OBLIQUE PHOTOGRAPHS

The photo-interpreter is concerned with making measurements on photographs, and from these measurements calculating the corresponding dimensions of the ground object. The method derived by A. H. Katz is included here as a means of calculating the height of an object. It will not yield good results when the camera angle of depression approaches 90°, ie., vertical position.

> The formula may be used for determining the height of objects from a single oblique photograph. This includes objects of interpretation interest such as bridges, ships, hangars, and the like which in normal high altitude photography will yield small images. The conditions under which use of this formula is reducible to a simple and quick procedure are the conditions under which most oblique photography will be produced; the camera will be mounted with a known and fixed depression angle in an oblique position. The amount of tilt induced by normal aircraft roll will be measured and available.
>
> Consider the geometry of the oblique photography (Figure VI) where the optic axis is along the line of flight. The ground object of height "h" is located as shown, at an angle ϕ below the optical axis which is at an angle of depression " θ ". The angle ϕ is always measured in a positive sense. clockwise from the optic axis.[3]



h- Object height in feet
H- Flying height in feet
f- Focal length in feet
I- Image size in feet
θ- Depression angle
φ- Angle off Optic Axis

Figure VI

The height of the object is then;

$$h = \frac{2HI}{f} \frac{\cos^2 \theta}{\sin 2(\theta + \phi)}$$

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[3] A.H. Katz, "Contributions to the Theory and Mechanics of Photo-interpretation From Vertical and Oblique Photographs", Photogrammetric Engineering, XVI (3) (1950), Pp.339-86.

The preceding formula may be used for computing object height, but would not be applicable for photographs taken with 60% overlap in the vertical position since θ would equal 90° and ϕ would be small. Measurements could be made with triple airbase convergent photography since θ would then be 80°, but the method would be applicable only for objects of great height located outside the optic axis. Even under these conditions the accuracy would be low.

Assuming an image size of 0.001 feet , 36 inch focal length, 40,000 ft. height, $\theta = 80^\circ$, object on axis. Then,

$$h = \frac{2 \times 40{,}000 \times 0.001}{3} \; \frac{\cos^2 0^\circ}{\cos 2(80+0)}$$

$$h = \frac{80}{3} \times \frac{1}{2\sin 80^\circ \cos 80^\circ}$$

$$h = 156 \text{ feet approx.}$$

This figure for measurement of object height considerably limits the number of objects whose height could be measured. Therefore another criteria for recognition and detection must be considered.

V. THE USE OF THE STEREOSCOPIC EFFECT FOR RECOGNITION AND DETECTION

Since the height of many objects will not have to be accurately known for interpretive information then the scope of recognition and detection is considerably broadened by the addition of the stereoscopic effect. This effect then will be the limiting factor of recognition and the inability to make accurate measurements merely restricts the amount of information available to the interpreter.

To illustrate the point consider an object whose plan view is imaged as a rectangle of uniform tone in the print. This could be the image of either a two dimensional or three dimensional object, but a single print does not supply enough information to tell us which it is. The addition of a second print which forms a stereoscopic pair with the first print will verify that the object is three dimensional if the object height is sufficient to produce apairmof images above the threshold for stereoscopic vision. If this is the case then more information has been made available and the limit of interpretation has been placed on the ability to recognize the third dimension instead of measuring this dimension.

It was shown earlier that a triple airbase will reduce the stereoscopic threshold to one third of that with normal air base. This is enough justification for recommending its use and the aim of the laboratory tests will be to prove that the use has practical application. An attempt will also be made to obtain figures which can be applied to aerial photography.

VI THE PROBLEM WHICH HAS TO BE SOLVED.

All the previous information stated predicts an increase in information which can be obtained by using a convergent system of photography. Calculations lead one to expect to be able to recognize objects of one third the height of those capable of being recognized by standard methods of photography. This might cause an erroneous assumption that we will then get three times the information from photographs using the convergent system. Anyone familiar with aerial photography knows that this is not true. The three fold increase will,in all probability, never be realized and, in practice, the increase might be only a small percentage of what has been predicted. It is necessary then to set up tests to determine the actual increase resulting from the whole camera system. This can be done by aerialtests over targets of known height, a less expensive method, but not necessarily as factual, is to scale down the whole system and perform laboratory tests.

Using laboratory tests allows more control to be maintained during the initial study phase. Such factors as illumination, haze, turbulence, vibration, all affect the results obtained in the air, while in laboratory tests these factors can be eliminated or controlled and photographs can be taken under the same conditions at all times, once the best conditions have been established.

After laboratory tests are complete and possible variations have been exhausted then the aerial test becomes more meaningful. Relatively few aerial flights can establish a relationship and then the laboratory tests become of real value. Until this time the results had been merely relative. Once a relationship has been established, then the results of aerial flights can be predicted with reasonable accuracy.

The question that has to be answered by the laboratory tests is then:

> " How much increase in interpretability can be achieved by using convergent photography compared to the results obtained from 60% overlap vertical Photography?"

The results of the comparison will be relative and will not give figures capable of predicting aerial results until a relationship has been established. It was originally intended that aerial flights would be included in this study, but time limitations and the unexpected problems encountered in the laboratory prevented inclusion of these tests.

VII PRELIMINARY APPROACH TO THE LABORATORY TESTS.

It was necessary at the beginning of the tests to set up arbitrary conditions of operation. These conditions were subject to change as information was accumulated since there were no previous tests on which to base the original conditions. It seemed logical at first to try to duplicate as much as possible the conditions which would exist on an aerial flight. For this reason a high speed film and a high contrast developer were chosen, but it was later necessary to change the film and developer.

The conditions and equipment originally chosen for the first part of the tests were:

a. Camera Canon 35 mm. , 50 mm. focal length

b. Film Kodak Super XX 35 mm. roll, This film has the same speed and grain as Aero Super XX, but does not have the same spectral sensitivity characteristics.

c. Development D-19 with the film developed to a Gamma of 1. The gamma is lower than normally used for aerial photographs, but is easier to reproduce uniformly throughout the tests. A higher gamma was not necessary because of the high target contrast.

d. Illumination. A single Photoflood Lamp. The reason for using a single lamp was to simulate sun conditions. This had to be changed later because it introduced a source of error in reading the results

e. Camera Distance Originally chosen at 20 feet.

f. Target Target contrast was chosen as infinite since it was ea easier to make targets with very high contrast. Two separate targets were made, One had white objects on a black background and the other had black objects on a white background. It was a three dimensional target consisting of objects of three cross-sections, 0.25, 0.50, 0.75 inches square, Ten objects of each cross-section were made varying in height from 0.25 to 0.75 inches. The target array is shown in Figure VIII.

g. Diagram of Equipment Arrangement

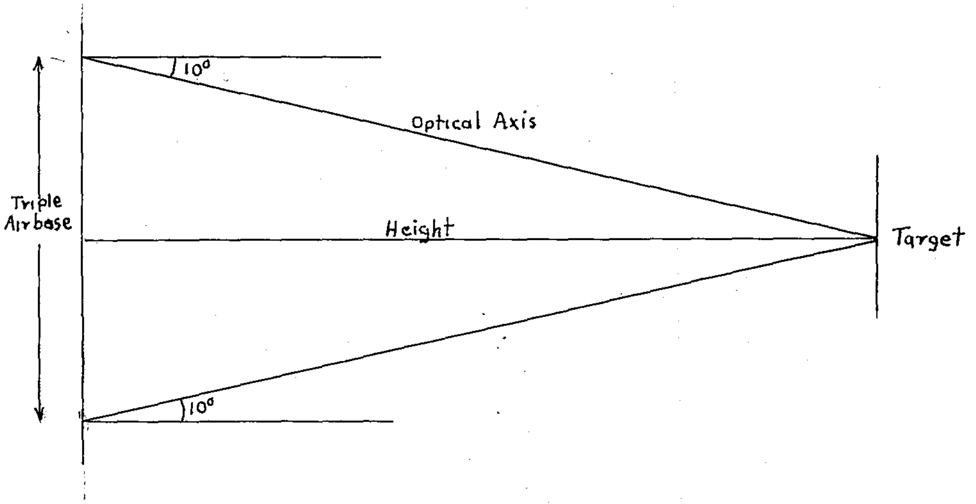


Figure VII

h. Airbases At a distance of 20 feet the airbases were 9 feet for the triple base and 3 feet for the single base. Therefore pictures were taken at 1.5 and 4.5 feet left and right of the axis on the normal to the axis at 20 feet from the target.

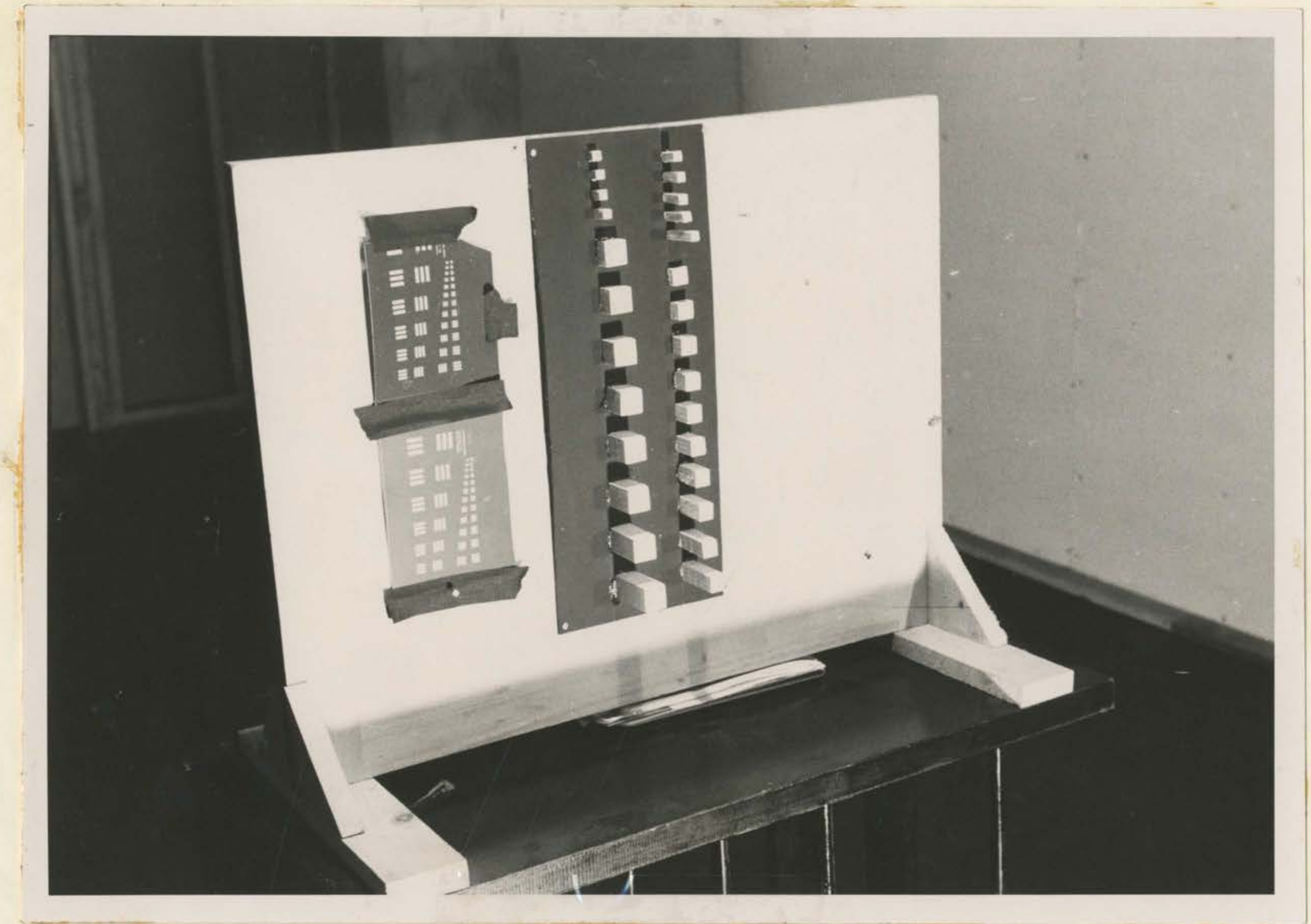


Figure VIII Target # 1 Black Objects on White Removed.

i. Criteria of Evaluation The means of comparing the two systems was chosen as the object of minimum height which could be reproduced stereoscopically. Objects smaller than this could be considered to be below the limit of stereoscopic resolution for the conditions under which the photographs were taken. The height of the object which is just stereoscopically resolved by each system would give a relative comparison figure and would be a measure of the increase in detail which can be obtained in the third dimension by convergent photography.

VIII LABORATORY TESTS TO DETERMINE SUITABILITY OF THE TARGET AND THE ESTABLISHED CONDITIONS

Photographs were made using target #1 with both black objects on a white background and white objects on a black background to determine whether the conditions previously established for the tests would yield usuable results for evaluation purposes.

1. Initial Test Conditions

The following test conditions were established for the first tests:

a. Target Distance 20 feet

b. Single Airbase 3 feet

c. Triple Airbase 9 feet

d. Film Super XX

e. Illumination A single photoflood lamp 10 feet from the target, 4 feet to the right of the axis.

f. Exposure $\frac{1}{2}$ second at f/5.6 and f/4.

After a set of pictures had been taken at the stated conditions, a white cardboard reflector was added to the system to the left of the target, and another set of photographs was made. The reflector was added to allow some diffuse light to fall on the left side of the target since the shadow cast by the objects was darker than would be encountered under ordinary conditions.

The negatives were developed in D-19 developer for 6 minutes at 68° F, and contact printed on Azo F-2 paper using Dektol developer.

2. Results

a. The exposure was too high resulting in negatives which were toodense for satisfactory prints.

b. The photographs where the reflector was used gave the best results since some light was cast into the shadows, but more light was required for the pictures to have interpretative value.

c. The black objects on the white background were poorly recorded, due to the flare of the background into the image of the objects. Thispart of the target was omitted in further tests.

d. The target distance appeared to be too large for evalution purposes, but this cannot be decided until pictures of better quality are examined.

3. Altered Test Conditions

The conditions of the following tests were changed to overcome thelimitations of the system as originally established. The conditions were changed to:

a. Target Distance 15 feet

b. Single Airbase 27 inches

c. Triple Airbase 81 inches

d. Illumination Two photoflood lamps 8 feet from the target 4½ feet to the right and left of the axis.

e. Exposure f/5.6, 1/4 to 1/40 seconds

f. Film and Processing Same as first tests.

4. Results

The photographs resulting from these tests were considerably improved over the initial tests, particularly in the exposure and lighting conditions.

a. The best negatives were produced at an exposure of f/5.6, 1/20 second.

b. The use of two photoflood lamps provided better illumination on the target, but cast a sharp shadow out on both sides of the objects. These shadows made evaluation difficult so the lighting arrangement was changed to remove most of the shadow from the sides.

c. The combination of Super XX film and D-19 developer produced negatives which were extremely grainy with low resolution and poor edge rendition and thus made low quality prints. Therefore it was decided to use Plus X film in combination with D-76 developer in order to get better quality pictures.

IX LABORATORY TESTS WITH TARGET # 1

The previous tests were performed for the purpose of finding the faults in the system and correcting the ones that affected interpretation. It was then possible to take a series of photographs that would allow an evalution of the system in order to determine if the criteria of evalution as originally chosen was a valid method of comparison.

1. Test Conditions

   a. Target Distance 5, 10, 15, and 20 feet

   b. Single Airbase 9, 18, 27, and 36 inches, respectively,forthe above target distances

   c. Triple Airbase 27, 54, 81, and 108 inches, respectively for the above target distances.

   d. Film Plus X

   e. Illumination Four photofloods as follows:

      1. 1 foot in front, 5 feet above the target
      2. 5 feet in front, 2 feet below the target
      3. 12 feet in front, 5 feet to the right, level with the target
      4. 12 feet in front, 5 feet to the left , level with the target

   f. Processing D76 developer, 20 minutes, 68°F, Printing Azo F-3 paper, Dektol developer.

2. Results

   a. The quality of the negatives was greatly improved by the change to Plus X film and D-76 developer. The resolution was increased to the point where stereoscopic viewing was achieved.

b. The use of the four photofloods did away with most of the shadows, but there was still enough shadow present to introduce error into the interpretation.

c. The dimensions of the target array introduced another source of evalution error which had not been considered. This error was caused by the different perspective angle of viewing the objects at the tpp and bottom of the target. Because of the length of the target in the vertical direction, the lower side of the upper objects and the upper side of the lower objects could be seen and this gave the impression of an object which was not vertical. Since the size of this surface was the same in both single and triple base photographs it does not contribute anything to stereoscopic viewing, instead it is a confusing factor which had to be eliminated. It is also possible to see the side surfaces of the objects, but this is desirable for stereoscopic viewing since these dimensions will vary for the two airbases and becomes a part of the method of comparison.

d. The target distance which gave the best stereoscopic viewing conditions was 10 feet. This distance was chosen for future tests.

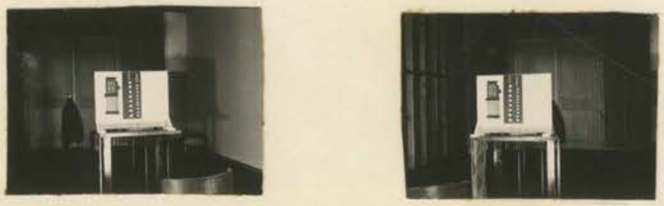
e. The different target cross-sections presented too many objects to the observer and made viewing difficult. The most usable objects were those with the 3/4 inch cross-section.

3. Analysis of the Results

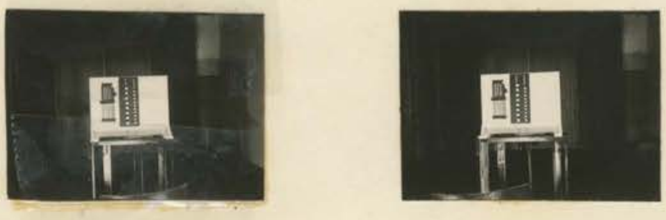
Photographs of the target taken at 5 and 10 feet are shown in Figure IX. From these photographs the smallest object height which was just stereoscopically resolved could not be accurately determined. This was due to a number of factors such as illumination, angle of perspective, too many objects in the target array, and the factor of personal opinion on which object was just stereoscopically resolved. It was necessary then to change the whole target array to overcome the difficulties and to establish a new criteria of evalution. The method of determining which object height was just stereoscopically resolved was too dependent upon personal opinion to be of value.

Triple Airbase, 5 ft. Target Distance

Normal Airbase, 5 ft. Target Distance



Triple Airbase, 10 ft. Target Distance



Normal Airbase, 10 ft. Target Distance

Figure IX Stereoscopic Pairs of Target # 1

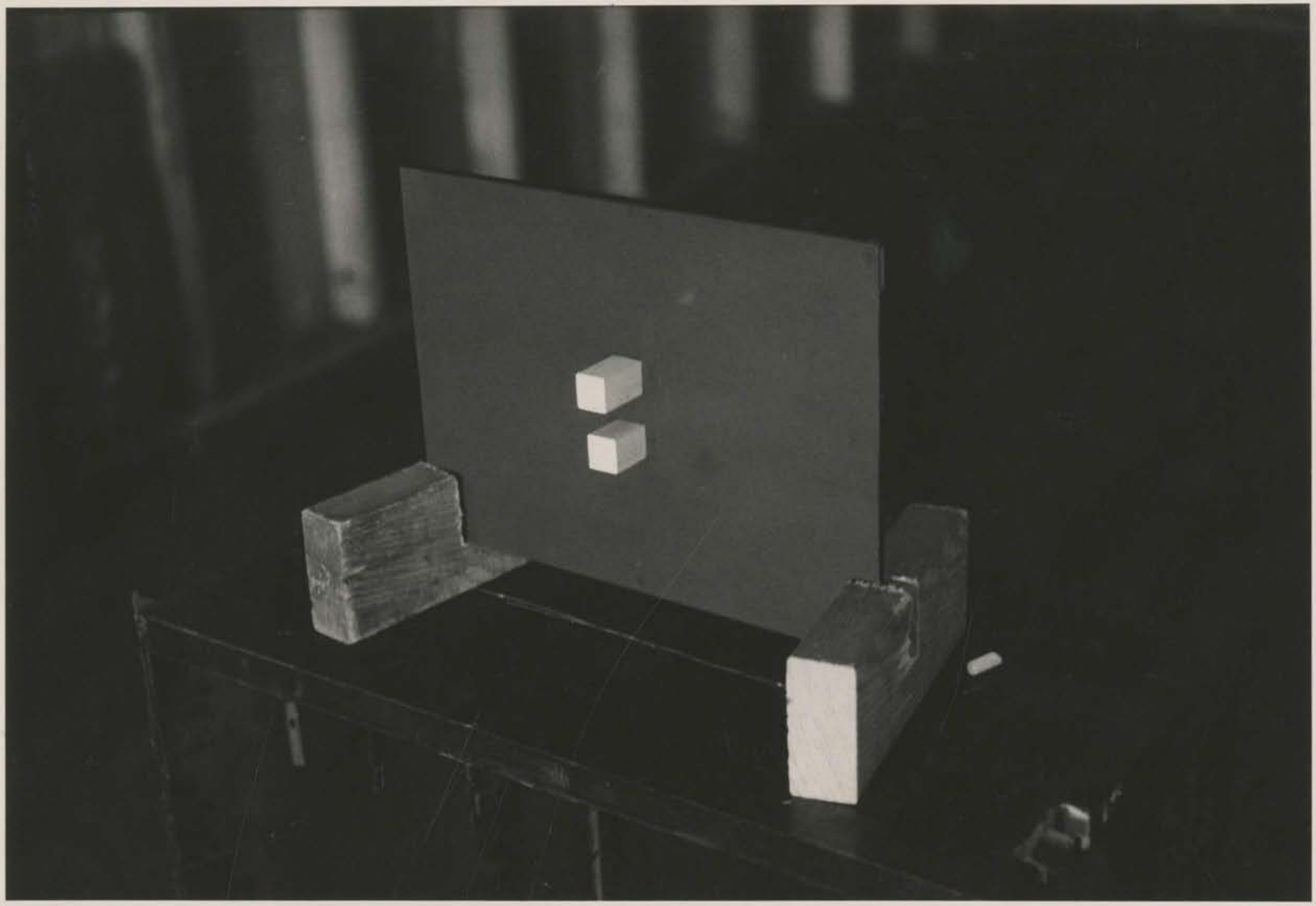


Figure X Target # 2

X LABORATORY TESTS WITH TARGET # 2

The previous results indicated that the test apparatus required changes in order to overcome the difficulties encountered. Therefore, a two object target (Figure X) was adopted which eliminated the physical difficulties and presented the observer with just the single choice as to which object was higher. Illumination was planned as a single source with a large reflector on the axis of the system. An optimum object height and the range of movement of the movable object had to be established. Two sets of photographs were made to determine these conditions.

The method of illumination proposed above had to be abandoned since a suitable reflector could not be obtained. The system was approximated by putting two photofloods on the axis at a distance of 10 feet. No shadows were formed by this means of lighting, but the sides of the objects were too dark to be properly recorded by the film. The sides were lighted by two photofloods placed 20 feet from the target, 5 feet left and right of the axis, and level with the target. This illuminated the sides sufficiently, but cast a slight shadow on each side of the objects which was not expected to cause any difficulty because there was very little contrast between the shadow and the background.

The following conditions remained the same for the remainder of the tests:

a. Object Distance	10 feet
b. Single Airbase	1.5 feet
c. Triple Airbase	4.5 feet

d. Film Plus X

e. Exposure f/4.5, 1/30 second

f. Processing Negatives, D-76 Developer, 20 minutes at 68° F

Prints, Azo F-3 Paper, Dektol Developer.

g. Illumination 2 Photofloods on axis at 10 feet

2 Photofloods 20 ft. from target, 5 ft. on each side of the axis, level with the target.

1. Test # 1, Object Height 1.5 inches

In the first test the object height was chosen as 1.5 inches, which was the approximate height of the highest object in the first target. The movable target was varied between 1.25 and 1.75 inches in 1/16 inch increments.

When the photographs were examined it was found that both the object height and the range of height difference were too small. The object height was too small in relation to the total increment used so the larger object could be determined from a single photograph with the triple base. This occured because the ¼ inch difference was too large a percentage of such a small object height. The range of difference was not large enough to obtain accurate results with the normal base since the difference of ¼ inch was too small for 100% probability of detection.

2. Test # 2, Object Height 4.0 inches

The height was increased to 4 inches and the range of difference was changed to ½ inch above and below the fixed object with 1/8 inch increments. This increment was chosen in order to get quick results on the amount of height difference required without obtaining an excess of photographs for evaluation in these preliminary tests. This increment was not expected to be of much value, but accurate results were not required at this stage.

The 4 inch object height was too large for the object distance used. The stereoscopic effect of the triple base was so exaggerated with this height that the pictures could not be properly fused. The $\frac{1}{2}$ inch range of movement for the other object was sufficient for the triple airbase, but was just on the borderline for the normal base. The 1/8 inch increment was too large as expected so the 1/16 inch increment was chosen for evaluation purposes.

3. Results

The photographs obtained in these two tests were presented to four viewers for evaluation. There were 36 stereoscopic pairs and the viewers were asked " Which object is higher?". The results were not expected to be accurate, but were used to determine if the new target was usuable and if the range of difference in height was sufficient for interpretation.

A graph was plotted of " The number of right answers vs. height difference" and this graph indicated that the results were following a trend similar to the theoretical calculations. From this graph it was determined that a slightly greater height difference would have to be used for the normal air base since the height difference for 100% probability of detection had not been reached.

The decision reached was that an intermediate object height (between 1.5 and 4.5 inches) should be used and the height difference should be slightly increased for the normal airbase. The establishing of these conditions solved the last major problems which had to be overcome before tests could be performed that would yield accurate results for arriving at conclusions on the practical application of the systems being studied.

XI. FINAL LABORATORY TESTS FOR EVALUATION PURPOSES

The previous results indicated that the object height should be between 1.5 and 4.0 inches, so the new object height was chosen as 2.5 inches. It was selected closer to the smaller height in order to avoid,as much as possible,the exaggerated stereoscopic effect produced by the 4 inch targets when viewed at the larger airbase.

1. Conditions

The conditions of illumination, exposure, etc.,as previously established, were maintained. The only changes made in this test were as follows:

a. Fixed Target Height 2.5 inches

b. Movable Target Height 3.0 to 1 13/16 inches in 1/16" increments

Photographs wereemade at both the normal and triple airbase for each increment and 40 stereoscopic pairs of photographs were produced for evaluation purposes

It had previously been observed that the slight shadows present in the prints were a source of confusion to the viewers. An attempt was made to reduce or remove these shadows in the printing process by overexposing the print. The background-shadow contrast could be reduced below the visual contrast threshold,by the overexposure of the print, without seriously affecting the high object-background contrast. This method worked satisfactorily, but some of the prints were a little too light due to the inability to judge the best exposure until the prints were dry and could be examined under the stereoscope. The variation in illumination across the printing surface caused some of this effect.

2. Procedure

The pairs of photographs were mixed and presented to the observers in random order so that the viewers would not be influenced by a regular pattern existing in the manner in which the pictures were viewed. Some of the stereoscopic pairs are shown in Figure XI. A simple pocket stereoscope was used for observation and no time limit was placed upon the viewers. Lighting conditions for viewing were chosen individually by each observer so that an unsuitable condition would not be forced upon them which might cause eyestrain and give erroneous results.

The viewers were asked to chose which object appeared to be of greater height in each of the 40 stereoscopic pairs. The basis for evalution was; " A wrong answer for a certain height difference indicated that the particular height difference was below the threshold of stereoscopic resolution and the observer could detect no difference in the height of the two objects."

3. Results

The photographs were viewed by 10 observers and a graph was plotted of " The Number of Right Answers vs. Height Difference" (Figure XII). Because of the duplication of height differences above and below the fixed object there were 20 possible answers at each difference. At first it was intended to have more than 10 viewers read the photographs, but the results were being reproduced so closely by each observer, it was felt that this number of viewers was sufficient.

The probability of detection of a height difference is the ratio of the number of right answers to the number of possible answers at the particular height difference. The probability figures would not be too accurate because of the small number of observations, but can be considered accurate for 100% probability, ie. when there are no wrong answers. At height differences below the stereoscopic threshold the observer had a 50% probability of giving the right answer and the probability of detection increased until a height difference for 100% probabilityof detection was reached for each airbase. Referring to the graph in Figure XII, it can be seen that the height difference for 100% probability of detection is smaller for the triple airbase. This was the expected result predicted by the theoretical calculations, which indicated this value should be 1/3 that for the normal airbase. Actually the difference is approximately 1/2, but this does not mean that the results are inaccurate. The threefold increase is a maximum value and might be reached under optimum conditions, while the conditions used for these tests yielded only a twofold increase. One reason for not obtaining the full increase was that the triple airbase photographs were difficult to fuse stereoscopically. The factors causing the difference in results might be corrected after exhaustive laboratory tests had established optimum test conditions, but a full threefold increase would not necessarily be realised.

The deviation in the graph (Fig. XII) for the normal airbase at the 8/16 inch difference was caused by one print being of lower density than the other, making it more difficult to view the pair of prints stereoscopically. The 1/16 inch difference point was caused by more than 50% of the viewers chossing the right answer at a point where only a 50% probability existed. Statistically, this point would show half the observers as right for a sufficient number of observations.

Triple Airbase Top Object Height- 2.5 inches

Height Difference 7/16 inch

Height Difference 3/16 inch

Normal Airbase Top Object Height- 2.5 inches

Height Difference 1/2 inch

Height Difference 1/4 inch

Figure XI Stereoscopic Pairs of Target # 2 (10 ft. Distance)

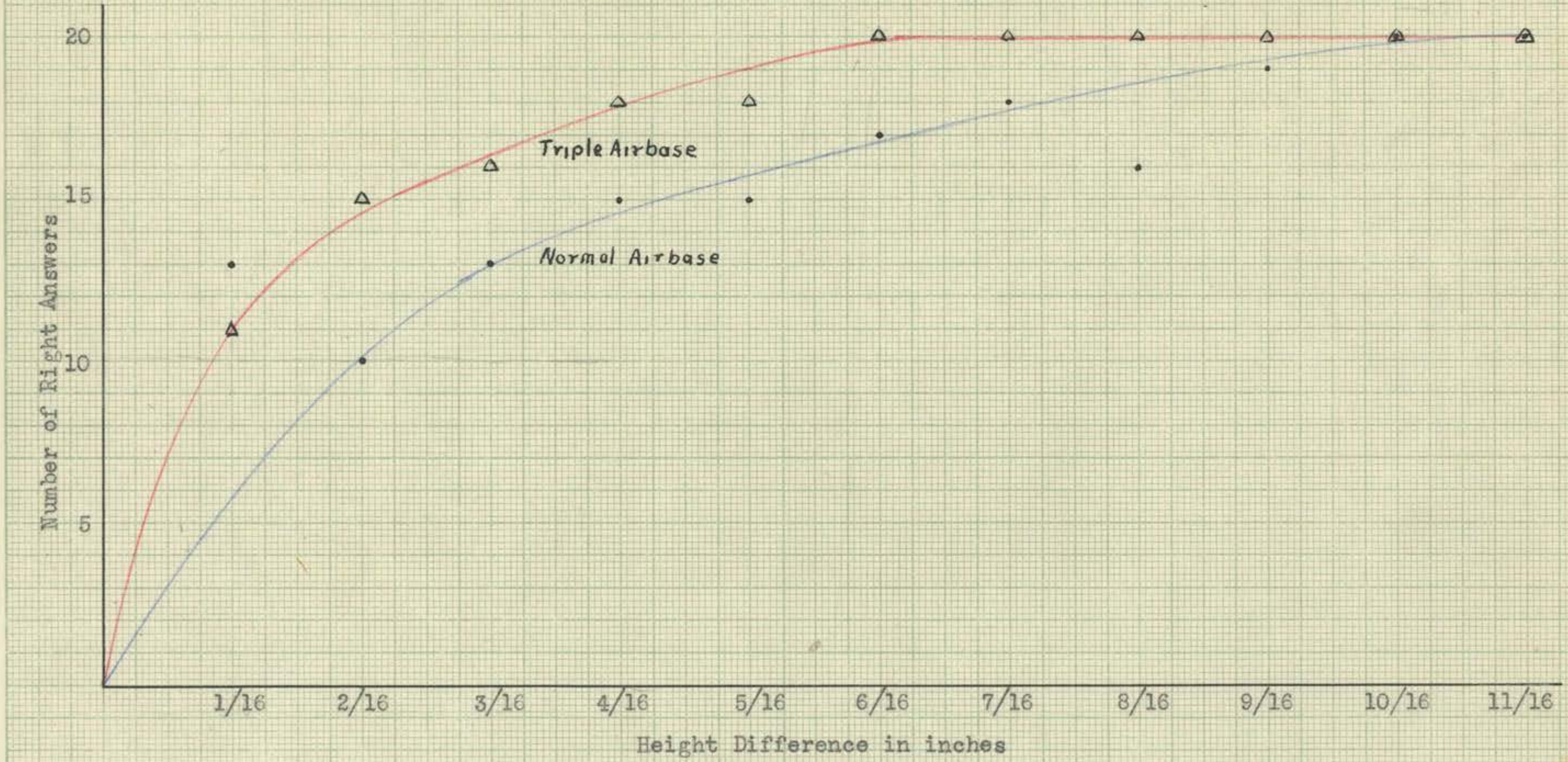


Figure XII Graph of the Results.

XII CONCLUSIONS

The results obtained in the laboratory tests prove that in practice an increased airbase will improve the interpretative ability in the third dimension of height. The results do not achieve the full return indicated by the theoretical calculations based on the geometry of the system, but a number of factors could cause this difference such as:

a. The Combination of Exposure on the Negative and Print. In order to approach the expected three-fold return, the exposures would have to be such as to produce the best negative and print for interpretation purposes. Each print would have to have the same contrast and density range and all conditions detrimental to stereoscopic viewing would have to be removed.

b. The Exaggerated Stereoscopic Effect with the Triple Airbase. This effect could be reduced to a minimum by finding the optimum object height for the camera distance being used. The selected object height has to be suitable for both the normal and increased airbase since both systems must be photographed under the same conditions so they may be compared.

c. The Target Construction. Much more accurate results could be obtained if it were possible to use a smaller increment. It was felt that a 1/16 inch increment was the smallest that could accurately be used with the target as it was constructed. With proper equipment and material, a target array could be constructed which has accurately machined objects that could be varied in height by a micrometer arrangement in much smaller increments than were used for these tests. This would greatly improve the accuracy of the results since more points could be plotted for the curves and the points of 100% probability of detection would be much more accurate.

The twofold increase shown by the results of these tests could very probably be close to the maximum obtainable by the system in actual use. This could be caused by the exaggerated stereoscopic effect itself which prevents proper fusing of the images for the increased airbase and limits the improvement to a figure less than predicted.

On the basis of the results obtained, the height difference which could be determined in laboratory tests was;

a. Normal Airbase. Approximately 5/8 inch difference could be determined at a 2.5 inch object height. Therefore, the height difference/height ratio would be 0.25, indicating that it would be possible to distinguish between the height of two objects if one is 25% lower or higher than the other, assuming both are above the stereoscopic threshold.

b. Triple Airbase. Approximately 3/8 inch difference could be determined at a 2.5 inch object height and the height difference/height ratio is 0.15. The height difference required for detection is then 15% or approximately half that needed for the normal base, under the same conditions.

Aerial test flights would have to be run in order to determine if all the figures can be scaled up to aerial photo conditions. If this can be done, an object can be resolved stereoscopically if its height is equal to the height difference, determined in these tests, scaled up to the operating conditions. The height necessary for stereoscopic resolution at 40,000 feet with a 24 inch focal length camera would be:

$$h = \frac{d}{D} \times \frac{H}{F_a / F_t}$$

$$h = \frac{0.375}{120} \times \frac{40,000}{24/2} = 10.4 \text{ feet}$$

h- Ground Object Height
H- Flying Height
d- Height Diff. in Test Objects
F_a Focal Length of Aerial Camera
F_t-Focal Length of Test Camera

This figure of 10.4 feet is considerably less than the 156 feet required for measurement of the object as was calculated in Chapter IV. This illustrates the advantage of the stereoscopic effect for interpretation purposes. The height required for the normal airbase would be about twice the value calculated above or 17.4 feet. The difference in resolved heights would mean a large difference in the amount of information available from the two systems.

The results and calculations indicate that there is a practical advantage in using convergent photography for high altitude reconnaissance, since objects of about one half the height detectable by the normal airbase can be stereoscopically resolved. This achieves the same effect for vertical dimensions as using a camera of at least twice the focal length, which cannot be used because of the space limitations in jet aircraft. Convergent photography then offers a solution to the high altitude reconnaissance problems, but the exact amount of increase in information cannot be accurately determined until a flight program has been completed and evaluated.

The writer wishes to acknowledge the aid and guidance so kindly given by Dr. D.E. Macdonald, Dr. L.J. Reyna, Dr. C.M. Aschenbrenner, and Miss Ann Simons. I also desire to thank all the observers for the time spent and patience exhibited in viewing the stereoscopic photos.

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ABSTRACT

The introduction of jet aircraft into the field of reconnaissance greatly increased the height at which missions could be flown and the reduced scale fo photography made interpretation less accurate and more difficult. The original scale of photography could not be maintained by increasing the camera focal length because size and weight limitations were placed on the camera due to the aircraft itself. The space is not available in the camera compartment for a longer focal length camera. In order to overcome this difficulty, a method was proposed which would use a convergent method of photography. This consists in using two cameras of the same moderate focal length and rotating the optical axes along the line of flight in opposite directions and fixing them in these positions. With the cameras in this arrangement and utilizing longer airbases, greater stereoscopic effect can be achieved.

The purpose of this project was to determine how much increase in interpretability could be expected from this type of system. An airbase three times normal was chosen for the tests and for the established conditions it was found that the two cameras would have to be rotated 10° from the vertical position. A rotation beyond 10° would have left a gap in camera coverage at the nadir point.

The effect of camera tilt on the projected horizontal and vertical dimensions was calculated so that an excessive tilt angle would not be used. The loss in projected horizontal dimensions was negligible and could be neglected. The increase in projected vertical dimensions indicated that a three-fold increase in height determination could be expected for the triple base.

A method of making height measurements from oblique photographs was studied for the purpose of discovering what object height was necessary for accurate measurements. This height was approximately 156 feet for the chosen conditions, and is too large for practical use. Therefore, it was decide that the stereoscopic effect would have to be used as a means of comparison of the two systems.

With this in mind a target was devised in which a number of objects of different height were stereoscopically presented to the viewers. The purpose of this method was to determine which object was just stereoscopically resolved. This method had a number of faults and was discarded.

The next target devised had only two objects which could be varied in height. One object was held at a fixed height while the other was moved in specified increments above and below the fixed target. These photographs were presented to the viewers and they were asked which object appeared higher to them. The assumption was made here that a wrong answer at a particular height difference indicated that this difference could not be stereoscopically resolved. After a number of trial tests which were made to determine operating conditions, a final set of photographs was made. This set consisted of 40 stereoscopic pairs in which an increment of 1/16 inch was used and the total height difference was varied up to 11/16 inch. This set was presented to 10 viewers and the number of wrong answers was plotted against the height difference.

The graph of results showed that, under the conditions established for the tests, one half the height difference could be determined by the triple airbase as compared with the normal base. This was not the three-fold increase expected, but was a satisfactory answer considering the factors which introduced possible error.

The conclusion reached after studying the results, was that a convergent system of photography does have a practical application.in high altitude reconnaissance since the ability to determine heights would be considerably improved. The actual figures relating the ground tests and aerial flights cannot be determined until a flight test program establishes a relationship between the two situations.