VIEWING PHOTOGRAPHS IN THREE DIMENSIONS

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THREE dimensional vision impressions are gained, in general, by four separate factors: (1) Perspective relationships; (2) Stereoscopy (binocular vision); (3) Focus changes within the eye; and (4) Differential relative motion of the object and background when observer is in motion.

In the viewing of photographs only the first two apply because the eye focus is fixed at one viewing distance and the observer is stationary. An inexperienced observer often has difficulty in the three dimensional viewing of photographs because the separate factors involved are not in normal balance. The writer has attempted here to explain and evaluate some of the the photographic distortions arising from this lack of balance in the three dimensional vision factors particularly with regard to aerial photography.

FIG. 1. Photograph illustrating perspective distortion.

PERSPECTIVE

One of the factors in three dimensional viewing is the perception of perspective. *Perspective is here defined as the relationship between the image size and the distance to the object.*

With visual experience a subconscious impression of the distance to an object is built up whenever a familiar object or scene is observed. An object of known dimension will cast an image of a certain size on the retina of the eye at a given viewing distance. Experience enables the observer subconsciously (or consciouly) to estimate the size of the object in the field of view and obtain an impression of the approximate distance from the observer to the object.

The optical system of a camera records theoretically true perspective without distortion. However, photographs often appear distorted because the focal length and object distance are so arranged to fall outside our normal human visual experience. For instance a photograph taken with a short focal length lens often appears distorted (Fig. 1). The photo perspective is not distorted. The apparent distortion occurs simply because our eye's optical system will not allow us to see a duplicate of the same scene with the same perspective values. When the photo is viewed at a normal viewing distance, the size and relation of the various photo images cast on the retina of the eye cannot be duplicated in viewing the actual scene that is photographed. Because the picture does not fall within our visual experience the perspective seems distorted.

The average observer's reaction in looking at a photograph is that a familiar

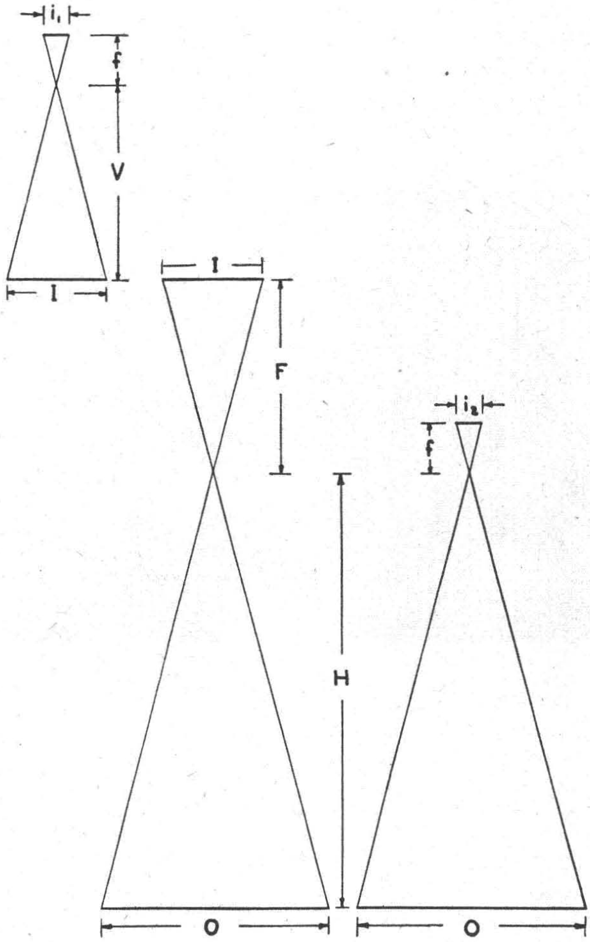

FIG. 2. Relationships between viewing the photograph of an object and the actual object itself.

image so viewed is the same distance from the observer as the actual object would necessarily be to cast an image of the same size on the retina of the eye. Figure 1 appears distorted because the objects in various parts of the photo present an impression of conflicting distances. The objects in the foreground appear too close and the objects in the background appear too far from the observer.

In viewing photographs an image of the actual object is observed. This image casts a second image on the retina of the eye. The perspective relationships between the viewing of a photo image and the actual object follow a mathematical pattern. In Figure 2;

V = Viewing distance (distance eye to photo)
f = Focal length of eye
i_1 = Image on retina cast by photo
i_2 = Image on retina cast by actual object
I = Photo image of object
H = Distance of lens of camera (and of the eye) from actual object
O = Object

$$\frac{i_1}{f} = \frac{I}{V}$$

$$I = \frac{Vi_1}{f}$$

and

$$\frac{I}{F} = \frac{O}{H}, \qquad \frac{i_2}{f} = \frac{O}{H}$$

then

$$\frac{i_2}{f} = \frac{I}{F}$$

or substituting

$$\frac{i_2}{f} = \frac{Vi_1}{Ff}$$

therefore,

$$\frac{i_2}{i_1} = \frac{V}{F}. \tag{1}$$

Thus, it can be seen that in order to cast an image from the photo on the retina of the eye of the same size as that from the actual object V must equal F. In other words for true image and perspective relationships the viewing distance must equal the camera focal length. The viewing distance of the average person is about 12 inches. To the observer a 12 inch focal length lens would provide an undistorted picture. However, where viewing magnification is involved,

$$\text{effective viewing distance} = \frac{\text{view. dist. from eye to photo}}{\text{magnification}}.$$

Where photo enlargement is involved,

$$\text{effective focal length} = \text{focal length} \times \text{enlargement}.$$

Then in order that the image perspective values will not appear distorted;

$$\text{effective focal length} = \text{effective viewing distance}$$

or substituting

$$\text{view. dist.} = \text{focal length} \times \text{magnification} \times \text{enlargement}.$$

It is obvious that in viewing photographs the size of the retinal image varies in inverse proportion to the apparent distance from the object to the eye

$$\frac{i_2}{i_1} = \frac{Ha}{Ht}$$

substituting

$$\frac{V}{F} \quad \text{for} \quad \frac{i_2}{i_1} \qquad \text{(from 1)}$$

$$\frac{Ha}{Ht} = \frac{V}{F}. \qquad (2)$$

When Ha = apparent distance to object
Ht = distance from camera lens to object

Where magnification and enlargement are involved,

$$\frac{Ha}{Ht} = \frac{\text{effective viewing distance}}{\text{effective focal length}}$$

or substituting

$$\frac{Ha}{Ht} = \frac{\text{viewing distance}}{\text{focal length} \times \text{magnification} \times \text{enlargement}}.$$

Then for viewing aerial photos;

$$\text{apparent altitude} = \frac{\text{viewing distance} \times \text{altitude}}{\text{focal length} \times \text{magnification} \times \text{enlargement}}.$$

Stereoscopy

Orthostereoscopic Relationships

In order to obtain photographic orthostereoscopy where the vertical values represented by photo parallax are of the same scale as the horizontal values, certain conditions must be met in the viewing of the stereo photos.

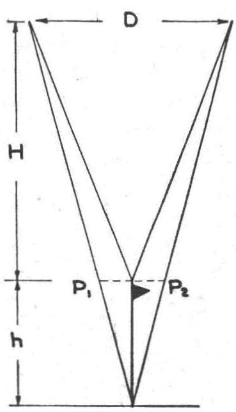

Fig. 3. Parallax relationship of a flagpole photographed from camera stations separated by distance "D."

In Figure 3 it is seen that P_1P_2 is the actual spatial parallax for the flagpole height. This value is represented to scale as photographic parallax in Figure 4 ($P_1T_1 + B_2T_2 = p_1p_2$). In order to view the stereoscopic "model" so that an ortho relationship between horizontal and vertical scale is obtained, the ratio $h/P_1P_2 = i/p_1p_2$ must be maintained. It can be seen that the value p_1p_2 would equal the spatial parallax for an actual model made to the same scale as the photos. The interpupillary distance (d) is fixed, so the orthostereoscopic relationship can only be established by regulating the viewing distance (V).

From Figure 3 it can be shown that

$$\frac{h}{P_1P_2} = \frac{H + h}{D}.$$

Similarly in Figure 4

$$\frac{i}{p_1p_2} = \frac{V + i}{d}.$$

Since orthostereo requires that

$$\frac{h}{P_1P_2} = \frac{i}{p_1p_2}.$$

Then

$$\frac{V + i}{d} = \frac{H + h}{D}$$

or

$$V = \frac{d(H + h)}{D} - i. \quad (3)$$

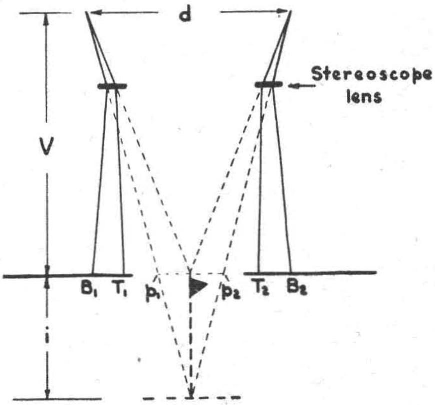

FIG. 4. Viewing set-up to stereoscopic photographs of a flagpole.

Where
Ortho V = Orthostereo viewing distance
d = Interpupillary distance
H = Altitude or distance from object
h = Height of object
D = Distance between camera stations
i = Image height

In aerial photography the height of the object photographed is usually very small compared to the altitude and correspondingly the height of the stereo image is small compared to the viewing distance. In this case both can be disregarded. Then for viewing aerial photos where the altitude is very large com-

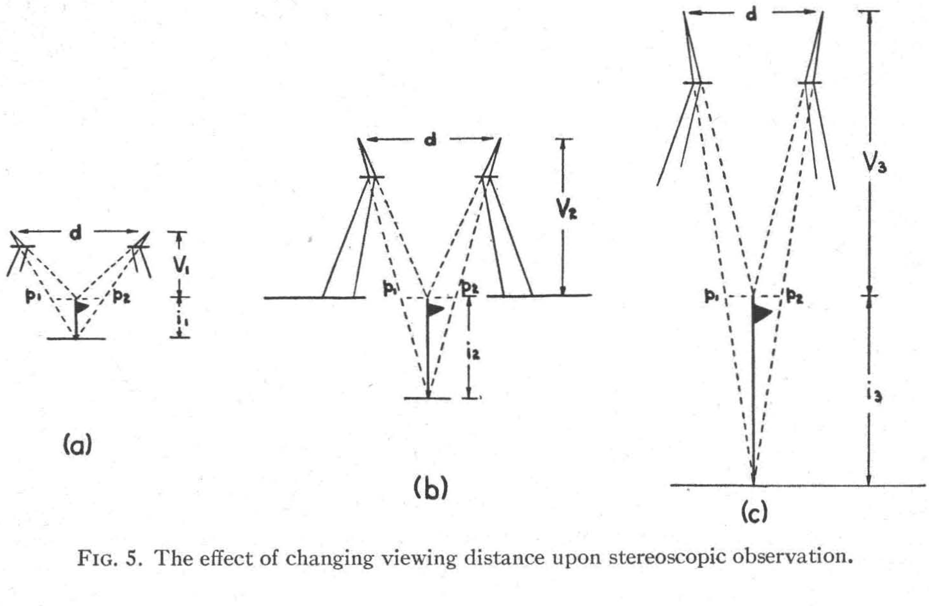

FIG. 5. The effect of changing viewing distance upon stereoscopic observation.

pared to the height of the object photographed the following formula applies;

$$\text{Orthostereoscopic viewing distance} = \frac{\text{interpupillary distance} \times \text{altitude}}{\text{distance between camera stations}}$$

or substituting

$$\text{Orthostereoscopic viewing distance} = \frac{\text{interpupillary distance} \times \text{focal length}}{\text{distance between photo centers}}.$$

The viewing distance is here considered as the actual distance a ray of light travels between the photo and the eye, excepting the distance between the front and rear lens surfaces of any optical system involved.

Stereoscopic Distortion

Figure 5 illustrates the effect upon the stereo model vertical values by changing the viewing distance. The interpupillary distance (d) remains constant as does the photo parallax value (p_1p_2). Diagram (b) in Figure 5 shows an orthostereo relationship while diagrams (a) and (c) show vertical distortions.

The amount of stereo distortion can be mathematically evaluated;

$$\frac{d}{p_1p_2} = \frac{V_2 + i_2}{i_2} = \frac{V_3 + i_3}{i_3}$$

Figure 5 diagrams (b) and (c), where (b) is orthostereoscopic and (c) is distorted.

$$\frac{V_2 + i_2}{i_2} = \frac{V_3 + i_3}{i_3}$$

$$\frac{V_2}{i_2} = \frac{V_3}{i_3}$$

$$\frac{i_3}{i_2} = \frac{V_3}{V_2}. \qquad (4)$$

The rate i_3/i_2 is the amount of vertical distortion or the ratio of apparent height to true height. Therefore, it is seen that the vertical distortion equals the viewing distance divided by the orthostereo viewing distance. When viewing the photos with a magnifying stereoscope the viewing distance is effectively changed. Photo enlargement would have the same effect on the stereo values involved. These factors can be taken into account by the formula;

$$\text{Effective viewing distance} = \frac{\text{viewing distance}}{\text{magnification} \times \text{enlargement}}.$$

Then, to calculate the vertical distortion the formula becomes;

$$\text{Vertical distortion} = \frac{\text{effective viewing distance}}{\text{orthostereo viewing distance}}.$$

By substitution this becomes;

$$\text{Vert. distortion} = \frac{\text{viewing distance} \times \text{distance between photo centers}}{\text{magnification} \times \text{enlargement} \times \text{interpupillary distance} \times \text{focal length}}.$$

(Where vertical distortion is ratio of apparent image height to true orthostereo image height.)

Viewing Conventional Aerial Photographs

The following list illustrating vertical distortion has been compiled for several standard type aerial cameras based on an interpupillary distance of 2.4″, 60% stereo overlap, at any altitude, when viewed under an ordinary refracting stereoscope of $1\frac{1}{2}$ power and $5\frac{1}{2}''$ viewing distance:

Focal Plane Dimensions	Focal Length	Vertical Distortion
9″×9″	6″	1.37
9″×9″	12″	.68
9″×9″	24″	.33
7″×7″	$8\frac{1}{4}''$	.78
7″×7″	20″	.32
7″×7″	40″	.16

Viewing Sonne Continuous Strip Photographs

In many considerations Sonne photography is very different from conventional aerial photography. The amount of parallax (stereoscopic relationship) is adjustable by lens cone setting calibrated in degrees. The following table shows the vertical distortion for strip photos taken at various cone settings and observed under the Sonne viewer:

Stereo Lens Angle	Vertical Distortion	
	Low Magnification	High Magnification
5°	.36	.11
10°	.73	.23
15°	1.10	.35
20°	1.47	.46

(This table applies to all focal lengths at any altitude greater than 4 times the object height.)

Psychological Factors

The foregoing discussion of stereo distortion has been based entirely on the concept of viewing the stereo photos as a model in space. Stereoscopic photos obviously create an optical illusion. The observer doesn't see the actual scene nor does he see an actual model. He perceives a mental concept of a spatial model that is entirely outside normal visual experience. It has been shown in the discussion of perspective that the average individual probably subconsciously considers himself as viewing the actual subject from a distance established by the image size, rather than viewing a model at close distance.

It is a generally known fact that stereoscopic perception is lost at a distance somewhere between 1500′ and 2500′ from the average observer. Therefore using the premise that the observer imagines himself viewing the stereo photos as if he were observing the actual object in space, the vertical distortion is theoretically infinite where the observer imagines himself more than the stereoscopic range of 1500′ to 2500′ away from the object. In viewing aerial photos with this concept it can be seen that the vertical distortion would be enormous because of the tremendous difference between the stereoscopic base of the photos and the stereoscopic base of the eyes.

Factors to be considered which contribute to three dimensional perception are: (a) perspective, (b) binocular convergence (stereoscopy), and (c) change in focus of the eye. When viewing stereoscopic photos, the mind accustomed to normal viewing of three dimensional subjects in space where the three factors above are in harmony must adjust itself to conflict among these factors. The eyes are focused for a short unchanging viewing distance; the perspective is that of a location far from the subject; the convergence is that of viewing a model within stereoscopic range. Probably the most important factors are perspective and convergence. Since the conflict is present it seems logical that the average individual would arrive at a mental concept which would represent a compromise of the factors involved. Therefore it is probable that when viewing stereoscopic photos the observer's mental conception is somewhat confused; placing him subconsciously somewhere between imagining he is viewing the scene from a distance established by the image size and imagining he is viewing a model of the scene. Under these circumstances the observer probably sets his own psychological values somewhere between the mathematical values of stereo model viewing and the infinite or nearly infinite exaggeration of viewing with the concept of observing the actual scene from the air. It is the writer's opinion that with experience in stereo-viewing the observer approaches the concept of observing a model, thereby decreasing the impression of vertical exaggeration and approaching the actual stereoscopic values as previously listed for the individual cameras. In other words, a stereoscopic pair of photographs would not appear to have as much vertical distortion to an experienced photo interpreter as to a novice. For this reason the mathematical values of stereoscopic distortion only apply to persons with abundant experience in stereoscopic viewing.