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More on Distortions by Focal-Plane Shutters

A sample calculation indicates values too low by 2 percent in tree height, 4 percent in tree volume and 6 percent in plot volume.

INTRODUCTION

LARGE-SCALE air photography has become part of established sampling techniques in forest inventories. Reconnaissance cameras generally meet the requirements for high cycling rate and high shutter speeds to ensure proper overlap and sharp images at the scales commonly used (up to 1:1,000 and larger). Most of these cameras have focal-plane shutters which may cause severe distortion. However, Aldred (1968) pointed out that photo measurements can be corrected for this distortion.

ABSTRACT: *Large-scale air photographs are often obtained with reconnaissance cameras which have focal-plane shutters. Normally these cameras are mounted in such a way that the shutter moves in the same direction as the aircraft. For stationary objects, this causes an enlargement of the photographic scale in the direction of the shutter movement. This distortion might introduce significant errors in measurements taken from large-scale air photographs. A graph is given which permits easy determination of relative scale distortions.*

The objective of this paper is to analyse further the effect of distortions caused by focal-plane shutters upon measurements taken on large-scale photographs, and to provide required corrections for given sets of conditions.

DISTORTIONS BY FOCAL-PLANE SHUTTERS

Normally air photographs are obtained from a moving aircraft with the camera installed in such a manner that the focal-plane shutter travels in the same direction as the aircraft. The combined movement of aircraft and shutter relative to the stationary object causes an enlargement of the scale of the object's image in the direction of the shutter movement. This distortion is illustrated in Figure 1, in which points *PP1* and *PP2* represent the principal points of a pair of consecutive photographs obtained with a camera equipped with a between-the-lens shutter from positions *2* on the left-hand side and *3* on the right-hand side. To obtain the same principal points with a focal-plane shutter, the camera would have to be activated earlier, i.e. from position *1* on the left-hand side. The first principal point to be photographed would be *PP2*. By the time the shutter reached the center of the frame *(PP1)*, the plane would have moved to position *2*. The first principal point being photographed on the right-hand side would again be *PP2*.

Similarly, by the time when the shutter reached the position from which *PP1* could be photographed, the plane would have moved to position *4*. This photo-base distortion is always positive if the shutter and aircraft move in the same direction, and this principle also applies to differential parallax. The first tree point to be photographed on the left-hand photo would be the top of the tree on *PP2*. When the base of the tree is photo-

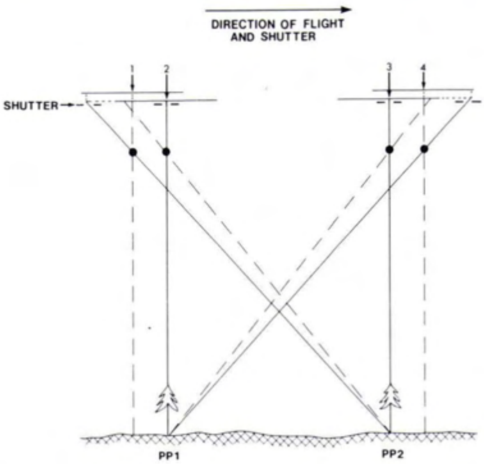

FIG. 1. Distortions caused by focal-plane shutters. Numbers 1 to 4 refer to different positions of the camera during two exposures.

graphed, the plane has come closer to the tree and the angle of view has decreased, making the tree appear larger than it really is. From the right-hand position the top and the base of the tree on *PP2* coincide. Of the tree on *PP1*, the base is photographed first. When the top is photographed, the plane is further away and the angle of view is increased. The effect is the same as for the left-hand position.

The distortions are linear and are a function of the aircraft speed, the shutter speed, the shutter-slit width, the photographic scale, and the angle between the direction of measurement and the direction of shutter travel.

The following example illustrates the maximum amount of this distortion (measured parallel to the direction of shutter travel) for a set of typical values:

Effective format	56 mm (nominal 70 mm)
Forward overlap	60 percent
Photographic base	$56 \times 0.40 = 22.4$ mm
Width of shutter slit	2.24 mm.

Assuming an aircraft speed of 50 m/sec (about 100 knots), an exposure time of 10^{-3} sec and a photographic scale of 1:1,000, the distortion can be computed as follows:

> The shutter requires $22.4/2.24 \times 10^{-3} = 0.01$ sec to travel the distance from conjugate principal point to principal point or vice versa on the photograph. During this time, the aircraft would move $50 \times 0.01 = 0.5$ m. At a scale of 1:1,000, the photographic base of 22.4 mm represents 22.4 m on the ground. The base is thus distorted by about +2.2 percent.

The same relative distortion applies to the differential parallax.

Effects of Distortion

On Tree-Height Measurements and Tree-Volume Estimates

If distorted photo base and distorted differential parallax values are introduced into tree-height formulas, the errors cancel each other. Sometimes, however, the flying heights at which the photographs are taken are computed from ground and photo measurements. In this event, an error in determination of the flying height can be introduced, which will reflect upon the computed tree heights. The worst error is encountered if the distances are measured parallel to the direction of the shutter and aircraft movement. Assuming a focal length f of 150 mm (6 inches), a ground-measured distance D of 22.4 m and a photo-measured distance d of 22.8928 mm (base distorted by 2.2 per cent at a scale of 1:1,000), the computed flying height H will be

$$H = \frac{22.4 \times 150}{22.8928} = 146.8 \text{ m.}$$

For a 20-m tree, the computed height will be

$$h = \frac{146.8 \times 3.5220}{22.8928 + 3.5220} = 19.57 \text{ m}$$

i.e., a negative error of slightly less than 2.2 percent occurs.

In forest-inventory applications, the effect of this error upon the estimate of tree volume depends on the volume regression used. A check with three volume regressions available showed that the relative error in tree volume is about double the relative error in tree height.

On Area Measurements

The size of sample plots is usually given in fractions of acres or hectares. The corresponding side lengths for a square plot reduced to the photographic scale are drawn on the photograph. For the sides parallel to the flight line, there will be a negative error, i.e., the distance represented on the ground will be shorter than it should be because the photo scale is increased. For the values given above, the sample-plot area would be 2.2 percent too small.

Correction for Distortions

The graph (Figure 2) represents maximum relative distortion values for linear measurements taken in the direction parallel to

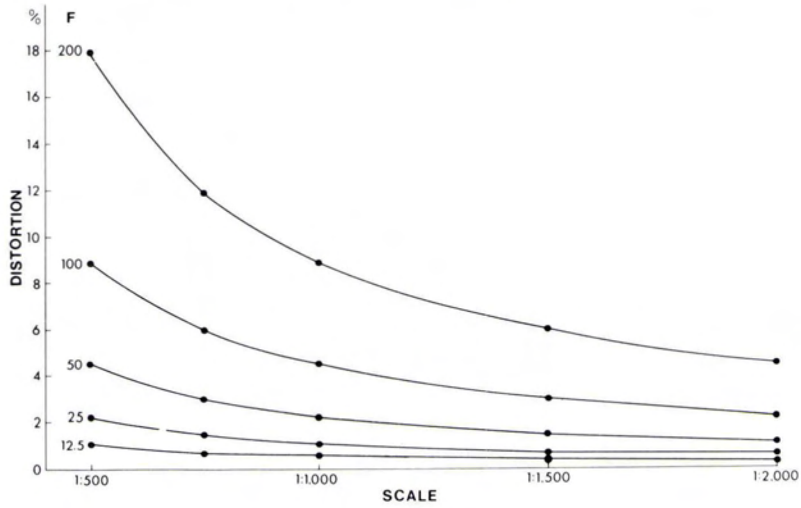

FIG. 2. Distortion caused by a focal-plane shutter with a slit width of 2.24 mm in dependence of aircraft speed × exposure time × 10^3 (F) and photographic scale.

the shutter travel for a shutter slit of 2.24 mm and for combinations of different scales and factors F computed as follows:

Aircraft speed in m/sec × exposure time in sec × 10^{-3}. For example, an aircraft speed of 50 m/sec and an exposure time of 1/1,000 sec gives a factor of $50 \times 0.001 \times 10^3 = 50$ m. The same factor is obtained with aircraft speeds of, for example, 25 and 100 m/sec and exposure times of 1/500 and 1/2,000 sec respectively:

$$25 \times 0.002 \times 10^3 = 50 \text{ m}$$

$$100 \times 0.0005 \times 10^3 = 50 \text{ m}.$$

If a shutter with a different slit width is used, the values obtained from the graph have to be multiplied by 2.24 and divided by the actual slit width.

Distortions of measurements taken at certain angles to the direction of shutter travel can be approximated by multiplying the values obtained from the graph by the cosine of the angles involved.

CONCLUSIONS

Focal-plane shutters cause distortions which may introduce errors in measurements taken from large-scale air photographs. These errors can be significant in the estimation of timber volume. The relative error of tree volume is approximately double the relative error of tree height. In the computation of sample-plot volumes, the final error will be increased further if the sample plot delineated on the photograph is too small. For the case given the error in tree height is about −2 percent, in tree volume about −4 percent and in plot volume about −6 percent.

Measurements from photographs can easily be corrected using the graph (Figure 2). The information required is the aircraft's ground speed, exposure time, width of shutter slit, and photographic scale. The graph gives the maximum relative distortion for the distance measured. As the measurement error is always positive, the value obtained has to be subtracted from the distance measured.

Although reconnaissance cameras do not always meet the precision standards of mapping cameras, measurements usually meet forestry standards if the appropriate corrections are made. The fast shutter speeds available in these cameras can provide photographs free of discernible image motion. Other advantages are their reliability, their low cost and their small size, which makes them easy to install in a variety of light aircraft.

REFERENCE

1. Aldred, A. H., 1968, Distortions by focal-plane shutters. *Photogrammetric Engineering* 34(7):688-689.