The Scheimpflug Principle—Part IV

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In Part I we reviewed the Scheimpflug rule which applies for thin, rectilinear, flat-field lenses. This rule states that the film plane, lens plane and plane of sharp focus intersect along a common line. This rule is certainly a help, but it is not complete. There are an infinite number of ways to meet the requirements of the Scheimpflug rule and still not have the camera in focus. We need something else to help us set up. That something else is the subject for this month.

I'm going to call this month's rule the "hinge rule"—for reasons which I hope will become clear. Pay close attention; this could be a little confusing. There are two more planes we have to deal with—five in all! The Scheimpflug rule addresses three of the planes, and the hinge rule addresses three. Fortunately one plane—the plane of sharp focus—is common to both rules.

The first new plane I will call the "Parallel-to-Film, Lens Plane"—or PTF plane, for short. This plane is placed through the center of the lens but oriented parallel to the film plane, as shown in Figure 1. If the lens is a 'thick' lens, this PTF plane passes through the front nodal point of the lens. Fortunately, for the hinge rule, it does not matter whether the lens is thick or not, so long as we remember that the PTF plane passes through the front nodal point.

The second new plane is associated exclusively with the lens. This plane is parallel to the lens plane, but one focal length in front of it. It is perpendicular to the lens axis, but one focal length in front of—on the subject side of—the front nodal point of the lens. I'll call this plane the Front Focal Plane. The significance of the front focal plane is that an object anywhere on this plane is focused an infinite distance behind the lens.

The significance of the PTF plane takes a little more description, but it's related. With the help of Figure 1 you will understand that the light rays from an object anywhere on the PTF plane are also aimed at the film an infinite distance behind the lens, no matter how close (or far) the film plane is to the lens. The rays are not necessarily in focus, however. If the lens were aligned with its axis perpendicular to the film, the lens would need to have 180° of coverage to 'see' any object on the PTF plane. But remember: we're talking about view cameras, so by tilting the lens we can actually place an object on the PTF plane where the lens can 'see' it. Placing the film where it can image that object sharply is not possible, but that doesn't matter. It's the principle of the thing that counts.

OK, here it comes. An object on the PTF plane can only be focused sharply at infinity when it is simultaneously on the PTF plane and the front focal plane. That is, it must lie at the intersection of the front focal plane and the PTF plane. This actually tells us a lot we need to know. If we know the orientation of the film plane, and if we know where the lens is, and how it is tilted, we know something else very important. We now know that the plane of sharp focus must pass through the intersection of the PTF plane and the front focal plane—no matter the lens-to-film distance! We'll give this three-plane intersection line a name too: the "hinge line". We don't know at what angle the plane of sharp focus passes through the hinge line, but it must pass through it. So long as we keep the film orientation fixed, we know at least one line on the plane of sharp focus that remains fixed in space—unless we change the lens tilt (or swing) or the back tilt (or swing).

The Hinge Rule, simply stated, is that the plane of sharp focus, the front focal plane and the PTF plane intersect along a common line: the hinge line. I know of no book on photography that describes this principle. If you have seen it, please let me know; I'd like to see another reference.

In practice the hinge rule tells us that if we know the film orientation (often vertical) and we know the lens tilt or swing, we know how far from the lens the plane of sharp focus will pass, measured along the PTF plane. I will use the symbol J for this distance. Figure 2 shows J and all the other symbols and relationships I will be using. We can even attach a distance scale to the tilt (or swing) scales using the formula for J indicated in Figure 2. We need a new scale for each focal length and unit of distance (feet, meters etc.), or we can use just one scale that measures in focal lengths. The distance J/f (the distance J divided by the focal length, f) is always related in a relatively simple way to the lens tilt angle α. Table 1 shows some examples of that relationship.

Now, put this hinge rule together with the Scheimpflug rule and you

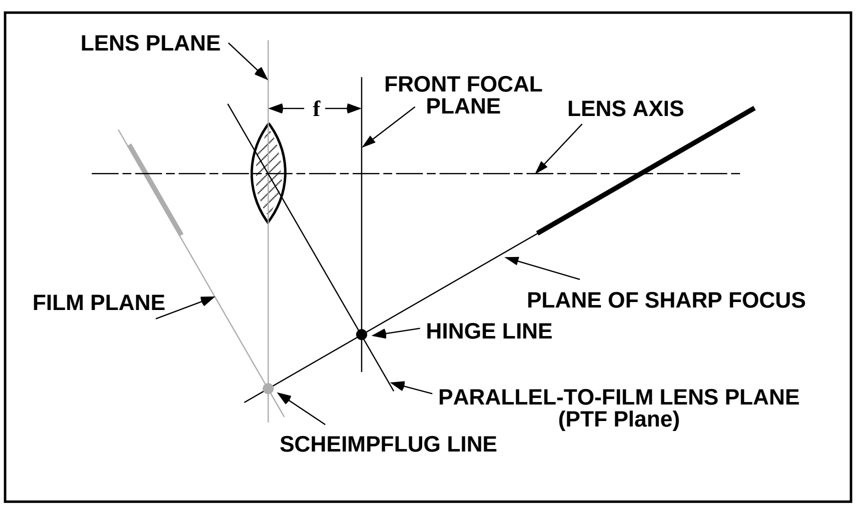

Figure 1: Two new planes are introduced. The Front Focal Plane is parallel to the Lens Plane, but lies one focal length in front of it. The Parallel-to-Film Lens Plane (or PTF plane, for short) is parallel to the film plane but passes through the center of the 'thin' lens. The Front Focal Plane, the PTF plane and the plane of sharp focus intersect at the "hinge line".

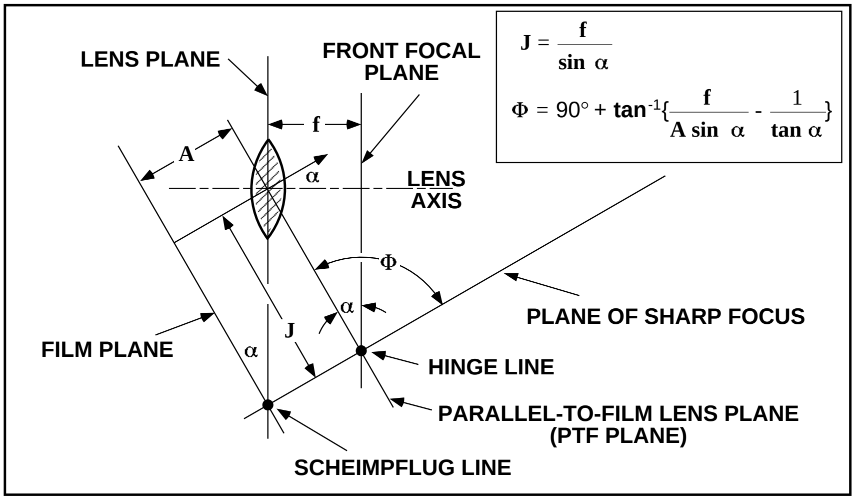

Figure 2: The Scheimpflug rule and the hinge rule combine to provide a complete solution to the view camera optical configuration. The lens-to hinge line distance, J, together with the lens focal length, f, determine the required lens tilt, a. The lens-to-film distance, A, and the lens tilt determine the orientation F of the plane of sharp focus relative to the film plane.

have the complete solution. And when we do this, you'll understand why I called the line the hinge line. With the help of Figure 3, you'll see that as the camera back is racked to and fro, the plane of sharp focus rotates on the hinge line. I call it 'hinging' on the hinge line because, behind for objects behind the hinge line, no image is possible. An object behind the hinge line, even if seen by the lens, cannot (even in principle) be imaged on the film. The 'visible' part of the plane of sharp focus ends at the hinge line. We use its extension, of course, in applying the Scheimpflug rule. Notice how, as the back is moved towards and away from the lens, the Scheimpflug line travels up and down the lens plane. The hinge line stays fixed. The only way we can solve both rules is to have the plane of sharp focus hinge up and down, rotating on the hinge line.

Let's consider an example. We set up our camera on a football field. The uprights are visible in the scene, so we keep the back vertical in order to achieve the correct perspective. We want every blade of grass between the camera and the goal posts to be in sharp focus. We mount the camera on the tripod, set its back vertical, and raise the back to see as much of the ground as possible and still see the uprights. We then measure the lens-to-ground distance—vertically, parallel to the film plane. The next step is to tilt the lens forward so that the front focal plane intersects the PTF plane at the ground right beneath the lens. Table 1 shows the lens-to-hinge line distances (J) for various combinations of lens focal length and tilt angles. We are using a 90 mm lens 41 inches above the ground, so we tilt it 5°. The plane of sharp focus now passes through the grass immediately below the lens. Watching the ground glass now, we move the back forwards, closer to the lens. The plane of

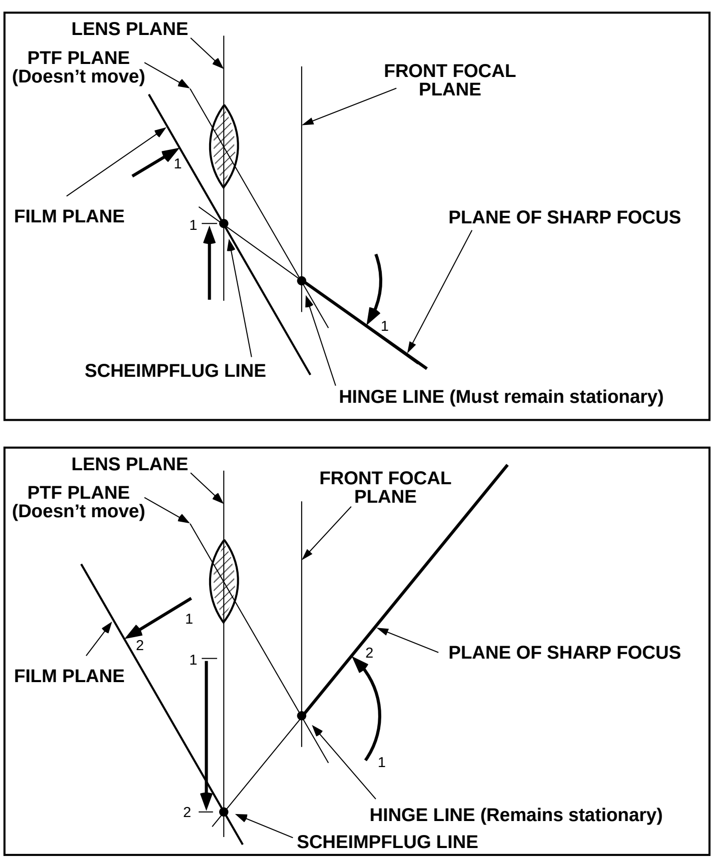

Figure 3: If the film plane is moved closer to the lens, the plane of sharp focus swings away from the lens, rotating on the hinge line. As the film is moved away from the lens, the plane of sharp focus swings up in front of the lens. So long as the angular orientation of the lens plane and the film plane remain unchanged, the hinge line must remain fixed in space.

	DISTANCE J (for focal length and tilt angle indicated.) (in inches)											
FOCAL LENGTH (in mm)	J/f	65	75	90	100	135	150	180	210	240	300	450
LENS TILT ANGLE (in degrees)												
0	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞	∞
0.5	114.6	293.2	338.4	406.0	451.2	609.1	676.7	812.1	947.4	1083.	1353.	2030.
1	57.3	146.6	169.2	203.0	225.6	304.5	338.4	406.1	473.7	541.4	676.8	1015.
2.5	22.9	58.7	67.7	81.2	90.3	121.8	135.4	162.5	189.5	216.6	270.8	406.2
5	11.5	29.4	33.9	40.7	45.2	61.0	67.8	81.3	94.9	108.4	135.5	203.3
7.5	7.66	19.6	22.6	27.1	30.2	40.7	45.2	54.3	63.3	72.4	90.5	135.7
10	5.76	14.7	17.0	20.4	22.7	30.6	34.0	40.8	47.6	54.4	68.0	102.0
12.5	4.62	11.8	13.6	16.4	18.2	24.6	27.3	32.7	38.2	43.7	54.6	81.9
15	3.86	9.9	11.4	13.7	15.2	20.5	22.8	27.4	31.9	36.5	45.6	68.5
20	2.92	7.5	8.6	10.4	11.5	15.5	17.3	20.7	24.2	27.6	34.5	51.8
25	2.37	6.1	7.0	8.4	9.3	12.6	14.0	16.8	19.6	22.4	27.9	41.9
30	2.00	5.1	5.9	7.1	7.9	10.6	11.8	14.2	16.5	18.9	23.6	35.4
35	1.74	4.5	5.1	6.2	6.9	9.3	10.3	12.4	14.4	16.5	20.6	30.9
40	1.56	4.0	4.6	5.5	6.1	8.3	9.2	11.0	12.9	14.7	18.4	27.6
45	1.41	3.6	4.2	5.0	5.6	7.5	8.4	10.0	11.7	13.4	16.7	25.1
50	1.31	3.3	3.9	4.6	5.1	6.9	7.7	9.3	10.8	12.3	15.4	23.1
60	1.15	3.0	3.4	4.1	4.5	6.1	6.8	8.2	9.5	10.9	13.6	20.5

Table 1: This table shows the lens-to-hinge line distance, J, for various combinations of lens tilt angle and focal length. For lenses of focal lengths other than those shown here, use the number in the J/f column and multiply it by the lens focal length. For example, a 10 in. lens tilted by 5° will result in a distance, J, equal to 115 in.

sharp focus swings down, away from the lens, as we do this. We move the back away from the lens, and the plane of sharp focus swings up in front of the camera. When we get the grass at the foot of the uprights in sharp focus, all the grass should be in sharp focus!

I didn't have a football field handy, so I used a concrete plant. Figure 4 shows two photographs of it from the same camera position. The only thing different between the shots is the horizontal position of the camera back. To get the daisies sharp, the back was moved forwards. And to get the top of the tower sharp, I moved the film backwards, swinging the plane of sharp focus upwards in front of the camera.

In my experience, this hinge rule is even more useful than the Scheimpflug rule. In my style of photographs, the thing I most want to do is to get the foreground under the camera, as well as the distant scene, all in sharp focus. The plane of sharp focus will usually be within 15° of horizontal in front of the camera. This requires forward tilt of the lens. And using tables like Table 1, I can set the lens tilt even before I put the camera on the tripod. Then one focusing motion with the camera back is all that is necessary to set focus.

We can also relate the tilt of the plane of sharp focus to the lens tilt and the film position mathematically, as illustrated in Figure 2. α (alpha) is the tilt of the lens axis relative to the bore sight. A is the lens-to-film distance measured parallel to the bore

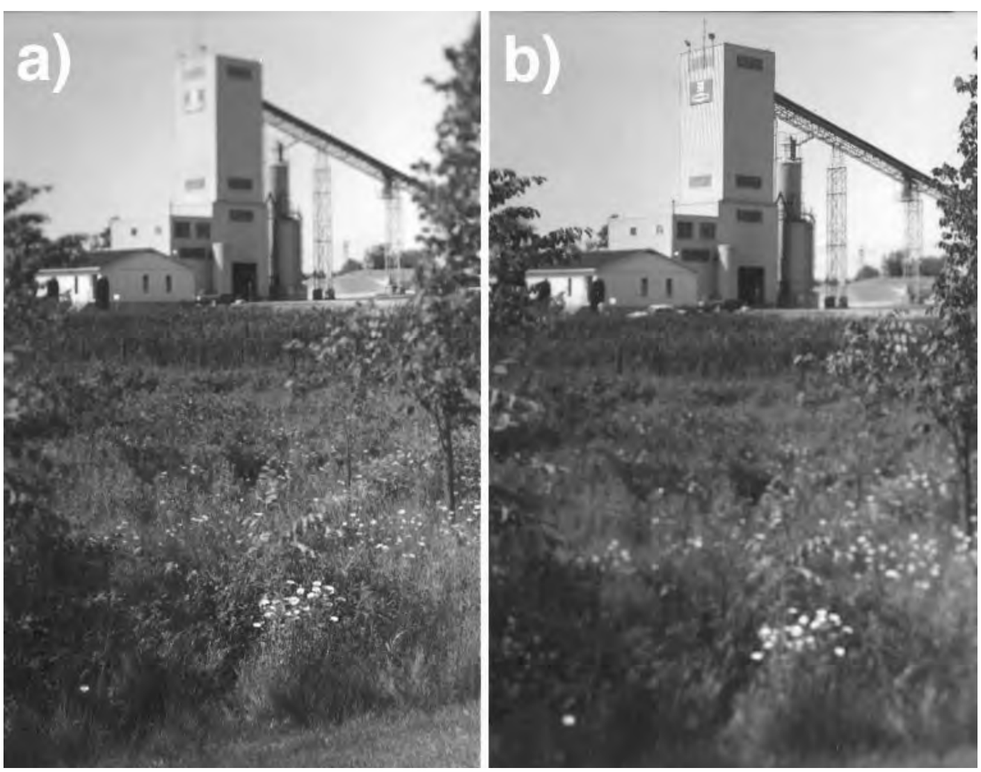

Figure 4: These two photographs were taken with a 5 by 7 inch camera with a 240 mm lens at f/11. The lens is tilted down by 12° to put the hinge line on the ground 46 in below the lens. For Figure 4 a), the film was moved forward so that the grass on the slope down and away from the camera would be in sharp focus. For Figure 4 b), the film was moved away from the lens so that the top of the tower of the concrete plant would be in focus. In principle, the grass on the ground directly beneath the lens would still be in focus also.

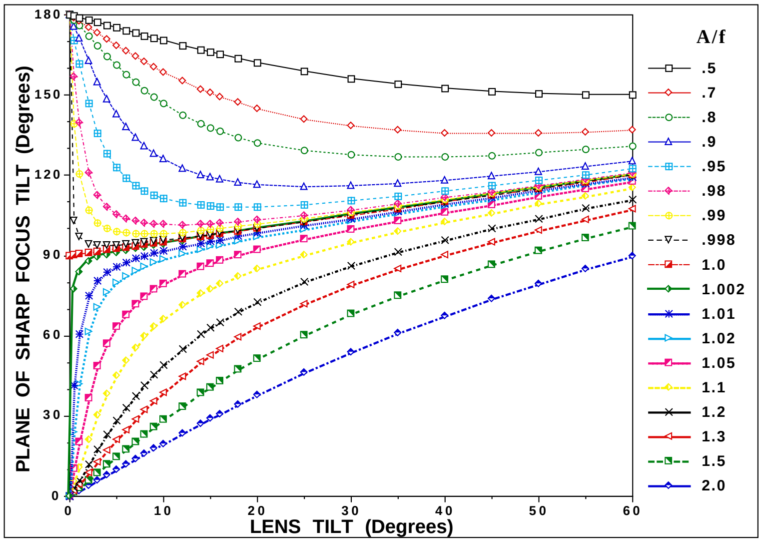

Figure 5: The angle between the plane of sharp focus and the film plane is determined by the lens tilt and the lens-to-film distance. This figure is a graph of plane of sharp focus tilt, F, as a function of lens tilt, a. for several different lens-to-film distances. These latter distances are given in focal lengths so that the graph will apply to lenses of all focal lengths.

sight (perpendicular to the film), and Φ (Greek capital Phi) is the angle of the plane of sharp focus relative to the film plane. In practice, it is often convenient—as for J—to express the distance A in focal lengths. That is, the lens-to-film distance is given as A/f. This allows one table or graph to serve for several different focal lengths of lenses.

And Figure 5 is the graph of the results. You will see that the relation between α and Φ depends very much upon the value of A/f. When A/f is near (but not exactly equal to) the value one, the angle Φ is very sensitive to the lens tilt α. When A/f is exactly one, the value of Φ is simply 90° plus one-half of α. This gives the rather curious result that even when a lens is perfectly aligned (axis perpendicular to film, α = 0), the tilt of the plane of sharp focus is 90°. But the hinge line is also an infinite distance from the lens in any direction! So it doesn't really matter.

Another detail needs clarification. We often want to both swing and tilt the lens. Can we use Table 1 to determine the tilt and swing angles independently? The simple answer is "no". For any combination of tilt and swing, the lens is effectively tilted by some angle α which depends upon both the tilt and swing angles in a complicated way. There is one procedure that will work, however. If the swing axis is parallel to the film plane, and the tilt axis is perpendicular to the swing axis, we can do as follows. If we know the lens-to-hinge line distance measured vertically along the swing axis, we can use that distance, and the known focal length of the lens, to determine the tilt angle via Table 1. To set the swing angle we need to know the horizontal lens-to-hinge line distance measured along the PTF plane perpendicular to the swing axis, and the effective focal length of the lens, given the tilt angle. That is, we need to pretend that the focal length of the lens has now changed as described by Table 1 in Part II of this series. We can then use Table 1 of this article (Part IV) to determine the swing angle, using the horizontal distance to the hinge line and the effective focal length of the lens. A bit complicated, perhaps.

Another curiosity. For a normal camera, that is for a camera having its lens axis perpendicular to the film, a lens-to-film distance less than one focal length leads to unsharp results, always. For a view camera, as soon as the lens is tilted even a little bit, it is in principle possible to have something in focus at any lens-to-film distance. You had better have a lens with super covering power to do this for small tilt angles, however.

There is another distance which will be useful later in working with depth of field. This distance is that between the lens and the plane of sharp focus, measured perpendicular to the plane of sharp focus. Figure 6 shows what I mean and gives the formula for determining this distance, D, from the angles α and Φ, and the lens-to-film distance A/f. It is curious that for an ordinary camera several directions and distances coincide with the lens axis. The bore sight, the lens-to-film shortest distance, the lens-to-plane of sharp focus distance and the mean line of sight for the camera all lie along the lens axis. For the view camera these directions are all independent and hence the optical problem is complicated substantially. We have to be very careful when talking

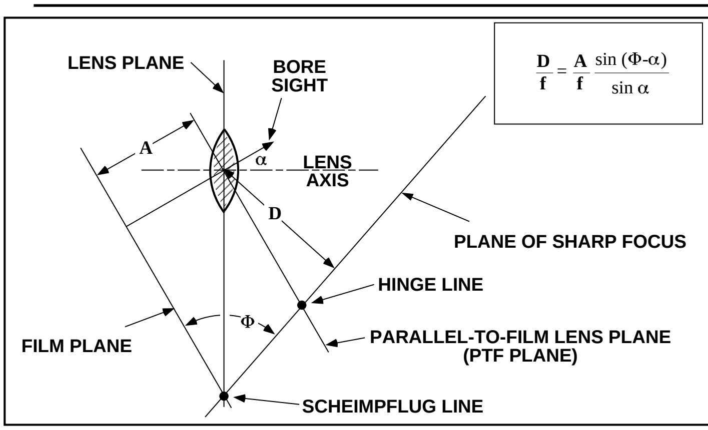

Figure 6: For view cameras, the lens-to-plane of sharp focus distance, D, is not necessarily measured along the lens axis, as it is for 'ordinary' cameras. It is measured in a direction perpendicular to the plane of sharp focus—both for 'ordinary' cameras and for view cameras.

about such things as the lens-to-plane of sharp focus distance. We have to define exactly how it is to be measured. In the case at hand, it must be noted that distance D is NOT the lens-to-plane of sharp focus distance measured along the lens axis, or along the bore sight. It is the distance measured perpendicular to the plane of sharp focus. Incidentally, as α is increased from zero, D stays very nearly constant until Φ is equal to 25° or so. Beyond that, D decreases, eventually reaching a minimum of one focal length.

We now have the tools to work out the depth of field problem for view cameras. Next episode, we'll look at the traditional view of depth-of-field. That is, depth of field for a stated allowable circle of confusion at the film. We'll see such further curiosities as sharpness increasing for objects close to the camera as we focus farther into the scene! This only happens under just the right circumstances, of course.