The Bellows Extension Exposure Factor: Including Useful Reference Plots for use in the Field

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Abstract: *The need for a bellows correction factor to ensure proper exposure for field and view cameras is discussed. Included in the presentation are convenient plots that can be used in the field to determine proper exposure corrections when using bellows extension to focus on relatively close objects.*

Introduction

We all use light meters to determine proper exposures for photography. Some of us use meters that are built into the camera, meters that measure from some of the same light that the film will see. But for those of us who use field cameras or view cameras, or any camera with a meter that is separate from the camera itself, the exposure indicated by the light meter is valid and will give a "proper" exposure only when the camera is focused on infinity. If the focus is considerably closer to the camera than infinity, an exposure correction is necessary, and this is particularly significant for large format cameras. This article provides a convenient and reliable method to quickly determine the appropriate exposure correction, a method that can be readily used in the field.

At the infinity focus position, the film in a camera is located at a distance from the lens equal to the focal length of the lens. At that position, for the appropriate shutter speed and f-stop setting for the available light in the scene and film chosen that is indicated on a light meter, the film receives the appropriate amount of light for each square inch of the film to properly expose it. But, if we increase the separation between the lens and the film (as we do when we focus on something that is closer than infinity), and we don't change the shutter speed or the f-stop setting, the film will receive less than the appropriate amount of light per square inch of film and will be underexposed. We must adjust the exposure for this new lens-film separation distance and we can readily do that by adjusting the shutter speed or the f-stop, but this is not a random act. We need a bit of guidance to do it properly. For a very experienced photographer, the required corrections become so automatic that little thought is required. For photographers with less experience, a numerical computation can be done in the field and the result can be applied. A more convenient approach for such a photographer is to do all the possibly relevant calculations in advance and put them in an easily accessible form, a form that removes guess-work and results in a proper exposure every time, without any calculation in the field. We will take this third approach here and create a simple and convenient plot that can be used in the field.

The Need for Exposure Adjustment

First, we remind ourselves in more detail why we need to make this correction. Figure 1, presents a side-view sketch of the position of the film plane in the back of a camera for a situation where, for example, the camera has been focused at infinity. The scene is to the left and the film to the right. The straight line paths of the light that reach the extremities of the film (the top and bottom of the sheet of film that is viewed edgewise) are shown as two solid lines. Where the solid lines cross at a point represents the position of the lens at the front of the camera. All the light between the two solid lines strikes the film. We have shown the path that the light would take beyond the film (if the film and back of the camera were not present) as dashed lines and have shown the light ray that passes through the center of the lens and hits the center of the film as a horizontal dashed line. For convenience and simplicity of discussion, we imagine here that light from the entire field of view of the lens covers the film plane.

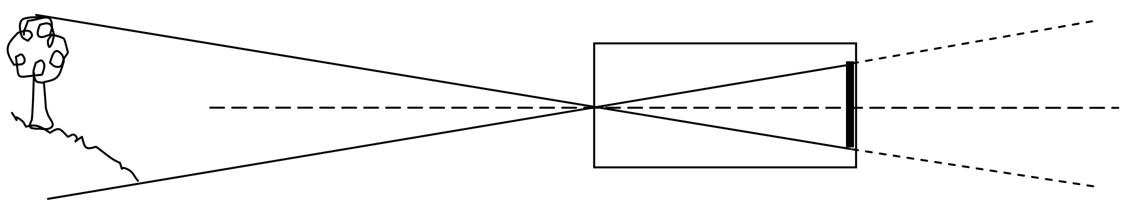


Figure 1: *Illustration of a field camera focused on a scene at infinity (with the scene shown closer to the lens than infinity for practical purposes). For this case the distance between the lens and the film is equal to the focal length of the lens and the image is in focus on the film. And, for convenience we have imagined that the entire field of view of the lens just fits on the film.*

Now, using the same lens with the same field of view, if we focus on something at a distance closer than infinity, we have to increase the separation between the film and the lens. This is because when the object of our interest is closer to the lens, the in-focus image of that object is located further from the lens than it was previously. Thus, some of the light from the field of view of the lens that previously hit the film and helped to expose it will miss the film. It will now be underexposed because it will not get enough light. This situation is shown in Figure 2.

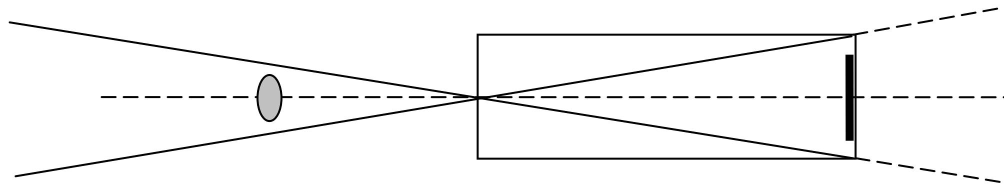
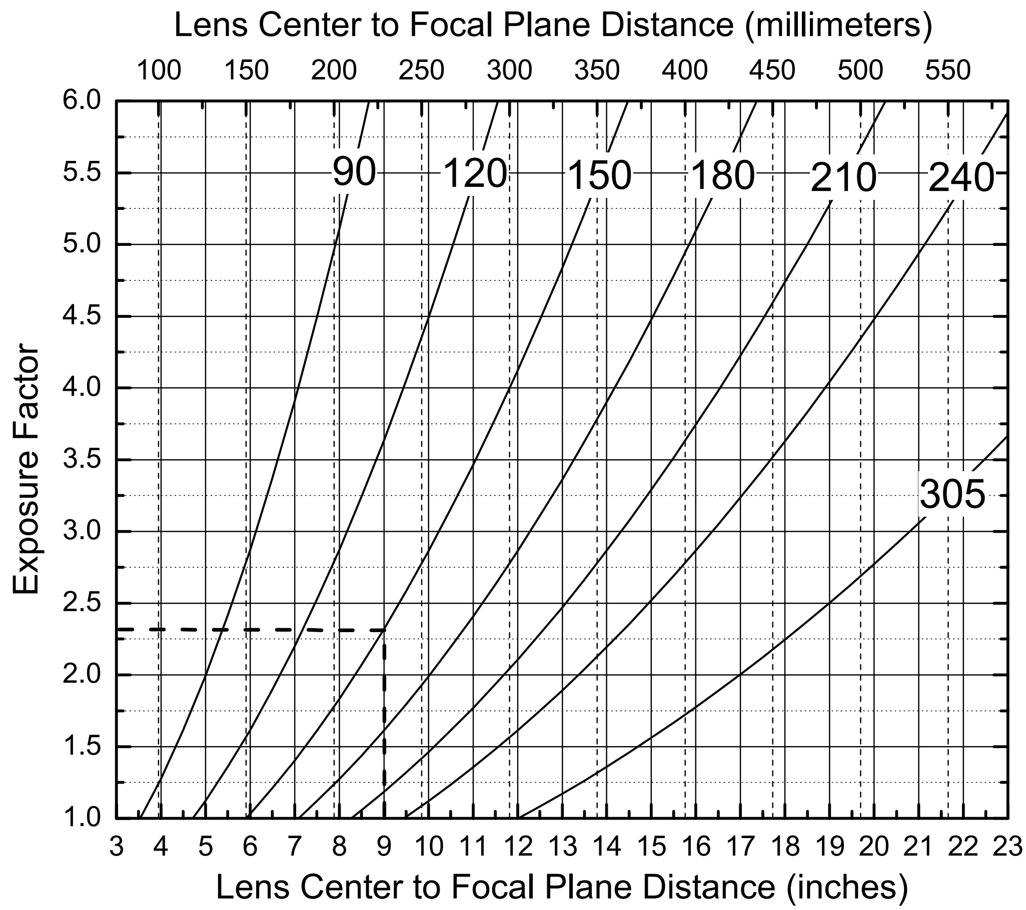


Figure 2: *Illustration of a field camera focused on an object closer than infinity, to illustrate the greater lens to film plane distance in this case compared with the case in Figure 1. Again, we have show the light that comes from the entire field of view of the lens. In this case, some of that light misses the film. Unless we make a correction, the film will now be underexposed.*

The exposure time and/or the diameter of the lens opening must be increased to compensate. The required exposure correction depends in a straightforward way on the new distance between the film plane and the lens compared with the old distance between the film plane and the lens when the focus was at infinity. This correction factor is traditionally termed the bellows correction factor, or the bellows extension factor, the bellows factor, or simply the *exposure factor*. Although we will not dwell on the mathematics, the relationship is that the exposure factor is given by the ratio of the square of the new lens-to-film-plane distance to the square of the old (infinity-focus) lens-to-film-plane distance. This can be readily computed in the field, but doing this in advance and keeping a plot of the results handy makes things more convenient. The proper exposure factors for several lenses with focal lengths from 90 mm to 305 mm are shown in Figure 3 as a function of the distance between the center of the lens and the position of the film plane (ground glass).



<u>Figure 3</u>: *Exposure factors as a function of the lens center to film plane distance for a range of lenses of focal length from 90 mm to 305 mm, as might be commonly used for photography with a 4 x 5 camera. As an example, (discussed more fully in the text), we consider the case of a 150 mm lens. If the focus was at infinity, the lens to film plane distance would be 150 mm, i.e. 5.91 inches, the exposure factor would be 1.0 and no correction would be needed. If, however, the lens were to be focused on something closer that resulted in, for example, a lens to film plane separation of 9.0 inches, an exposure factor of about 2.3 would be required. A millimeter scale is provided at the top of the plot for those who prefer to measure distances in millimeters rather than inches. (1 inch = 25.4 mm)*

To use the figure with a field or view camera, one measures the distance from the ground glass to the center of the lens, keeps in mind the focal length of the lens, and reads the correction factor from the plot. (Since the lens is thick, how do you know where the center of the "lens" is? Set the focus on infinity and measure the distance from the film plane to a position on the lens equal to the focal length of the lens. This location on the lens, which can be marked on the body of the lens or simply remembered, is the effective center of the lens for all measurements.) All that is required in the field is a ruler and a copy of the plot. A very convenient and portable ruler is a flexible cloth tape ruler of the type that is available in most sewing or fabric stores.

As an example, suppose we are using a lens with a focal length of 150 mm. For such a lens, the infinity focus has the film plane at a distance that is 150 mm (i.e. 5.91 inches) from the center of the lens. For this situation the curved line on the plot associated with the 150 mm lens meets the lens to film plane distance axis at 5.91 inches and the exposure factor is 1.0 since no correction is needed. If we focus on an object in a scene that is closer to the camera, there will be a new, larger, distance between the film plane and the center of the lens. For example, suppose the new position of the film plane is 9 inches from the center of the 150 mm lens. In this case, making reference to Figure 3, we read the correction factor by moving along the curved line labeled by 150 mm until we reach a point directly above the distance of 9 inches. We then read from that point (on the 150 mm line) horizontally back to the left and find the exposure factor to be about 2.3. The dashed line on Figure 3 illustrates this case. This means that we must admit 2.3 times the amount of light that is indicated by the light meter to get a proper exposure. So, if the original shutter speed was 1/30 sec at, say, f/16, we need to make the exposure a bit more than double what the meter reading indicated. Since shutter speeds are discrete, we may not be able to correct this perfectly by shutter speed alone, and that is the case in this example. So, in this case, with a factor of 2.3 we shift the shutter speed by a factor of two to 1/15 sec and we shift the aperture a bit more open, say from f/16 to almost half-way between f/16 and f/11. This gets us close to the required correction of 2.3, close enough for a good exposure. If we were to make no correction, the film would be underexposed by more than one stop. (An exposure factor of 2 represents a factor of two in the amount of light, i.e. one stop.)

As an illustration of the need for this sort of adjustment, consider figure 4, which is a photograph of peeling paint found on the side of an old trailer. The illumination was bright overcast. To focus on the curled paint required a substantial bellows extension, one close to the illustration presented in the discussion in the paragraph immediately above. An average of direct meter readings of the reflected light intensity from various regions of the paint indicated an exposure of ¼ second at f/32 and this had to be corrected by a shift in the time of exposure and a small shift in the aperture. The resulting negative was properly exposed as seen in the resulting print shown in figure 4.

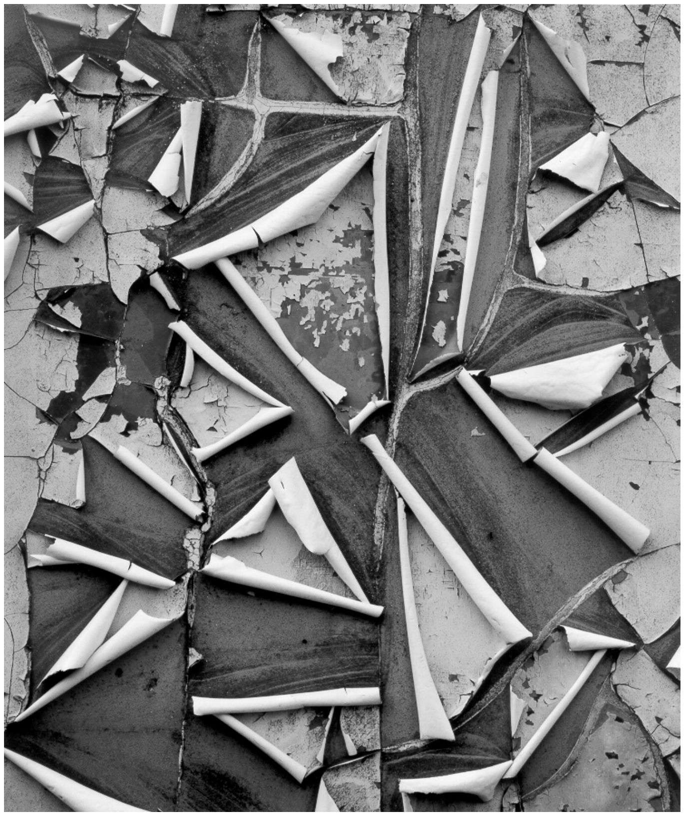


Figure 4. *Photograph of peeling paint on the side of an old trailer under conditions of bright overcast light. Here the proximity of the lens to the side of the trailer required a considerable bellows extension to bring the image into proper focus. A bellows factor of about 2.3 was necessary to achieve proper exposure.*

Figure 5 is a different version of Figure 3, useful for lenses of shorter focal length. Figure 6 is yet another version, useful for longer focal length lenses such as might be used with 8 x 10 and other large format cameras.

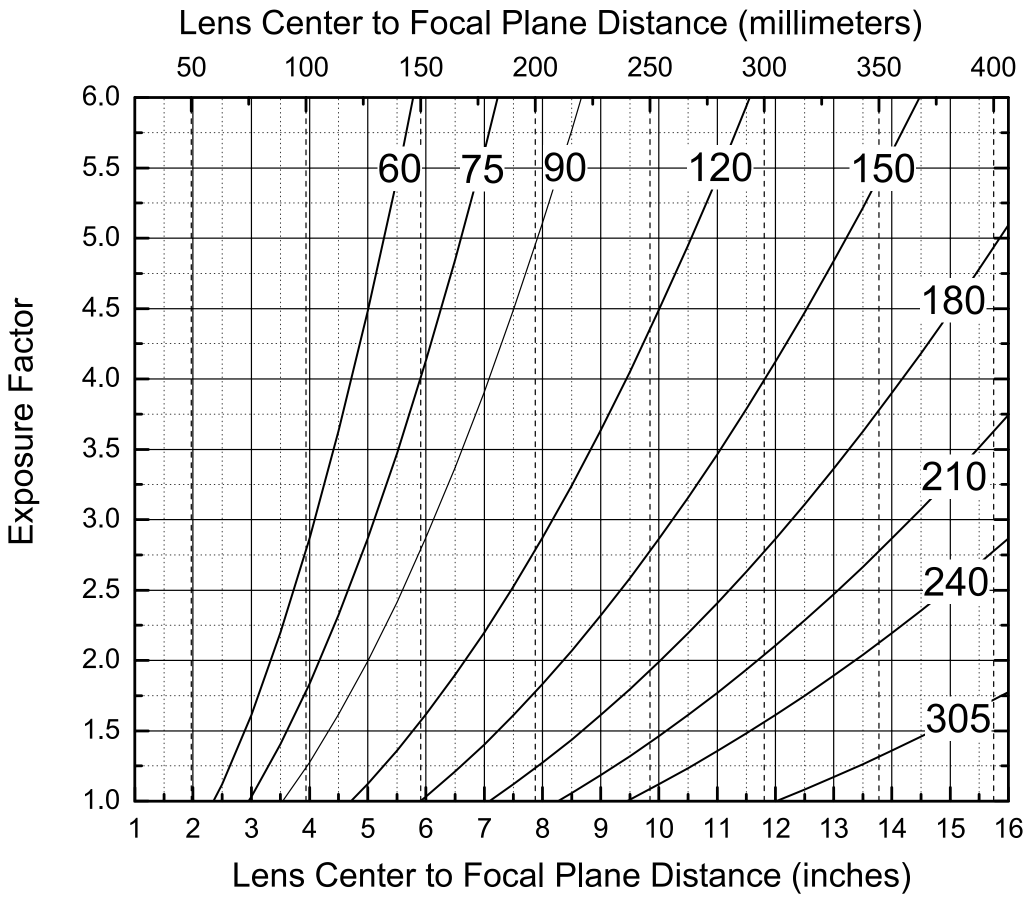


Figure 5. *Similar to Figure 3, but for use with shorter focal length lenses.*

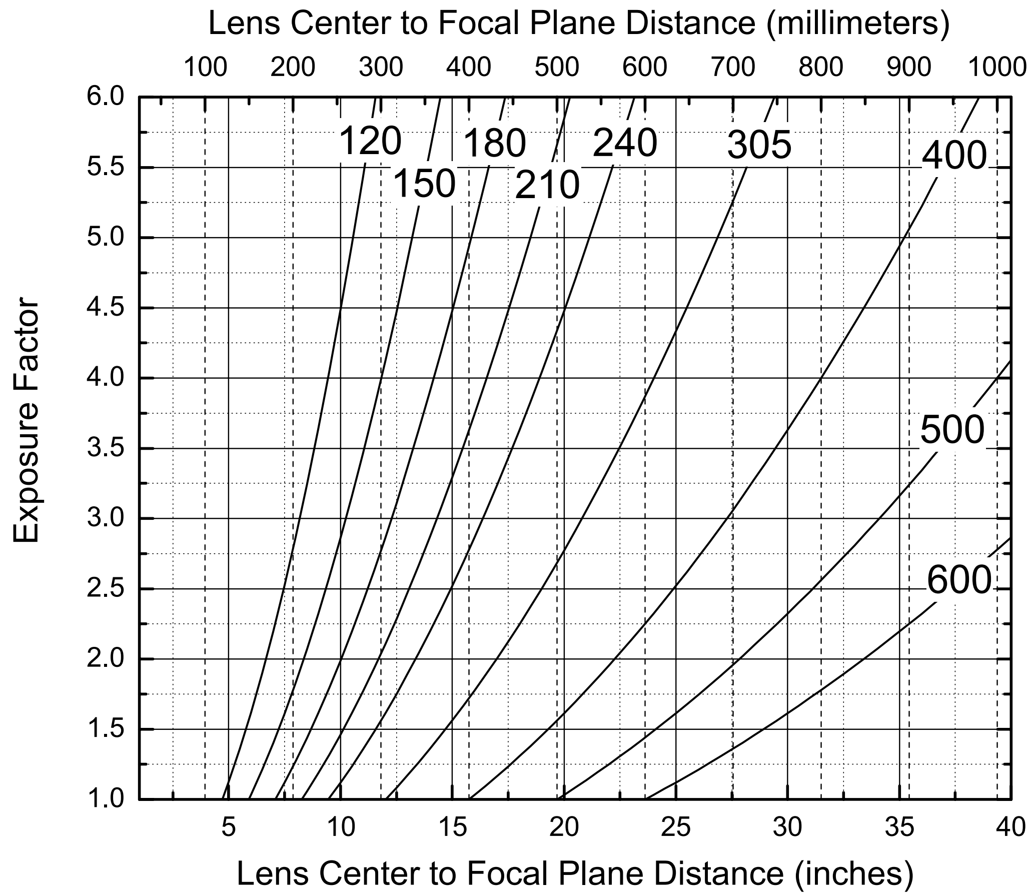


Figure 6. *Similar to Figure 3, but for use with longer focal length lenses as might be appropriate for 8 x 10 cameras.*

Summary

As noted at the beginning, many cameras have built-in exposure meters that automatically account for this correction. And, it is the case that for small format cameras the changes in distance between the lens and the film plane that take place without the use of extension tubes or bellows are often rather small. But, for those who use field or view cameras, the use of a plot such as presented here is a very convenient way to avoid exposure errors in the field when focusing on objects that are relatively close to the camera.

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Robert Hallock is Distinguished Professor in the Department of Physics at the University of Massachusetts, Amherst, where he has taught and done research for more than thirty years. He has been involved with photography for even longer, and for the past ten years has emphasized black and white photography with traditional archival darkroom techniques with image capture in 4 x 5 and 6 x 7 formats. He currently teaches a course on the physics of light, applications and perception, "*Seeing the Light*", with an emphasis on topics of relevance to students interested in Art and Photography.

E-mail Contact: hallock@physics.umass.edu. Some examples of the author's photography can be found at http://www-unix.oit.umass.edu/~rbhome/draftmaster.htm