ADDENDUM to

FOCUSING the VIEW CAMERA

by Harold M. Merklinger

World Wide Web Edition

Notes About This Booklet

What follows began life as the 24-page ADDENDUM to the book *FOCUSING the VIEW CAMERA.*

That book describes a scientific method for focusing a view camera and for determining depth of field with tilted lenses. The Addendum provides more material, including a simplified explanation of the method as well as some refinements. The Addendum explains, for example, how depth of field with for tilted lens is related to depth of field for an un-tilted lens. This World Wide Web edition of the Addendum has been edited to eliminate the few references to the original book that existed in the original Addendum.

Because this is an addendum, the figures start at Fig 38, and the pages at 104. This Addendum is, however, intended to stand on its own. It is not necessary to have a copy of *FOCUSING the VIEW CAMERA.* in order to understand the contents.

All figures are black and white line drawings; colour has been avoided in order to minimize file size.

ADDENDUM

Introduction

Since *FOCUSING the VIEW CAMERA* was sent to the printer, I've learned a lot. Thanks to people like Phil Davis, John Ward and Craig Bailey who contacted me with questions or seeking clarification, a few new ways to look at the view camera problem have emerged. I'm also quite aware that *FOCUSING the VIEW CAMERA* is not an easy read. The purpose of preparing this addendum is two-fold: to try to make it easier for photographers to grasp the basics of this way to control the view camera, and to describe a few refinements to earlier ideas.

I'll attempt to offer a "Getting Started" section, something like computer software manuals use to introduce new users of the software to its basic features. A tutorial item will examine how depth of field for view cameras is related to placement of the plane of sharp focus, and how depth of field for view cameras is related to that for normal cameras. Then I'm going to reflect on what I wrote earlier, commenting on some of the factors I missed the first time around. You'll learn, for example, how the depth of field method I described as approximate can be corrected so that it is even more accurate and convenient to use than the depth of field tables.

The sections in this addendum are as follows:

1. Getting Started

In what follows it will be assumed that the reader possesses some basic familiarity with the view camera. You know what is meant by tilting and swinging the camera back and the lens. You know that tilting the lens relative to the back—or the back relative to the lens—causes the plane of sharp focus, that surface on which the camera is accurately focused, to move out of parallel with the film plane. You may be aware that the Scheimpflug rule states that the film plane, the lens plane and the plane of sharp focus intersect along a common line. If you don't know this rule, that's OK. It's not absolutely necessary to understand it, anyway.

Figure 38 shows a schematic (symbolic) diagram of a normal camera: one with the lens attached in such a way that the lens axis must stay perpendicular to the film. Figure 39 serves to indicate what happens when the lens axis (or the lens plane which is a surface perpendicular to the lens axis) is tilted. The film plane, the lens plane and the plane of sharp focus obey the Scheimpflug rule. You need not worry about it; the laws of physics will make sure that it is obeyed. The general principle is simple: if we tilt one of the three planes relative to any one of the others, the third plane will get tilted too.

In a normal camera, the camera is always focused on a plane that is parallel to the film. The view camera allows the photographer to focus on objects arranged on a plane that is not

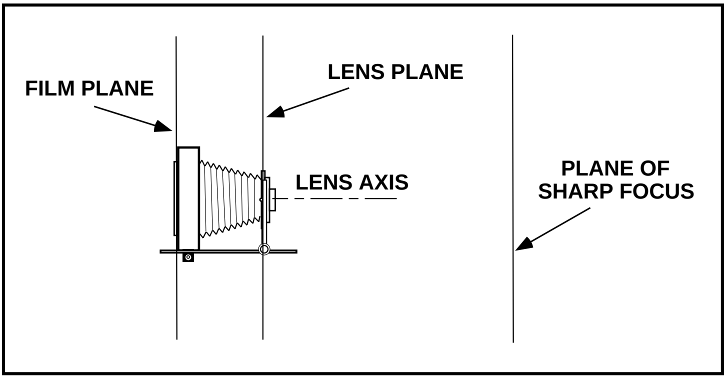

FIGURE 38: *For a 'normal' camera, the film plane, lens plane and plane of sharp focus are parallel to one another.*

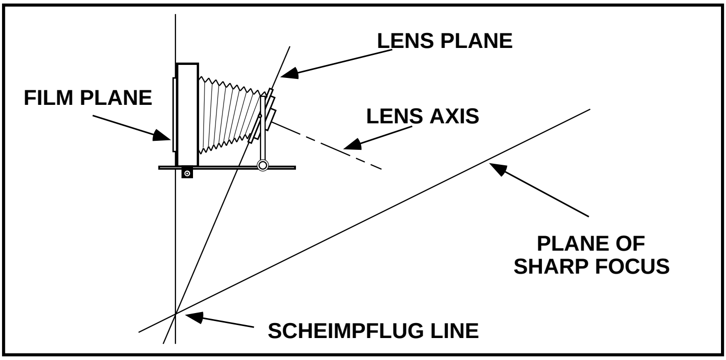

FIGURE 39: *For a view camera, tilting the lens causes the plane of sharp focus to tilt also. The Scheimpflug rule requires that the three planes intersect along one line*

parallel to the film. This condition is achieved by tilting either the lens or the film relative to the other. That is, we can leave the lens where it is and tilt the back, or we can leave the back where it is and tilt the lens. Or, indeed, we can do a bit of both: tilt both the back and the lens, but not by the same amount in the same direction.

The trouble comes in trying to figure out what to tilt and by how much in order to achieve the intended position for the plane of sharp focus. A further challenge arises when we want to focus on the intended plane of sharp focus and maintain correct perspective in the image.

Maintaining correct perspective is perhaps the easier task. Standard perspective usually requires that the film plane remain vertical and more-or-less square to the line of sight of the camera. Sometimes we actually want false perspective in order to make the photograph appear as though it was taken from a place other than the camera's true location. A classic example is taking a picture of a glass-covered water colour painting. If we place the camera squarely in front of the painting, we risk seeing the camera in the final image due to its reflection in the glass. The solution is to move the camera to one side and so view the painting at an angle. This eliminates the reflection. But we also want to make the image look as though the camera had been facing the painting squarely. We accomplish the desired perspective by having the film face the painting squarely—that is, keep the film and the painting parallel to one another—and let the

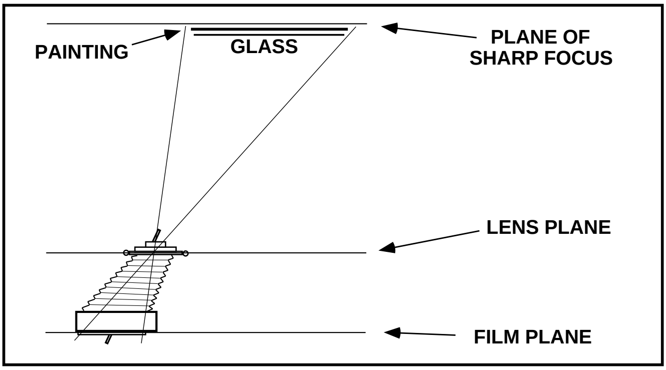

FIGURE 40: *The view camera can 'squint' sideways, maintaining the proportions of the painting. The final image will look as though it had been taken straight on. Taking the picture as illustrated here avoids seeing a reflection of the camera in the glass.*

arrangement of the back and lens effectively squint sideways at the painting. Figure 40 illustrates the resulting arrangement.

If achieving the desired perspective were the only problem, we could get by with lens and back shifts (plus rise and fall) only.

Let's look now at a somewhat more complex situation. We are photographing a painting, but we want to include in the image, not only the painting, but some of the room it is in. Specifically, the large painting is hanging in a church on a wall some 30 feet from the camera. We also want to include a plaque on the church floor indicating where the artist is buried. We want a sharp image of the painting, but also a sharp image of the plate on the floor some 10 feet from the camera. To ensure both are sharp, we wish the plane of sharp focus to pass through the centers of both the painting and the plaque. Figure 41 illustrates a side view of the problem. To keep the painting rectangular, and the other features of the building in correct perspective, the camera back must remain vertical and parallel to the painting. And we employ the necessary rise and/or fall to achieve the desired composition. How do we arrange for the plane of sharp focus to fall precisely where we want it to be?

There's another rule that arises from the laws of optics. I call it the hinge rule. The hinge rule will tell us the precise amount of lens tilt needed. The hinge rule is another rule very much like the Scheimpflug principle, but let's skip the details for

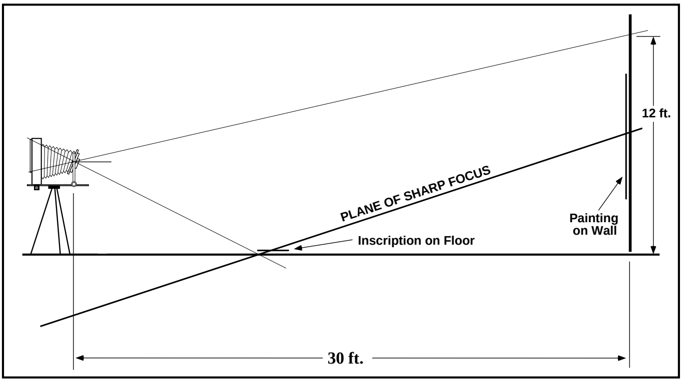

FIGURE 41: *Here the task is to adjust the plane of sharp focus so that it passes roughly through the centers of the painting and the inscription. What amount of lens tilt will accomplish this?*

now. The hinge rule states that the required amount of lens tilt is related to only two things: the focal length of the lens, and the distance the lens is from the plane of sharp focus measured in a very special way. We must measure how far the lens is from the plane of sharp focus along a plane through the lens but parallel to the film. In the example at hand, the concept is quite simple. The camera back is vertical. Therefore we measure this special distance in a vertical direction. The special distance is quite simply the height of the lens above the plane of sharp focus, as illustrated in Figure 42. I use the symbol **J** to denote this

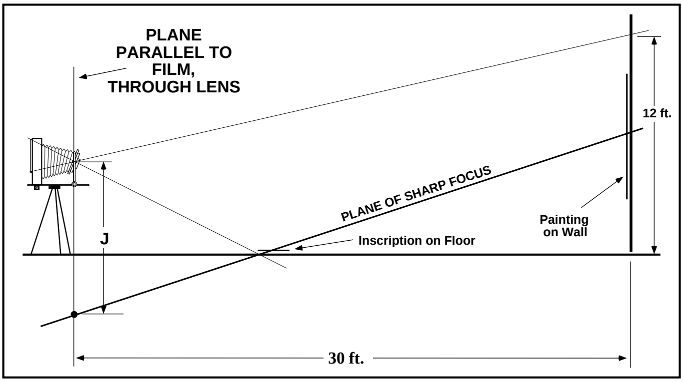

FIGURE 42: *The amount of lens tilt required is set by the special distance* **J** *and the focal length of the lens.* **J** *in this case is the height of the lens above the plane of sharp focus.*

distance, and the symbol α to denote the amount of lens tilt needed, measured in degrees.

The required amount of lens tilt is given mathematically by this expression:

$$\alpha = \arcsin(\mathbf{f}/\mathbf{J}).$$

The symbol, **f**, is of course the focal length. Don't be scared off by the math; it's really quite tame. The arcsine function can be found on many $15 'scientific' calculators, but we can do better. One could, for example, use the calculator to create a table. The table might have columns for lenses of various standard focal lengths. A column at the left of the table would show a number of distances. The other columns would show the tilt angles required for the various focal lengths. In our example, **J** is equal to 8.5 ft. and the lens in use has a 75mm focal length. The pre-calculated table would show a required tilt angle of about 1.75°.

Better yet, for small tilt angles we can even dispense with the table. For lens tilts less than 15°, we can get an approximate value of the lens tilt from either of the following:

if we measure **f** in inches and **J** in feet:

$$\alpha = 5\mathbf{f}/\mathbf{J}.$$

If we measure **f** in millimeters and **J** in feet:

$$\alpha = \mathbf{f}/5\mathbf{J}.$$

It's still math, but its pretty simple math.

So we set the lens tilt to 1.75° towards the intended plane of sharp focus. Not all view cameras have tilt scales. My own does not. I use a high school geometry protractor to set the tilt. I can't set it to better than about half a degree, and that's usually good enough.

(The direction of lens tilt will have a bearing on the orientation of the plane of sharp focus. The plane of sharp focus will always be parallel to the lens tilt axis. If we imagine a plane parallel to the film but passing through the lens, that plane will intersect with the plane of sharp focus. If we mark that intersection, we will find it is a line, and it will always be parallel to the axis about which we moved our lens. In common view camera language, if we use vertical tilt only, the tilt axis is horizontal. If we use swing only, the tilt axis is vertical. If we use both tilt and swing, the matter gets complicated.)

In essence, the hinge rule tells us that if we move the back of the camera to and fro (without changing its angle), closer to or farther from the lens, the plane of sharp focus must pivot on a line a distance **J** from the lens. In our example this pivot line is on the plane of sharp focus directly below the lens. I call that line the hinge line. I call it that because that line is like the pin in a hinge. The plane of sharp focus hinges on that line. As we move the back away from the lens, the plane of sharp focus will swing up in front of the camera. If we move the camera back closer to the lens, the plane of sharp focus will swing down, away from the lens. (It's the Scheimpflug rule working in consort with the hinge rule that causes this rotation, by the way.) So, to achieve the desired focus in our example, we focus, using the ground glass, either on the center of the painting, or on the center of the plaque. If we have done things right, when one is in focus, the other will be too.

That's it; we're done focusing.

But what about depth of field? Well, here the view camera really has the advantage over normal cameras. Calculating view camera depth of field is dead simple. Plainly put, the depth of field at a distance one hyperfocal distance, **H**, in front of the camera is our friend **J**. Like the distance **J** itself, this depth of field is measured in a direction parallel to the film. Either side of the plane of sharp focus, the depth of field is **J**. In this sense depth of field is symmetrical, always—just so long as we measure it parallel to the film.

Can't remember what the hyperfocal distance is? There's an easy way to remember it. The criterion for image sharpness is often that the circle of confusion at the image should be no greater in diameter than some fraction of the lens focal length. The number often cited is 1/1500. Well, the hyperfocal distance is then 1500 lens aperture diameters. If our 75 mm lens is set to f/22, the hyperfocal distance will be 1500 times 75mm divided by 22. That is about 5100 millimeters or 16.8 feet. Again, it might be useful to pre-calculate things and create a handy card showing hyperfocal distances for a variety of focal lengths and apertures.

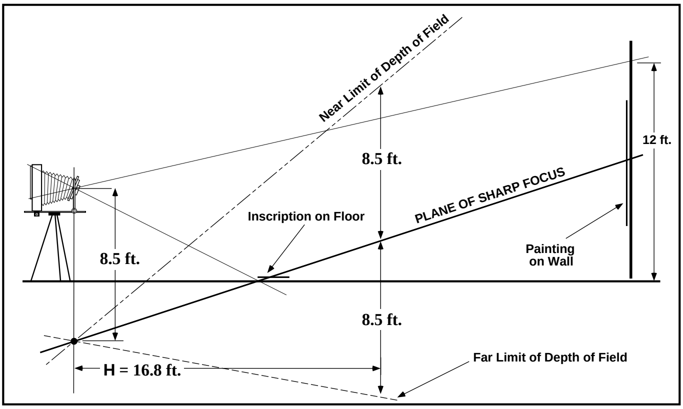

FIGURE 43: *Depth of field for view cameras is easy. At a distance of one hyperfocal distance,* **H**, *the depth of field measured in a direction parallel to the film is simply* **J** *on either side of the plane of sharp focus. (Camera is is not to scale.)*

It can be demonstrated that the limits of depth of field are also planes, and that they too pass through the hinge line. Getting back to our example, we can now sketch in the limits of depth of field. We know the depth of field at one hyperfocal distance, and we know the limits pass through the hinge line. See Figure 43 for the result. Looks fine: essentially everything included in our photograph is within the limits of depth of field.

The example just described is pretty straight forward. Unfortunately, the photographic situation will not always be quite so easy to analyze. The film will not always be vertical, and the plane of sharp focus will not always be near-horizontal. The basic principles to remember are as follows:

The lens tilt, measured relative to the film plane, determines the distance from the lens to a line about which the plane of sharp focus pivots. That line, called the hinge line, will also be parallel to the lens tilt axis.

Shortening the distance between lens and film plane causes the plane of sharp focus to rotate (about the hinge line) away from the front of the lens.

Increasing the distance between the film plane and the lens causes the plane of sharp focus to rotate towards the front of the lens.

Depth of field, measured parallel to the film varies directly as the distance, **J**. Increasing the lens tilt decreases **J** and so also decreases depth of field. Depth of field measured this way is always symmetrical about the plane of sharp focus.

Now you have the basics; the rest is just details.

We'll continue with a tutorial that might help to illustrate how one might go about deciding where to place the plane of sharp focus and how depth of field interacts with that placement. Along the way, we'll see how depth of field for view cameras is related to depth of field for normal cameras.

2. Tutorial

A challenging three-dimensional problem was presented to me by Craig Bailey of Alvin, Texas. The camera, positioned perhaps three feet above the ground, views a pathway passing through a gate. The gate is moderately close to the camera: about seven feet away. The path itself extends from the extreme foreground to the distance, but always at ground level. If the problem were just to focus on the pathway, the solution would be easy—for a view camera. We would simply set the lens tilt to give a distance, **J**, equal to the height of the lens above the path, then focus on the path—any part of it. The gate, however, extends from ground level to perhaps five feet above ground level. And in the background are bushes and trees between ground and a significant altitude. Figure 44 sketches a "side

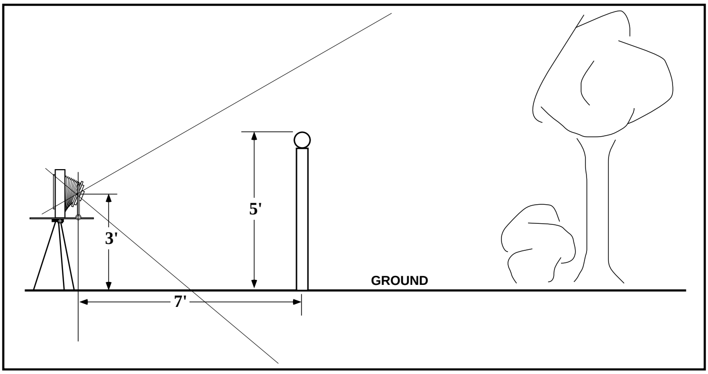

FIGURE 44: *Here's a side elevation view of the problem posed to me by Craig Bailey of Alvin Texas.*

elevation" view of the situation. Can we use lens tilt to good effect under these conditions?

Considerations

To obtain standard perspective for the gate and other vertically oriented objects, the film plane must be oriented vertically. This prevents the gate posts from pointing in towards one-another or from splaying apart in the image. The main three-dimensional object in the foreground is the gate. Since the depth of field in the vertical direction (parallel to the film) is equally distributed about the plane of sharp focus, a first guess is that the plane of sharp focus should pass through a line half-way up the gate posts. But what value of **J** (or lens tilt) should be used? To answer this, we must understand what happens to depth of field as the plane of sharp focus pivots, not about the hinge line, but about a line half way up the gate posts.

Perhaps we should not bother with lens tilt at all; we might consider just setting focus at the hyperfocal distance. Figure 45 shows the plane of sharp focus and near limit of depth of field for the case of no lens tilt. Here the camera is simply focused at the hyperfocal distance (12.1 ft.) for its 90 mm lens at f/22. The far limit of depth of field is at infinity. Alternatively one might focus on the gate posts, giving rise to the limits of depth of field shown in Figure 46. I've used the symbols Z_o, Z_n, and Z_f to denote the distance at which the lens is focused, the near limit of depth of field and the far limit of depth of field respectively.

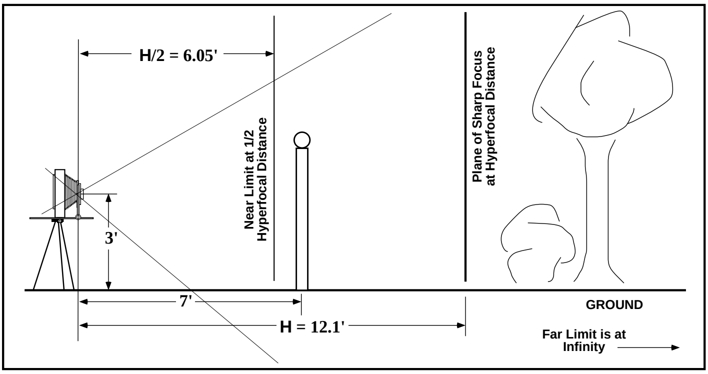

FIGURE 45: *Using an aperture of f/22 with a non-tilted 90 mm lens yields the depth of field situation shown above if the lens is focused at the hyperfocal distance. Objects in the distance fall within acceptable limits, but the path in the foreground does not.*

If we focus at the hyperfocal distance, the gate is within the established limits, but not the path in the foreground. If we focus on the gate posts, the path is sharpened but the nearest bits of it will still not be quite be as sharp as desired. And anything beyond the tree shown will be noticeably out of focus.

Let's reconsider tilting the lens. Using the principles illustrated in Figure 43, we can sketch the limits of depth of field for a number of candidate tilted-lens situations. Two such possibilities are shown in Figure 47.

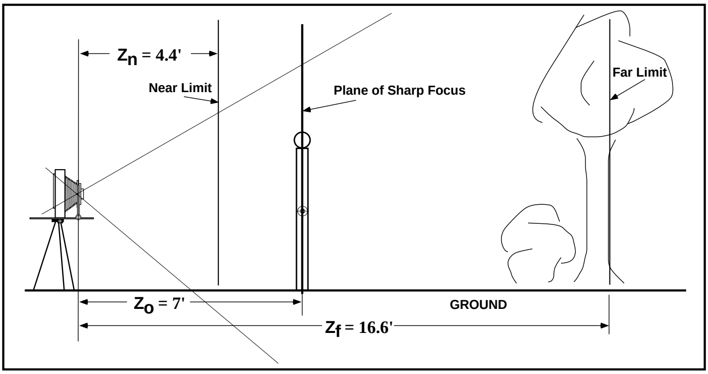

FIGURE 46: *Using an aperture of f/22 but focusing on the gate posts yields too little depth of field at near and far distances.*

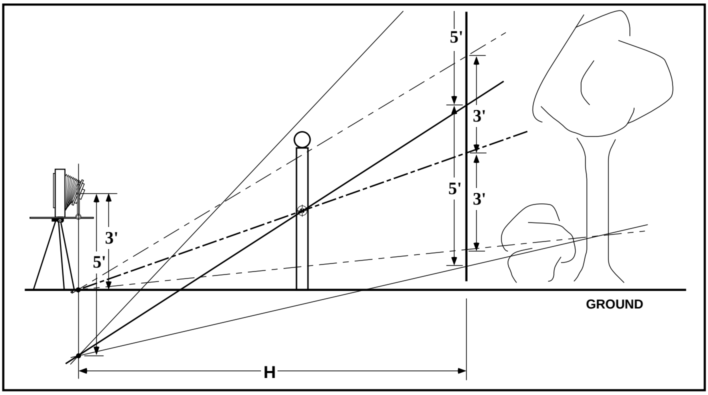

FIGURE 47: *Tilting the lens forward by 3.3° or 5.6° yields the depth of field limits indicated by the solid and dashed lines respectively. The aperture is f/22. Note that increasing the lens tilt decreases depth of field.*

Figure 47 clearly illustrates that if the distance **J** is reduced from 5 feet to 3 feet (by increasing lens tilt), the region of acceptable definition—the space between the near and far limits of depth of field—shrinks noticeably. To maximize depth of field, one must minimize lens tilt. Yet tilting the lens can still be valuable for sharpening particular regions, such as the foreground.

As the sharp-eyed may have observed, Figures 46 and 47 are related. The place where the two near limits of depth of field cross in Figure 47 corresponds to the near limit of depth of field in Figure 46. And the same is true for the far limits. Furthermore, these two points of intersection, and the spot where the plane of sharp focus pivots, all lie along a straight line through the lens. This is not an accident. When the plane of sharp focus is rotated about a fixed point in the object field—by both tilting the lens and adjusting the lens-to-film distance—the near and far limits of depth of field, along a ray through that fixed point, cannot change significantly. The principle at work here is that depth of field is related only to the focal length, the aperture, the allowable circle of confusion diameter, and the distance at which the lens is focused. The depth of field, along a ray from the lens to a fixed point constrained to be in focus, cannot change just because the lens is tilted.

In the problem at hand, we choose to hold focus on a point half-way up the gate post. This ensures that both ends of the post will be acceptably and equally sharp.

The procedure for plotting depth of field is simple. First we select the point in the object space where we want the plane of sharp focus to pivot. After any camera adjustments we will always focus again on this spot. Lets call this spot “point **P**”. Then we draw (or imagine in our minds) the near and far limits of depth of field using classical techniques for untilted lenses. For this purpose the camera is presumed to be focused at a distance equal to the lens-to-pivot point distance (measured in a direction perpendicular to the film plane). Then we draw, or imagine, a ray from the lens to point **P** and beyond. Where this ray intersects the near and far limits of depth of field indicates the pivot points for these planes. We’ll call these pivot points “point **C**” for the near or close limit of depth of field, and “point **F**” for the far limit of depth of field.

But we also know that, for a tilted lens, the near and far limits of depth of field must pass through the hinge line. These

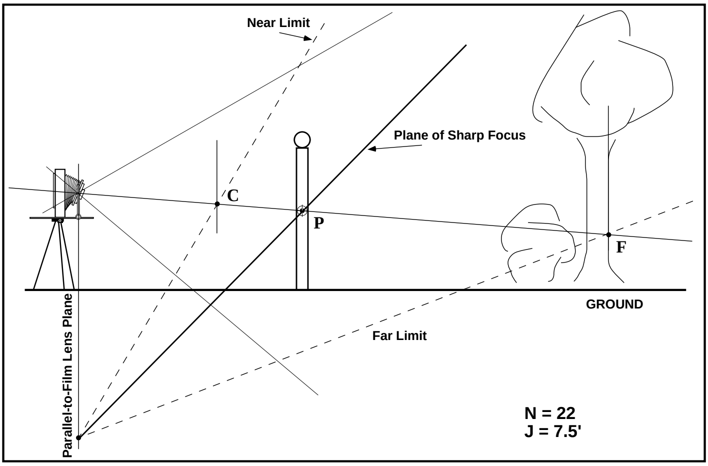

FIGURE 48: *Using* **J** *equal to 7.5 feet (2.3° lens tilt) and f/22 solves the foreground problem, but falls short of giving the desired result for objects in the distance. The base of the tree is outside the permissible limits. The points* **C** *and* **F** *are at the limits of depth of field for a non-tilted lens focused on point* **P**.

facts tell us everything we need to know. In our drawing, the near limit of depth of field extends from the hinge line to point **C** and beyond. Similarly, the far limit of depth of field extends from the hinge line through point **F**. As we adjust lens tilt, always readjusting the lens-to-film distance to keep the plane of sharp focus passing through point **P**, the hinge line moves along the Parallel-to-Film Lens Plane. Figure 48 illustrates the depth of field limits for a **J** distance of 7.5 feet and for f/22. With this set-up the foreground and gate post should be in focus, but the base of the tree will not be. But, as a first try, we're not far off.

(Before proceeding further, one might note that as lens tilt is adjusted towards zero, the distance **J** goes to infinity, and the limits of depth of field become parallel to the film plane. Thus the approximate method described here for view cameras is quite in accord with the traditional theory for non-tilted lenses.)

The problem now is to refine the positions of the hinge line and the points **C**, **P** and **F** to best achieve our goal.

A Solution

Applying this knowledge to the problem of the gate posts, we can make the following statements. Point **P** should be half-way up the gate posts, as noted earlier. Now we have just two things left to determine. We must choose an f-number and we must choose the lens tilt. The lens tilt is determined by the lens-to-hinge line distance, **J**. Point **C** must be such that the near limit of depth of field clears the tops of the gate posts. The hinge line will probably need to be somewhere near ground level. It can be below ground level provided the near limit of depth of field rises above the ground where the ground first comes into the camera's view.

The next step is to draw the near and far limits of depth of field for a lens focused at a distance of 7 feet, but for several apertures. We can do this using standard depth of field tables, or formulae. If we use **Z** to denote distance in front of the lens, measured in a direction perpendicular to the film plane, the appropriate formulae are, for the near limit:

$$Z_n = Z_o H/(Z_o + H)$$

and for the far limit:

$$Z_f = Z_o H/(H - Z_o).$$

H denotes the hyperfocal distance for whatever criteria we choose, while Z_o indicates the distance to the selected "point P". In this example Z_o is 7 feet. For a 90 mm lens on a 4 by 5 camera, we'll assume the hyperfocal distance is equal to 900 lens aperture diameters. This corresponds to a circle of confusion diameter equal to 0.1 millimeters or 1/1500 of the format diagonal. Figure 49 shows the positions of the limits so calculated, marked along the line from lens to point **P**, for various apertures. Table 1 provides the numbers appropriate to the problem at hand.

A line from the top of the gate post, through the nearest bit of ground that can be seen by the camera, indicates that the distance **J** should be no greater than 8.4 feet. If **J** is greater than 8.4 feet, the near ground and the top of the post cannot both be in acceptable focus. The construction also indicates that an f-stop a bit smaller than f/11 could be used to solve the foreground problem. But, as shown in the figure, f/11 leaves things in the distance much outside the far limit of depth of field. In order for objects in the extreme distance at ground level to be sharp, the hinge line must be at the same level as, or above, the appropriate point **F** for the aperture chosen. This ensures the far limit of depth of field will slope downwards away from the camera.

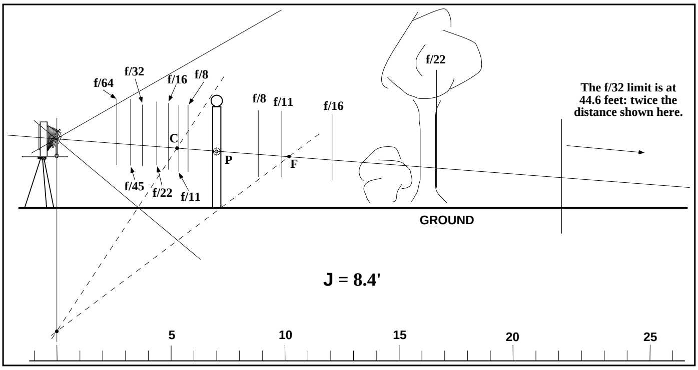

FIGURE 49: *We can estimate the depth of field situation for a number of f-stops simultaneously by plotting the limits of standard depth of field for several apertures. An aperture just a bit smaller than f/11 is sufficient to solve the foreground problem so long as* **J** *is at 8.4 feet. But f/11 is far short of what is needed to sharpen objects at ground level in the distance. (Distance scale at bottom is in feet.)*

f-Stop	H	Z_n	Z_f
2.8	94.9	6.5	7.6
4	66.4	6.3	7.8
5.6	47.5	6.1	8.2
8	33.2	5.8	8.9
11	24.2	5.4	9.9
12	22.1	5.3	10.2
16	16.6	4.9	12.1
22	12.1	4.4	16.6
27	9.8	4.1	24.2
32	8.3	3.8	44.6
38	7.0	3.5	-7382.8
45	5.9	3.2	-37.8
64	4.2	2.6	-10.2
90	3.0	2.1	-5.1

TABLE 1: *This Table shows Hyperfocal Distances in feet for various f-stops as well as the near and far limits of depth of field for a non-tilted 90 mm lens focused at 7 feet.*

Re-examination of Figure 48 will illustrate that even f/22 is not sufficiently small to guarantee such an outcome. Decreasing **J** helps sharpen objects in the extreme distance, but worsens matters at, for example, the base of the tree. With the camera position chosen, it might appear that a very small aperture will be needed. A higher camera position might be called upon to alleviate the problem substantially. The higher lens position would both raise point **C** and depress point **F**. But it also may not

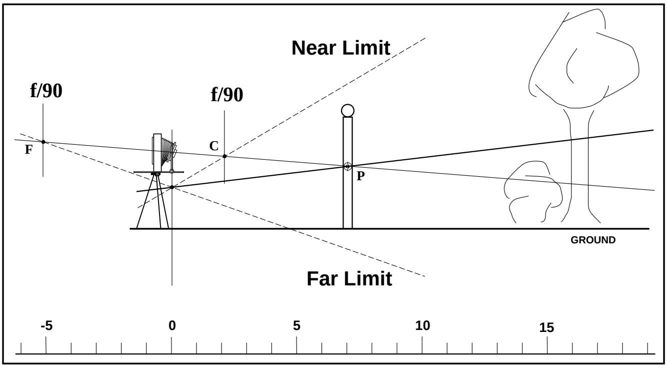

FIGURE 50: *When point* **P** *is beyond the hyperfocal distance for the aperture under consideration, the point* **F** *lies behind the camera! The situation is illustrated here for f/90 and a lens tilt of 12°. Even f/90 fails to supply enough depth of field if too much lens tilt is used.*

give us the image composition desired. Let's not sacrifice composition.

At first thought, it may appear that the far limit of depth of field can never be depressed below the angle of the line from lens to point **P**. It might seem that for point **F** at infinity or beyond, the far limit of depth of field is parallel to this line. For point F precisely at infinity, this is true. But in those cases where the hyperfocal distance, **H**, is less than the distance, Z_o, the formula indicates a negative value for Z_f! For **H** less than Z_o we have to plot point **F** behind the camera! Figure 50 shows this situation, using f/90 as an example. We now see that a reasonable aperture might permit us to achieve our goal.

All in all, it looks reasonable to use about f/27, yielding the situation depicted in Figure 51. The distance **J** is 5.5 feet, corresponding to a lens tilt of about 3°. We may still have a problem with objects at ground level beyond the tree. If such elements of the image are important we will have to use f/32. The set-up shown in Figure 51 puts the plane of sharp focus through the extreme foreground, the centers of the gate posts, and through the top of the tree. This factor should help make the image appear very sharp "from top to bottom".

We might also have kept our lens set to f/38 with the tilted lens. In this case *all* the important elements of our image would have been *well within* the limits for depth of field. Figure 52

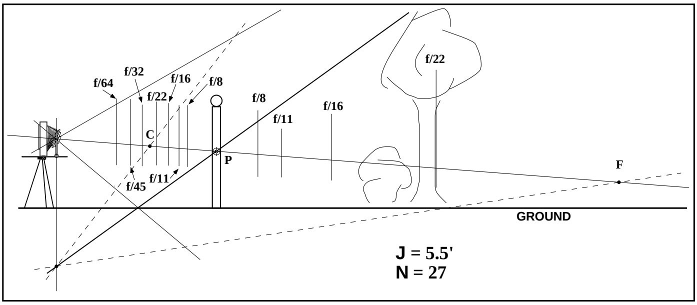

FIGURE 51: *A reasonable compromise set-up might be f/27 with* **J** *equal to 5.5 feet (lens tilt of 3°). Objects at ground level beyond the tree may be just a bit fuzzy, however. Using f/32 would probably sharpen the image of distant objects if that were necessary.*

shows this example. The penalty for using f/38 would be poorer definition in the sharpest parts of the image, due to diffraction.

Additional Comments

It is difficult to provide instant answers on how to best set-up for a view camera if the important elements of the subject being photographed are not naturally arranged along a plane. There are, however, relatively simple geometric principles that can be used to sketch the depth of field situation and help the photographer decide what might be best for the situation at hand. One example has been examined here to illustrate these ideas.

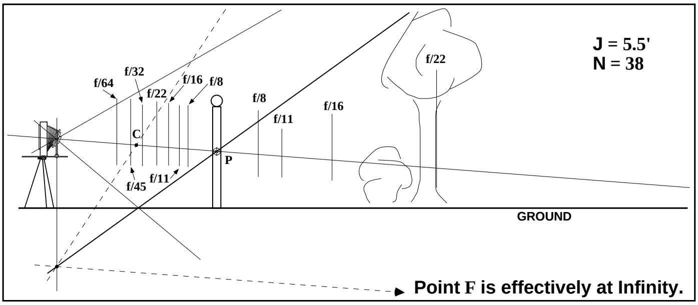

FIGURE 52: *Another solution might have been to use f/38. With this aperture every element of our image is well within the depth of field limits. Without lens tilt, the near limit of depth of field would have coincided with the foreground. Yes, using lens tilt gives us a sharper picture!*

In the example studied here, we could have used the standard "focus at the hyperfocal distance" rule to maximize depth of field. The result would have been that we would have had to use about f/38 and only the gate posts would have been in critical focus. By tilting the lens 3° we have put the extreme foreground, the gate posts and the top of the tree in critical focus, and, we could open the lens by one stop. The penalty is that objects at ground level beyond the tree will tend to be just a bit soft. Then again, maybe this will tend to emphasize depth in the final image.

In real shooting situations there is seldom a need for precise calculations. Estimates of distance are usually good enough to provide the insight necessary, and guide the procedure to be followed. I carry with me a table of lens tilts and **J** distances for various lenses, and a similar table of hyperfocal distances. These guide my determination of the desired lens tilt, which is then set with the aid of a protractor. The final adjustment is done simply by using the ground glass to set focus on the selected "point **P**". I doubt that I can set the lens tilt more accurately than perhaps on-half of a degree. Thus I really don't know the value of **J** to better than perhaps six inches at best. What I do know, is that I could not set the camera as accurately if I were to set the lens tilt by trial and error!

3. Other Ways of Illustrating Depth of Field

The simple relationships just described will allow us to draw a depth of field diagram for multiple f-stops, but one orientation of the plane of sharp focus and one **J** distance. An example is shown in Figure 53. It will be seen that depth of field measured parallel to the film plane scales directly as the f-number. The depth of field measured this way for f/32 is twice that for f/16 and so on. (The significance of lines drawn parallel to the film plane is that image magnification is constant for any object along such a line.)

We do not always need the same degree of definition at every point within the "sharp" part of our image. Can we determine quantitatively what the circle of confusion will be for any object in the scene being photographed? The simple relationships between depth of field and hyperfocal distance, and between hyperfocal distance and circle of confusion diameter, make the problem easy. Depth of field is one-third as great if we

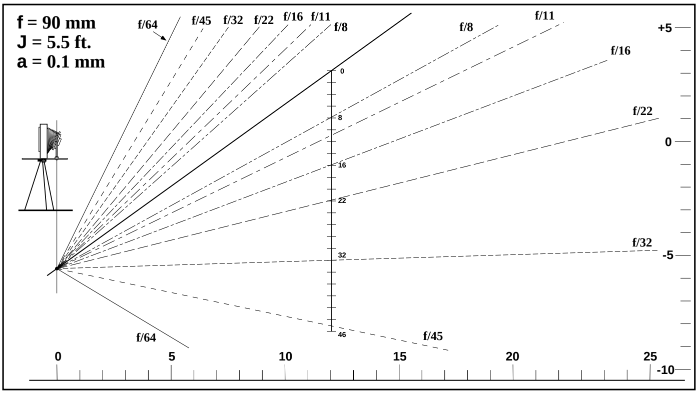

FIGURE 53: *We can show the depth of field for a number of apertures simultaneously, as shown here. Details of the scene have been removed to reduce the clutter. The horizontal and vertical scales (along the edges) are in feet. Optical conditions and distances in this diagram are the same as those used in Figure 51. The center scale shows that the vertical depth of field scales directly as the f-number of the lens.*

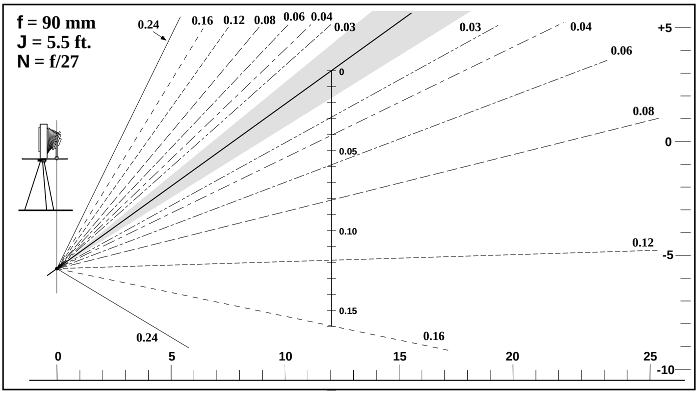

FIGURE 54: *The very same drawing used for Fig. 53 can be re-labeled to map out the circle of confusion diameters (measured at the image) for any point in the scene. The numbers represent the diameter of the circle of confusion, in millimeters, for an aperture of f/27. The vertical scale in the center has been adjusted to measure the diameter of the circle of confusion at the film. The gray area shows the region for which the lens will be diffraction limited.*

use one-third the original circle of confusion diameter. It is four times as great for four times the circle of confusion diameter and so on. This simple scaling allows us to draw a “contour map” of the circle of confusion diameter for any point in the object field. In fact such a “contour map” of circle of confusion diameters for a single f-stop is just a re-labeled version of Figure 53. An example is illustrated in Figure 54.

We can go one step farther here by also indicating the zone for which the lens definition will be limited by diffraction: the gray area in Figure 54. The smallest circle of confusion a lens can produce is limited by diffraction to about **N**/1600 mm where **N** is the f-number. That limiting diameter is about 0.017 mm at f/27 or 0.025 mm at f/38. These figures are about one-sixth to one-quarter the limit we set for depth of field purposes.

4. Making the Approximate Method Exact

The method of determining depth of field described so far is approximate. The method gives increasingly incorrect answers as the backfocus distance (lens-to-film plane distance), **A**, becomes significantly larger than the lens focal length, **f**. The matter is easily put right with one relatively simple correction. When we do the calculations without making mathematical approximations, we find that the depth of field on either side of the plane of sharp focus is not **J** but rather **fJ/A**. And that’s all there is to it! Figure 55 below illustrates.

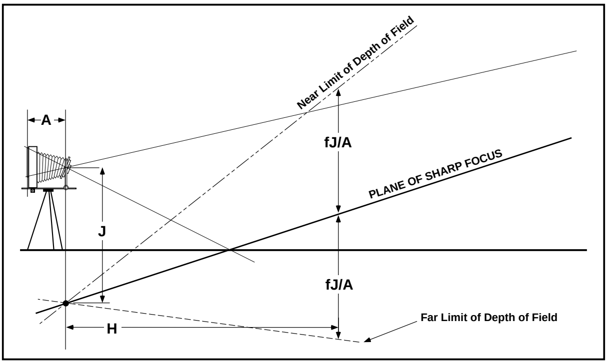

FIGURE 55: *The exact calculations for depth of field require that the depth of field at one hyperfocal distance be* **fJ/A**, *rather than just* **J**. *The matter is of little consequence except in close-up photography.*

5. Proving the Exact Depth of Field Result

A decision I had made when I originally wrote *FOCUSING the VIEW CAMERA* was that I would not include any of the mathematical proofs: I would simply state the result. But proving the exact result is so easy, that I'm going to include it in this addendum. The proof builds on the work in *The INs and OUTs of FOCUS,* however. If you are not familiar with my object-based depth of field concept (or do not accept the validity of it), you may find this difficult to follow. If that is the case, just skip this section.

With reference to Figure 56, the derivation is as follows. The diameter of the disk-of-confusion, or spot size, is zero on the plane of sharp focus (PSF). Along any straight line intersecting the PSF, the spot size, **S**, varies linearly. Along any line parallel to the film plane and in the object field, **S** will simply be:

$$\mathbf{S_h = d(h/J)}$$

where **d** is the aperture diameter and **h** is the distance from the PSF measured along that line parallel to the film. On the film,

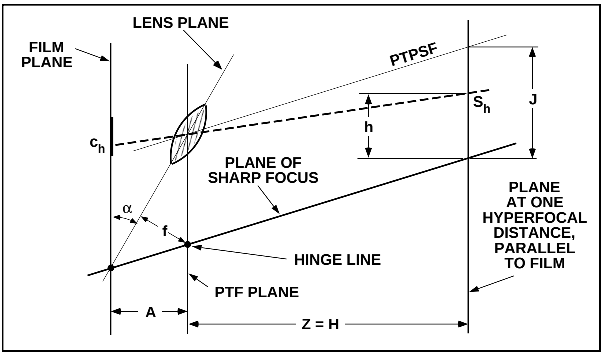

FIGURE 56: *Here's the general scheme of things needed to determine the exact image-based depth of field from a knowledge of the object space depth of field. "PTPSF" stands for the plane which is Parallel To the Plane of Sharp Focus. The spot size diameter,* $\mathbf{S_h}$*, is determined in relation to its distance from the plane of sharp focus,* **h***. The corresponding diameter of the circle of confusion is determined by the image magnification. "PTF" stands for the Parallel-To-Film lens plane.*

the image of that spot will be simply the magnification times $\mathbf{S_h}$. That is:

$$\mathbf{c_h = (A/Z)\ d\ (h/J)}.$$

In order for $\mathbf{c_h}$ to be less than $\mathbf{a}$, the maximum permitted diameter of the circle of confusion, we require:

$$\mathbf{Adh/ZJ < a}$$

or

$$\mathbf{h < aZJ/Ad}.$$

Since $\mathbf{d = f/N}$, and $\mathbf{H = f^2/Na}$, we have:

$$\mathbf{h < fZJ/AH}.$$

For the limit of depth of field, we then replace the “less-than” sign by “equals”. That’s all there is to it. Of course one has to believe what’s in *The INs and OUTs of FOCUS* first. There’s no trigonometry required either in this derivation, or in the result! There’s still just a bit of trigonometry needed to calculate the distance **J** from the lens tilt, α.

One of John Ward’s questions was: “Is **H** equal to $\mathbf{f^2/Na}$, or is **H** equal to $\mathbf{f + f^2/Na}$?” The answer is “yes”. I have found four slightly different definitions for hyperfocal distance. Two of them give the answer with the extra **f** in it. One gives only the f-squared term. The fourth is more complex. The definition I used in *The INs and OUTs of FOCUS*, yields the simplest expression ($\mathbf{H = f^2/Na}$) when I do it ‘right’. The four definitions are: The inner limit of depth of field, measured from the lens, when the lens is focused at infinity (as in my book); same again measured from the film; The distance (measured from the lens) which, when focused upon, gives infinity as the far limit of depth of field; and, this last again, but measured from the film. The differences are subtle and inconsequential for most purposes.

The exact result requires that we use the *marked* f-number for the aperture rather than the ‘true’ f-number, no matter how large **A** is. That’s just *less* calculation to do! (The depth of field tables in *FOCUSING the VIEW CAMERA* assumed one would always use the ‘true’ f-number. At 1:1 image magnification, for example, the true f-number is twice that marked on the lens.)

6. Another Look at the Reciprocal Hinge Rule

In Chapter 2 of *FOCUSING the VIEW CAMERA* I indicated I could see no immediate application for the reciprocal hinge rule. That was rash of me. While reading a 1904 photography text by the British author Chapman Jones, I realized that it is essentially the reciprocal hinge rule that has allowed view camera users to use back tilt as a substitute for lens tilt. According to Chapman Jones, one should never attempt to adjust the camera using lens tilt. He claims that will just result in trouble. If one must set the lens axis out of perpendicular with the film, only back tilt should be considered—even though this may lead to unnatural perspective.

If one keeps the lens-to-film distance constant as one tilts a lens, the plane of sharp focus moves in a complicated way that is not easy to understand. The plane of sharp focus changes both its range from the camera and its angular orientation as the lens tilt is adjusted. Furthermore, the apparent movement of the plane of sharp focus depends upon the lens-to-film distance that is set. Thus the effect of tilting the lens is difficult to anticipate. It is very difficult to learn how to judge the right amount of lens tilt by adjusting the lens tilt directly. I refer in Chapter 8 to it being like driving a car on ice.

Adjusting the back tilt is a much ‘friendlier’—more predictable—operation. According to the reciprocal hinge rule, rotating the back about some fixed axis (on the film plane) merely regulates the distance of the plane of sharp focus from the camera without changing its angular orientation. The angular orientation is fixed by the relative positions of the lens and the axis about which the back is being tilted. The plane of sharp focus must remain parallel to the plane defined by the lens and the back tilt axis.

The reciprocal hinge rule makes it easier to understand some of the arguments over whether base tilts or axis tilts are preferable for the camera back. The ideal, I guess, is to be able to position the back tilt axis so as to determine the desired orientation of the plane of sharp focus.

The difficulty I see with using back tilts is how to maintain correct perspective. One solution I learned from a friend—who had learned it at a photography workshop—is to determine the required amount of tilt by tilting the back, but then transfer that amount of tilt to the lens and straighten the back. Actually this method is only an approximation; it breaks down under various circumstances, especially in the close-up range. It is possible to use a correction table to translate back tilt into the correct corresponding lens tilt. Alternatively, one can repeat the process once or twice to refine the setting. Each successive time, the new back angle suggests the *correction* needed to the tilt at the front.

Closing

I hope this addendum has accomplished a few things. I hope the Getting Started and Tutorial sections have helped make the methods described in *FOCUSING the VIEW CAMERA* somewhat easier to understand. It should also serve to give confidence in using what I had thought was an approximate method for estimating depth of field. We now have an exact method that is manageable in everyday use. And finally, I hope it has provided a bit of extra insight into the optical principles governing view cameras.

I'd like to thank all those who have helped me to understand these things. Without their questions and encouragement, I would not have had such fun!