Affect of Eye Pupil on Binocular Aperture
by Ed Zarenski
August 2004

This information has been discussed before, elsewhere in other forums and also here in the CN binocular forum. However, the question keeps coming up and it is certainly worthwhile to document all of this in one complete discussion. In a telescope, you can vary the exit pupil by changing the eyepiece. In a fixed power binocular the exit pupil you purchase is the exit pupil you live with. **The question answered here is this: What happens when your eye pupil is smaller than the binocular exit pupil?** The implications are not at all intuitive, and certainly without explanation may not be clearly understood. There has been much prior debate over this issue, some of which I have participated in. Research, as always, provides some answers. Hopefully, this article will answer the question for you.

Clear skies, and if not, Cloudy Nights

Edz
Aug. 2004
The author practices astronomy from his home in Cumberland, R. I.

How big are your eye pupils?
An important aspect to consider when choosing any binocular is the maximum dilation of your own eye pupils. Your own eyes may have a significant impact on the effective performance of a binocular. Depending on your desired use, failing to take maximum dilated eye pupil into consideration before you make your purchase may lead to an inappropriate choice. Exit pupil larger than eye pupil results in not realizing the maximum potential of the binocular.

There are several simple methods to determine the size of you eye pupils. I had my optometrist measure mine. You can get a close approximation in a dark room by looking into a mirror and using a low level light and an easy to read scale or have someone do it for you. The easiest method I have found is this; make a photocopy of a star magnitude dot scale, as is found on every page of a star atlas. Cut right through the middle of the dots so you have a paper scale with a series of half dots. The copy from SkyAtlas 2000.0 gives a series of half dots that increase in size by about half mm. In a darkened room, stand in front of a mirror with the paper scale held up to your eye. Covering the bottom half of your pupil with the paper scale, slide it back and forth until you find the half dot that matches you pupil. Make note of the dot that matches and then you can use a scale to measure it.

The average adult has eye pupils that can dilate to about 5mm, although this figure can vary widely from one individual to another. Maximum eye pupil dilation usually diminishes with age. It is usually stated that youth have the capability to reach a maximum dilation of about 7mm. The need to measure your own eye pupil dilation will soon become apparent. Personally, at the time of this writing I am 51 years old and my pupils reach a maximum dark-adapted dilation of 6.5mm. I know another avid binocular astronomer at the age of 49 has a maximum dilation of only 4mm.

What is the exit pupil?
In general most binoculars have large exit pupils. Exit pupil, the beam of light that exits the eyepiece, is determined by dividing the diameter of the objective lens (the entrance pupil) by magnification. For example, a 10x50 binocular has a 50/10 = 5mm exit pupil and a 7x50 binocular has a 50/7 = 7.14mm exit

pupil.

Generally, it is stated that a larger exit pupil provides more light, or a brighter image, to the eye. Those who desire the brightest low light image will opt to purchase a binocular with the largest possible exit pupil. However, if the exit pupil of the binocular is larger then the maximum dilated pupil of your eye, all the light in the exit pupil beam will not enter your eye and the effective performance of the binocular will be reduced. To avoid this you simply need to more carefully match the binocular exit pupil to your eye pupil.

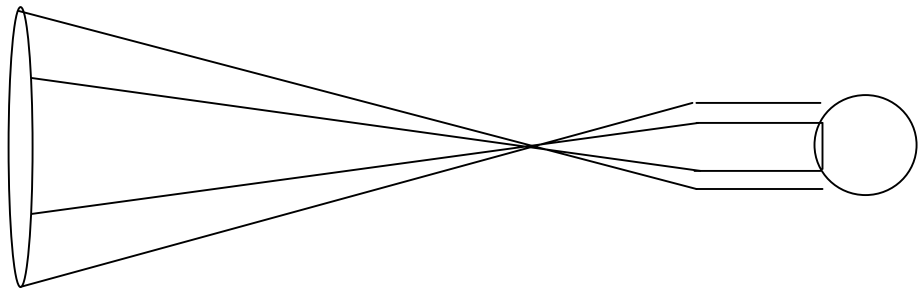
NOTE: Brightness as discussed here is that which is provided to the eye by the exit pupil. Leave no doubt in your mind that a higher quality optic of the same size (and sometimes of even a smaller size) may appear brighter than a lesser quality optic. Given all other measurements being equal, optical glass, coatings and baffles within a higher quality instrument will provide a brighter image to the eye. Now back to exit pupil.

What are the affects on image brightness and resolution when eye pupil is smaller than exit pupil?
At this point, I will tell you I have researched about two dozen various textbooks for a discussion of this affect. There is a general lack of discussion in the texts I have referred too as relates to the application of optical theory to the question raised above. The usual text discussion states objective diameter is the determinant of maximum resolution and maximum light gathering and that exit pupil is the determinant for brightness of the image delivered to the eye.

Many texts discuss diffraction and resolution. While some leave the reader groping for complete explanation on which to base conclusions, a few others give a clear explanation. When it comes to resolution, they all have one thing in common. They all say resolution is dependent only on aperture. And as relates to brightness, all state that a larger exit pupil delivers a brighter image. Few if any texts discuss the affects on resolution and brightness of image when eye pupil is smaller than exit pupil. It is up to the reader to develop a clear understanding of these concepts and apply the information correctly to arrive at accurate conclusions. What nearly all of these texts fail to mention is this; in order that the full performance of the objective lens be delivered to the eye, the entire exit pupil light beam must pass through the eye pupil. I have provided reference to three excellent texts that provide sufficient information to understand this concept.

Low power telescopes can be similar to binoculars.
Although this discussion has far greater implications for the astronomer choosing a binocular, it has relevance to the telescope user as well. It was shown above that exit pupil varies inversely as magnification varies. Low magnifications provide large exit pupils and higher magnifications result in smaller exit pupils. Telescope users know very well that a brighter image can be achieved by using a lower powered eyepiece. Optimum resolution is achieved at relatively high magnifications where exit pupil is very small, much smaller than dark-adapted eye pupil. At usual telescope magnifications for optimum resolution, there is little need to discuss exit pupil being larger than eye pupil. The situation where telescope users need to be concerned about exit pupil larger than eye pupil is when using very low magnifications for wide-field viewing or maximum low light observing of extended objects.

For example, using a 100mm scope at 20 power would result in a 5mm exit pupil. Using an 8” scope (203mm) at about 50 power would result in a 4mm exit pupil. When I use my 6” (150mm) refractor (focal length 1200mm = f8) with a 40mm eyepiece, I can get 30 power with an exit pupil of 6mm and about a 1.6° field of view. I also own a 6” reflector (focal length 750mm =f5). The lowest powered eyepiece I use with



Effective Aperture is Smaller - Equivalent to Aperture that would Create Smaller Exit Pupil my f5 scope is a 30mm. That gives a magnification of 25x with an exit pupil of 6mm and a 2° field of view.

Delivering maximum light to the eye.
If I were to put my 40mm eyepiece in my f5 6” reflector in an attempt to get a brighter image, I would get an 18.75x view with a 2.6° fov, but exit pupil would be 8mm. Two things would happen. The shadow of my secondary mirror may show up in the image and (more important to this discussion) my maximum dilated eye pupil of 6.5mm would cut off the outer edges of the exit pupil. In effect, my eye would reduce my telescope to an effective aperture of 6.5 x 18.75 = 122mm. Certainly acceptable if my goal is to get maximum field of view, but if it is maximum light I desire, I should have paid attention to my own eye pupils and used an eyepiece that produces a maximum 6.5mm exit pupil.

Eye pupil is an extension of exit pupil.
If eye pupil remains larger than the exit pupil in use, then the entire exit pupil beam enters the eye and exit pupil controls the amount of light delivered to the eye. The condition will sometimes occur where eye pupil is smaller than exit pupil and it helps to have an understanding of the implications.

What you will find in the references provided is all say eye pupil is an extension of exit pupil. If at any point along the light path a portion of the light beam is clipped, the effect in the exit pupil, or in this case the eye pupil, has a like affect on the entrance pupil. Ray trace diagrams may help to visualize the effect. It is the cumulative affect of all rays from every point on the objective that give the result in the image. If any of those rays are clipped and do not make it through the entire system, which in this case includes the eye, then the net result is a reduced effective aperture. While a reduced effective aperture will have no affect on your field of view, it will result in lower resolution and a less bright image.

When using a binocular, if eye pupil is smaller than exit pupil while the fixed binocular magnification does not change, does resolution still remain constant? Does image brightness remain constant? What else, if anything, in the optical system might change?

The key concept here is aperture, magnification and exit pupil are inextricably bound together. If exit pupil varies and magnification doesn’t change, something else must change.

What is constant, what can change?
In the binocular, (with the exception of those with interchangeable eyepieces) magnification is constant. There is no disputing the fact that the resolution and light gathering is delivered to the focal plane by the full aperture. But next, the eyepiece selected by the manufacturer must deliver the image to the eye. The eyepiece determines the magnification and the size of the exit pupil. The aperture and the size of the exit pupil determine the image brightness.

What happens to resolution and image brightness when it is delivered to an eye pupil smaller than the exit pupil?

As I vary the eyepieces and magnification in my telescopes, the aperture remains constant, so exit pupil changes as magnification changes and resolution remains constant. The ability to see that resolution increases as we approach optimum magnification. Image brightness varies with the size of the exit pupil.

That’s not what happens in binoculars and in some cases telescopes at very low powers. In binoculars, many times, entrance pupil can be made smaller by the eye but magnification cannot be changed in a fixed power binocular. Because of this and the laws of optics, something else is forced to change and that is referred to as “effective aperture.”

If eye pupil is smaller than exit pupil in binoculars, or any optics, given all other parameters in the system remain constant, one parameter has to vary for the laws of optics to still hold true. We could force aperture to remain constant, but then the only way you could get a smaller exit pupil with a fixed set of eyepieces (therefore a constant magnification) is for focal length to change. However, focal length is not changing. With magnification still constant, something else is changing. Magnification and focal length in a binocular are fixed, so the only other parameter left to change is the “effective aperture.”

A proper application of the laws of optics can give only one result. **If eye pupil is smaller than exit pupil while magnification remains constant, only one other parameter of the system can change and that is referred to as “effective aperture.”** The net affect this reduced “effective aperture” has on resolution and brightness can then be explained by the laws of optics. Effective aperture is considered that which would provide the equivalent exit pupil that matches the smaller eye pupil. Resolution and brightness would be based on that effective aperture.

These changes in "effective aperture" result in an effective f ratio. As effective aperture is forced to decrease, effective focal ratio increases. Focal ratio, or f#, while it is a number which gives us a quick indication of the performance of a system, is a resultant quotient, not an affect, therefore it is of much greater relevance to discuss the changes in aperture than to direct this discussion towards f ratio.

If resolution does change, why is it we may not be able to see this?
The magnifications used in binoculars are so far below the optimum magnification needed to see full resolution provided by the objective lens, you will not see maximum potential resolution of the objective in a binocular. Binoculars are designed for maximum brightness of image, not maximum resolution of detail. While a 70mm lens has the potential to provide a maximum resolution about 2 arcseconds, a premium 16x70 binocular is capable of resolving at best only 8” to 10” arc, depending on the acuity of the observer. Why? Magnification is too low to realize the full potential resolution. The 70mm objective would need a magnification about 87x to see maximum resolution.

Why is it we may not be able to see the difference in brightness?
Consider this. If you have been using binoculars with an exit pupil larger than your eye pupil, all along, your eye pupil has been creating an effective aperture. You cannot get a greater amount of light (a wider beam of light) into your eye than can be allowed thru your pupils. If you’ve been using a 10x70 binocular with a 7mm exit pupil and your eyes dilate to only 5mm, you have never received a larger beam than 5mm into your eyes. Therefore, all along, the binocular has been performing as if it were a 10x50.

So you might ask then, in bright daylight viewing, if eye pupils dilate to only about 2.5mm, would it not be the same to use a 10x25 as opposed to a 10x50?

What differences can be seen in terrestrial viewing?
Let's assume a terrestrial viewer is using a 50mm binocular with a 5mm exit pupil (10x50). Now assume the observer’s eyes in daylight can dilate to only a maximum of 2.5mm. The difference between the full aperture exit pupil of 5mm and the effective aperture exit pupil as a result of the 2.5mm eye pupil, for a 50mm binocular, observing an object at a distance of 100 feet is 5.5 arcseconds of angular resolution, a linear dimension on the object of interest of only 0.03 inches, approximately the width of a thin vein on a

leaf. While this is a very real number, it is not likely something most people are able to notice.

What happens in low light terrestrial viewing where many seem to prefer a larger exit pupil because it seems brighter?

Now we need to go back to the cardinal rule that states exit pupil controls effective aperture. There would be no more light delivered by either binocular if eye pupil is 2.5mm, BUT, as seen through a 2.5mm eye pupil, there may seem to be a difference in the two binoculars, and you might be able to see this difference. The 10x25 binocular is using the entire objective lens diameter and we have seen from vignette studies, many (if not all) binocular systems block (vignette) portions of the light from the periphery of the objective lens. The 10x25 is using the entire diameter of the lens to light the exit pupil and the light from the outer portions of the objective is reduced in the exit pupil due to vignette. Not all of the light gathered by the 10x25 reaches the eye.

Most vignette studies show that approximately the central 50% of an objective lens provides 100% illumination of the exit pupil. The light delivered from the area outside the central 50% of the objective does not all reach the exit pupil. In the 10x50 binocular, stopped down by the daylight contracted eye pupil to 10x25, only the central 50% of the objective diameter is putting light into the eye pupil. The key is this 2.5mm exit pupil is 100% illuminated from the central portion of a stopped down 50mm lens. A stopped down 10x50 is providing a lot more illumination to the same size 2.5mm exit pupil than a full aperture 10x25. That would account for a significant difference in apparent brightness between the two, even though both situations have a 2.5mm exit pupil. As a bonus, that same 10x50 binocular will serve the user better under lower light conditions when eye pupil is enlarged to possible 3mm or 4mm.

What implications does your choice have?
What are the implications of choosing a binocular with too large an exit pupil vs. one with the same aperture and a higher magnification that would result in a smaller exit pupil, one my eyes can take it all in?

Assume for example the user has a maximum dilated 5mm eye pupil. His choice in binocular is narrowed down to a 10x70, a 7x50 or a 10x50. For this observer with 5mm eye pupils, the 7x50 will be performing like a 7x35. The 10x70 will be performing like a 10x50. And finally the 10x50 will perform as designed, like a 10x50. It will see a lot more than the 7x50 and it will likely weigh (and cost) a lot less than the 10x70.

What consideration should be given to exit pupil for use in brightly lit light polluted skies?
In this case you might consider even smaller exit pupil than your maximum dilated eye pupil. You can vary the values in the relationship of aperture/magnification (which gives exit pupil) by either decreasing aperture or increasing magnification. Either choice will decrease exit pupil and therefore increase the apparent contrast in the image by decreasing the brightness of the background sky. This should help bring out the images of target objects.

Are there any other reasons for considering a smaller exit pupil?
For some users, another good reason to keep binocular exit pupil slightly smaller than eye pupil would be to mask deficiencies in the eyes. Among other deficiencies in the outer edges of the eye pupil, it is a well-known fact that the affects of astigmatism (in the eye, not in the instrument) become less obvious in the image as the exit pupil in the optical system is reduced. Personally, I can still see the astigmatism inherent in my less than perfect eyes when viewing thru exit pupils of 2mm or larger. So I keep my glasses on for all binocular viewing and allow myself the luxury of utilizing much larger binocular exit pupils.

So what's the right choice for the brightest astro images?

If you are looking for the brightest image, consider the maximum size of your own dilated eye pupils before you determine the size exit pupil you want in a binocular. It might be OK to go slightly larger with the exit pupil, assuming you would have ample opportunity to get out under the darkest of skies and use it to it's real performance potential. Keep in mind the sweet spot affect outlined in terrestrial use above. There is some advantage to not using the entire objective lens, but potentially at a significant price/gain ratio.

Consider the intended use of your binocular. If they will be used exclusively for hunting down faint diffuse objects, then you must consider the largest aperture that you can handle. Taking into consideration your maximum eye pupil, buy a magnification that suites your needs. However if binoculars will be used to observe all kinds of objects, not strictly faint diffuse objects, the light gathering difference of apertures may cause overall performance to vary so little, aperture might be the single aspect you should allow to vary the most. Don't buy a 7mm exit pupil because that classy 10x70 or 7x50 binocular is so hyped up by everyone. If your pupils dilate to only 5mm, a 10x70 binocular may not the right choice for you. You might be better of to stick with a 5mm exit pupil and vary magnification and aperture to suit your needs.

Then, whatever choice you make, get out there and use them as much as you can!

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