Parallax Suppression with a Target Rifle Aperture Sight— An Optical Demonstration

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ABSTRACT

In the use of the common aperture sight on rifles in precision target shooting, common wisdom emphasizes the necessity for the shooter to carefully maintain his eye position so the tip of the front sight post appears centered within the circular field of view of the rear sight aperture. Otherwise, goes the wisdom, parallax shift will occur, which will disrupt the accuracy of the shooter's aim.

A recent article by Robert J. Burdge and Douglas A. Kerr, P.E., points out that this parallax shift doesn't seem to really occur in practice, and advances an explanation for this in terms of basic optical theory.

Subsequently, Kerr conducted optical model tests in which the human eye is replaced by a digital camera in order to demonstrate the behavior involved. This article reports on these tests and discusses the results.

BACKGROUND

The aperture sight

An aperture sight (sometimes called a "peep sight"), often used on target rifles, comprises a rear sight, which is essentially a metal plate with a small circular hole in it (with a typical diameter of 1.0-1.5 mm), mounted near the rear of the receiver, and a front sight, which is a small vertical post (perhaps 1-2 mm wide) near the muzzle of the barrel. The shooter looks through the aperture in the rear sight (with the eye perhaps 40-50 mm behind the sight), observes the front sight, and aims the rifle until the top of the post is located on the desired location on the target.

Aiming in target shooting

For precision target shooting, it is common to adjust the sights so that proper aim is attained when the black aiming circle ("bull") of the target appears just perched atop the front sight post and centered on it (sometimes called the "pumpkin on a post sight picture").

Common wisdom in the target shooting world is that for greatest accuracy, the shooter must control the location of his eye so that the tip of the front post appears centered in the field of view through the rear sight aperture. Otherwise, supposedly, the uncertainty in the "point of perspective" of the eye will cause a variable *parallax shift*, disrupting the pointing of the rifle when the desired juxtaposition of front sight and target circle is attained.

The reality

In fact, it turns out that, subject to certain limits, change in the location of the shooter's eye does not cause parallax shift, and thus does not disrupt the accuracy of the aim.

Simplistically, the reason for this is as follows. So long as the rear sight aperture falls (from a line of sight standpoint) within the span of the pupil of the eye, the sight aperture becomes the "entrance pupil" of the joint optical system comprising the rear sight and the eye. The point of perspective of an optical system falls at the center of the system's entrance pupil. In this case, that entrance pupil (the rear sight aperture) has a fixed location with respect to the rifle, independent of the location of the shooter's eye. Thus no parallax shift actually takes place as the eye moves.

A recent article by Robert J. Burdge and this author[1] describes this situation and explains the optical theory in more detail.

"Live fire" testing by Burdge (reported in that article) confirms the practical implications of this situation.

Burdge coined the phrase "parallax suppression" to refer to this effect.

Parallax reduction

Our theoretical models suggest that when the eye shift is such that the entrance pupil of the eye begins to "encroach" on the entrance pupil defined by the rear sight aperture, parallax shift will start to appear. We would expect it to advance incrementally by about half the amount of the further eye movement. The combination of the delayed onset and the "half-rate" incremental advance means that the total amount of parallax shift will still be substantially less than what would be expected from simplistic consideration of the geometry. We call this effect "parallax reduction".

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[1] *Parallax Suppression with a Target Rifle Aperture Sight*, Robert J. Burdge and Douglas A. Kerr, P.E., Issue 3, May 29, 2007, published online at The Pumpkin:
http://doug.kerr.home.att.net/pumpkin/index.htm#ApertureSight

OPTICAL MODEL TESTS

Introduction

In order to further illustrate the implications of this finding, I conducted a series of optical model tests in which a digital camera plays the role of the human eye. The apparatus allows carefully controlled shift of the lateral position of the “eye”, and in the resulting images we can see to what extent (if any) parallax shift appears.

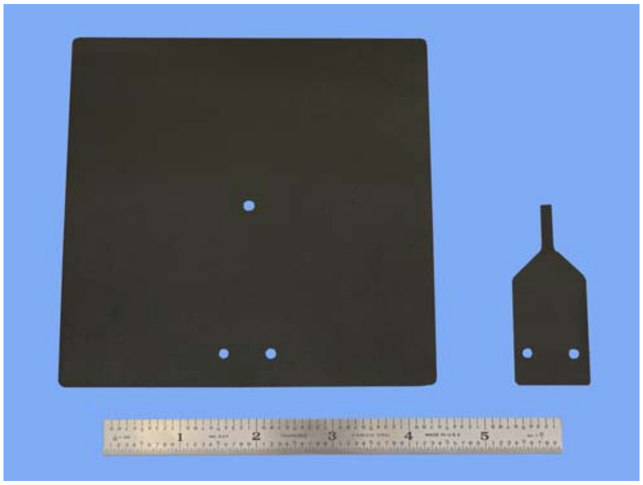
System scale

The test setup emulates the geometric relationships in an actual sight and eye situation. However, the system is scaled up by a factor of about 4 from actual practice (in most respects) in order to facilitate manipulation and measurement. The exact dimensions and parameters will be described later.

The sight dummy

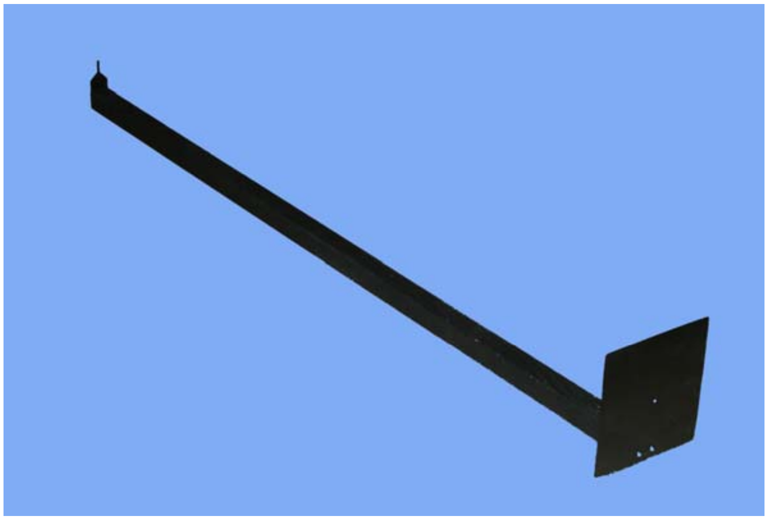
For the test, a “sight dummy” was constructed to play the role of the rifle’s sight system. The rear sight is a thin sheet metal plate 5” square, carrying at its center a circular aperture 4.0 mm in diameter. The front sight, also of thin sheet metal, is surmounted by a “post” 16 mm tall and 4.0 mm wide. Both are finished in flat black.

Here we see the two sight pieces. A 6” machinist’s scale is included for size comparison.



The two sights are mounted at opposite ends of a wood bar 1000 mm long. (This would in fact be a rather short “sight radius” at real world scale, a departure that was adopted for convenience. I feel that the impact of this does not affect the principles involved.)

Here we see the complete sight dummy:



Our eye is a camera

The role of the human eye is played by a Canon EOS 20D digital single lens reflex (SLR) camera. It is equipped with a Canon EF 24-105 mm f/4 L IS lens, used here at a focal length of 105 mm.

The lens affords a relative aperture adjustable from f/22 to f/4.0, giving (at our focal length of 105 mm) an entrance pupil diameter from 4.77 mm to 26.3 mm (corresponding to an eye pupil diameter of 1.19 mm to 6.58 mm at real world scale).

The camera is mounted on an Adorama two-axis macro focusing rail, in turn mounted on a tripod head atop a tripod. This focusing rail, reminiscent of a micrometer microscope stage, has rack and pinion mechanisms allowing the camera position to be finely varied both along the camera axis (used in macrophotography for precise focusing) and from left to right (used in macrophotography to allow precise lateral positioning of the image). Scales calibrated in millimeters are provided for each axis of movement.

The macro rail has been enhanced by the addition of a calibrated scale to the control knob for lateral movement, allowing the camera position to be directly read to a precision of 0.5 mm, with the prospect of interpolation to 0.1 mm.

The simulated rifle

In our "rifle", the sight dummy is mounted on a bracket arm connected to the frontmost leg and center column of the tripod. The tripod is equipped with an rack and pinion controlled elevator column, allowing the vertical position of the camera to be adjusted to attain the desired alignment with the rear sight aperture.

This figure shows the overall "rifle" setup:

The test target

The target used has a simple black disk (the "aiming circle") 40.0 mm in diameter on a white background. In the test situation, the width of the target disk on the camera image is essentially equal to the width of the front sight post. This is the approximate situation often arranged for in precision target shooting with this type of sight.

The target is mounted atop another tripod. The figure at the left shows the setup.

Although arrangements at our rifle provide for precise alignment of the camera to the sight, there is no convenient way to precisely aim the rifle at the target. Accordingly, the ultimate refinement of that aim is done by moving the target.

The target tripod has a rack and pinion elevator column for vertical adjustment. The target easel is set in front of the tripod head on a 12″ arm, allowing lateral movement of the target to be refined using the pan axis movement of the tripod.

The distance from the rear sight to the target for these tests is nominally 7.5 m. This is unrealistically small compared to the typical real-life situation but still allows the principles to be demonstrated.

THE TESTS

Procedure

After setting up all the apparatus, the alignment of the front sight post in the center of the rear sight aperture is established. Then the “pumpkin on a post” aiming juxtaposition is established.

At this point, the first formal shot is recorded.

Then, the camera (our “eye”) is moved to the left in increments, using the calibrated lateral shift mechanism of the focusing rail, taking a shot at each position, until the tip of the front sight post appears at the far left of the field of view of the rear sight aperture.

Test sequence specifics

For these tests, the distance from the rear sight to the entrance pupil of the eye was set to approximately 203 mm. This corresponds to an “eye-relief”, in real world scale, of 50.7 mm (about 2.0″). This distance was adjusted using the axial (“focusing”) movement of the focusing rail.

Note that for the typical human eye, the diameter of the entrance pupil varies from about 2 mm to 8 mm (depending on the eye’s accommodation of the ambient brightness).

In our “4x scale” setup, this corresponds to a range in the diameter of the entrance pupil of the camera of from 8 mm through 32 mm. In these tests, four rounds were taken, each with a different diameter of the camera aperture: 5.3 mm, 8.1 mm, 16.7 mm, and 21 mm. We can think of these as roughly corresponding to eye pupil diameters of about 1.3 mm (smaller than the actual range for the eye), 2.0 mm (about the smallest diameter for the eye), 4.2 mm (a nice “midrange” value for the eye), 5.3 mm, and 8.1 mm. We report here only the results for the 8.1 mm and 16.7 mm diameters.

RESULTS

Scale

From here on, all dimensions will be given in "real world" scale equivalents. We'll call attention to that for the first few.

Eye pupil diameter 4.2 mm

First, we will look at the results for a camera pupil diameter (real-world basis) of about 4.2 mm, a nice "mid-range" value. We start with the "eye position" matching the "sight alignment" technique that is taught in rifle shooting instruction: where the tip of the front sight post appears to be at the center of the field of view of the rear sight aperture, aligned the sight post with the target disk, and take an shot.

Then (with the aim of the "rifle" unchanged) we move the eye position to the left in increments of 0.125 mm ("real world" basis) and take shots at each position. Since the aim of the "rifle" is unchanged, any shift in the apparent alignment of the front sight post and the target disk is a manifestation of "parallax shift".

The images below correspond to the initial ("ideal") position and then eye position offsets to the left of 0.25 mm, 0.75 mm, 1.25 mm, 1.50 mm, and 2.00 mm. Please excuse the intrusion of a hanging lamp into the "scene" from the right; it apparently ignored the "Closed Set" sign.

Note that for eye movement up through 1.25 mm, the phenomenon of parallax shift does not appear to any discernible degree.

If there were no parallax suppression or reduction, for a 1.25 mm eye offset we would see an apparent misalignment between the target disk and the front sight post of almost the width of the post.

At an eye displacement of 1.50 mm, parallax shift is discernible. This reflects the transition of the system from the "parallax suppression" mode to the "parallax reduction" mode.

Ideal eye position Eye shift left 0.25 mm Eye shift left 0.75 mm

Eye shift left 1.25 mm Eye shift left 1.50 mm Eye shift left 2.00 mm

Eye pupil diameter 4,2 mm

Our rather primitive theory of the parallax reduction mechanism suggests that, for this combination of dimensions, parallax suppression lapses into parallax reduction at an eye offset of about 1.50 mm. I consider this in reasonable agreement with the results of the tests.

With an eye offset of 2.00 mm (the greatest possible before the sight post and target move out of the field of view through the rear sight aperture), the apparent parallax shift is about 0.16 × the width of the sight post. If there were no parallax reduction in effect, we would expect to see a misalignment of about 1.6 × the width of the post. This is a parallax reduction of 1:10.

Eye pupil diameter 2.0 mm

Next we look at the results for a pupil diameter of 2.0 mm (essentially the smallest diameter of the human eye pupil, as occurs in a very bright environment).

We show the image for the "ideal" eye position and then for eye displacements to the left of 0.25 mm, 0.50 mm, 0.75 mm, and 1.00 mm.

Ideal eye position Eye shift left 0.25 mm Eye shift left 0.50 mm

Eye shift left 0.75 mm Eye shift left 1.00 mm

Eye pupil diameter 2.0 mm

Note that the scale of these images is the same as for the previous ones. Thus we see that the decrease in "eye" pupil diameter results in a decrease in the field of view through the rear sight aperture.

We see that for an eye displacement of 0.25 mm, parallax shift does not appear in any discernible degree. But at a displacement of 0.50 mm, some parallax shift is visible. Again, this is roughly consistent with our model of the mechanism of parallax reduction.

At a displacement of 1.00 mm (the greatest possible before the sight post and target moves out of the field of view through the rear sight aperture), the apparent parallax shift is about 0.32 × the width of the front sight post (*vs*. a geometric expectation of about 0.8 × the width of the post). This is a parallax reduction of 1:2.5

Parallax shift unleashed

Finally, in order to illustrate what parallax shift would occur if not for the phenomena of parallax suppression and parallax reduction, we conducted tests with the same setup but with the rear sight plate removed.

> The camera pupil used here is 5.8 mm (actual), equivalent to an eye pupil diameter of 1.45 mm (smaller than would actually occur in nature). A larger pupil (in the absence of the smaller system entrance pupil normally provided by the rear sight) would lead to an unusably-blurred image of the sight disk. In this case the point of perspective is at the center of the camera entrance pupil, and parallax shift comes from its movement. The diameter of the pupil does not affect the degree of parallax shift.

These lower images in these panels show the result. In each case, the image with the rear sight in place (as seen earlier) is shown above for ease of comparison. (Thus we can readily see the degree of parallax mitigation with the sight.) To further facilitate the comparison, we have artificially “vignetted” the “rear sight out” images to have the same overall field of view as the images with the rear sight in.

Rear sight in place
Ideal eye position

Rear sight in place
Eye shift left 0.25 mm

Rear sight in place
Eye shift left 0.75 mm

Rear sight out
Ideal eye position

Rear sight out
Eye shift left 0.25 mm

Rear sight out
Eye shift left 0.75 mm

Rear sight in place
Eye shift left 1.25 mm

Rear sight in place
Eye shift left 1.50 mm

Rear sight in place
Eye shift left 2.00 mm

Rear sight out
Eye shift left 1.25 mm

Rear sight out
Eye shift left 1.50 mm

Rear sight out
Eye shift left 2.00 mm

With the rear sight aperture plate gone, the entrance pupil of the camera (that is, of the “eye”) becomes the entrance pupil of the optical system. Since the center of perspective is now at the center of this entrance pupil, which in fact moves when the eye position moves, we expect to see the full “geometric” parallax. And indeed we do, as seen by these images.

The parallax seen with the rear sight out very closely agrees with that predicted by theory for the various dimensions involved.

Note that the target exhibits more blurring here than in the corresponding earlier images. This is because the entrance pupil of the optical system (now the entrance pupil of the camera) is still larger than that provided by the rear sight aperture. Thus out of focus blur performance (the dual of depth of field) is worse.

For the case of the very small 2.0 mm eye pupil (where the onset of parallax shift comes sooner, as we saw), this table shows the comparison of the parallax shift observed with the rear sight plate out and with the rear sight plate in. The shift is denominated in terms of millimeters at the scale of the rear sight post (such that, for example, a parallax shift of 0.5 mm corresponds, visually, to half the perceived width of the rear sight post (whose total width is 1.0 mm). Note that because of the substantial blurring of the image of the target disk (in both situations), measurements of the parallax shift have limited precision.

Eye shift (mm)	Parallax shift in mm with rear sight plate Out	In
0.25	0.2	0.0
0.50	0.4	0.15
0.75	0.6	0.2
1.00	0.8	0.3

Geometric considerations predict a parallax shift (with no suppression nor reduction in effect) very nearly 80% of the eye shift. This is in good agreement with our “rear sight out” results.

CONCLUSION

While there is no assurance that the model used in these tests exactly reflects the real-world workings of an aperture sight and the human eye, the results certainly seem to confirm the behavior reported in our earlier paper.

ACKNOWLEDGEMENTS

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