The Scheimpflug Principle—Part II

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In Part I we examined how the view camera is different from ordinary cameras: the lens axis is not necessarily perpendicular to the film plane. One of the governing optical principles for view cameras is the Scheimpflug Rule which states that the film plane, the lens plane and the plane of sharp focus intersect along a common line. I also tried to whet your appetite for information by asking a number of questions, some of which may have sounded nonsensical. In Part II we'll answer two of the questions: Is every lens a zoom lens? and How does the Scheimpflug Rule work for thick lenses?

Yes, every flat-field lens acts in some respects like a zoom lens. The marked focal length is the focal length of the lens measured along its axis. This also turns out to be the minimum focal length of the lens. A fact of life when working with view cameras is that as soon as the lens is tilted or swung, the effective focal length of the lens changes. Usually, the focal length increases, but as we'll see, it can also seem to decrease. The effect usually means that the photographer may need a shorter lens than he anticipated. For a shot of the interior of a room, for example, based upon format size and the angle of view quoted for lenses of various focal lengths, the photographer might choose a 135 mm lens for his 4 by 5 inch camera. But if he then decides to tilt the lens in order to render sharply some object on a table in the foreground, he will get a surprise. He may need a 90 mm lens to achieve the desired angle of view with the lens tilted.

Figure 1 shows a flat-field lens focused at infinity. Notice that to maintain that flat image plane, the lens has to focus off-axis rays at a greater distance from the lens than for a ray along the axis. The greater the angle between a ray and the lens axis, the greater must be the effective focal length of the lens. There is a simple mathematical relationship, and it is shown in Figure 1 for those who are interested. The Greek letter δ (delta) is used in Figure 1 to represent the angle an off-axis ray makes with the lens axis. The symbol, f, is the focal length of the lens measured along its axis, and f' is the effective focal length at angle δ. Actual values showing the amount by which various focal lengths are increased are provided in Table 1. The table includes results for a 1 mm focal length. The 1 mm focal length allows you to calculate the effect for any other lens. Simply multiply the numbers for the 1 mm lens by the marked focal length of your lens. You will notice that for small angles, there is not much change in apparent focal length, but for a 30° angle, the lens is really acting like a lens of about 15% greater focal length. That typically corresponds to the next longer standard focal length: 75 mm instead of 65 mm, for example.

Since we will be talking about tilting or swinging a lens (or a camera back, independent of the lens) we will need to distinguish between several closely related angles. One is the angle δ which is the angle between a particular ray and the lens axis. Another is the angle by which a lens is tilted or swung. It is convenient to talk about this angle as that between the lens axis and what I will call the bore sight of the camera. The bore sight is a line through the center of the lens but perpendicular to the film plane. Notice I said bore sight of the camera, not of the lens. For an 'ordinary' camera the bore sight and the

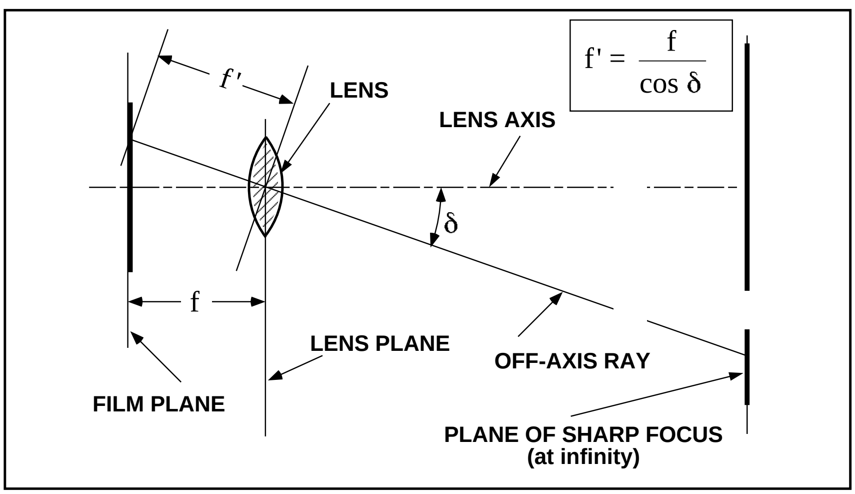

Figure 1: Only along the lens axis is the true focal length of a flat field lens equal to its marked focal length. At other angles, the effective focal length is somewhat longer, as expressed by the formula shown. Examples are given in Table 1.

Tilt Angle (degrees)	FOCAL LENGTH 1	58	65	90	150	210	300
5	1.0038	58.22	65.25	90.34	150.57	210.80	301.15
8	1.0098	58.57	65.64	90.88	151.47	212.06	302.95
12	1.0223	59.30	66.45	92.01	153.35	214.69	306.70
15	1.0353	60.05	67.29	93.17	155.29	217.41	310.58
20	1.0642	61.72	69.17	95.78	159.63	223.48	319.25
25	1.1034	64.00	71.72	99.30	165.51	231.71	331.01
30	1.1547	66.97	75.06	103.92	173.21	242.49	346.41
35	1.2208	70.80	79.35	109.87	183.12	256.36	366.23
40	1.3054	75.71	84.85	117.49	195.81	274.14	391.62
45	1.4142	82.02	91.92	127.28	212.13	296.98	424.26

TABLE 1: Effective Focal Lengths for Tilted Lenses. For focal lengths other than those indicated, multiply the numbers shown for a 1 mm lens by the focal length of your lens.

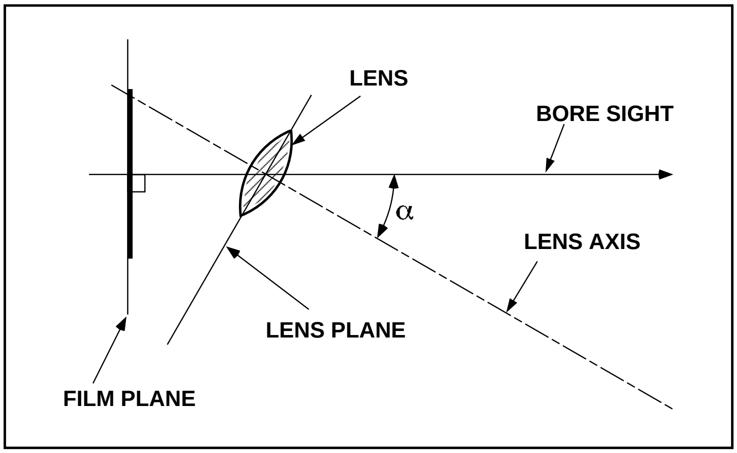

Figure 2: The bore sight of a camera is defined here as a line perpendicular to the film plane and passing through the optical center of the lens. When a view camera lens is tilted or swung, the lens axis and the bore sight are no longer aligned, Instead they intersect at an angle expressed here by the Greek letter a.

lens axis are coincident. For the view camera, when we swing or tilt the lens (or the back), we are causing the lens axis to become misaligned with the bore sight. I will call the angle between the bore sight and the lens axis α (the Greek letter alpha). Figure 2 illustrates this point. We will not be using the angle α right away, but I introduce the idea here so that you can distinguish later between a and d. You can also appreciate, I hope, that when the lens is tilted by an angle α, subjects along the bore sight will be at an off-axis angle, δ, equal to α. It is often the case in view camera photography (where we try to make everything sharp) that subjects located close to the bore sight must be in sharp focus. Thus, any tilting the lens will require an increase in the back focus distance to compensate for the effectively increase in the focal length of the lens, and putting objects near the bore sight back in focus.

Especially when working at close distances, or high magnifications, the effects of lens tilt will become even more noticeable. The reason for this is perhaps most easily explained with the help of Figure 3. Figure 3 shows a simple diagram which solves the fundamental lens equation (shown in the figure); that is, it shows how lens-to-subject and lens-to-image distance are related. For a lens of focal length, f, and for an object a distance D in front of the lens, the lens-to-image distance is found as follows. Mark a point at distance D along the lens-to-object scale. Then draw a straight line from that point through the corner of a square having sides a distance f long. Extend the straight line through until it crosses the lens-to-image scale. This marks the required lens-to-film distance. In the example shown in Figure 3, the distance, D, is four

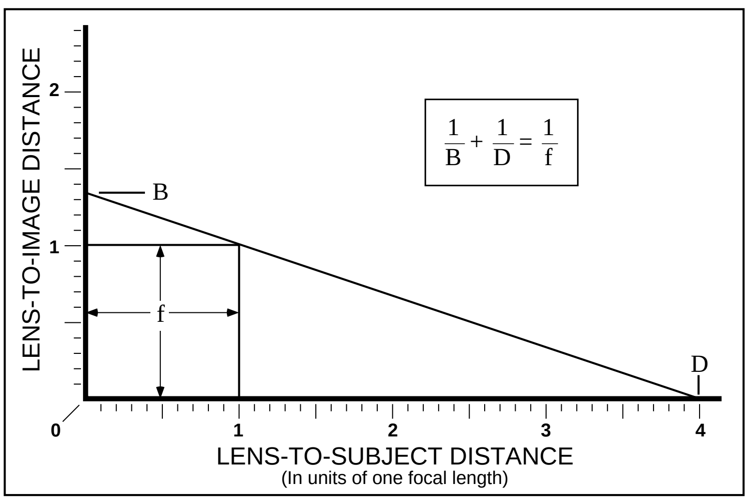

Figure 3: The lens equation relating object distance, image distance and focal length is easily solved with the help of this diagram. Any straight line passing through the top right corner of the square intersects the lens-to-object and lens-to-image scales at points which are valid solutions of the lens equation. An object in front of the lens at distance D will be focused behind the lens at distance B, the back-focus distance.

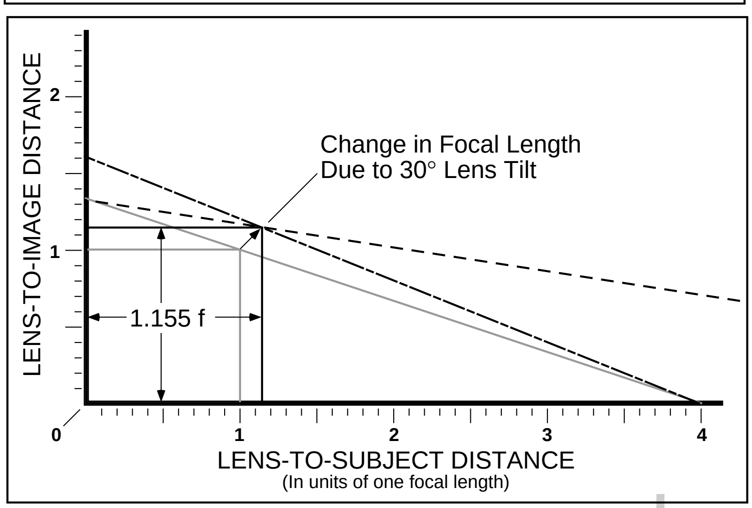

Figure 4: For a lens tilted by 30°, the focal length is effectively increased by 15.5%. If the lens-to-object distance remains unchanged, the image distance must be increased as shown by the dash-dot line. Otherwise, the camera is focused beyond the object, as shown by the dashed line.

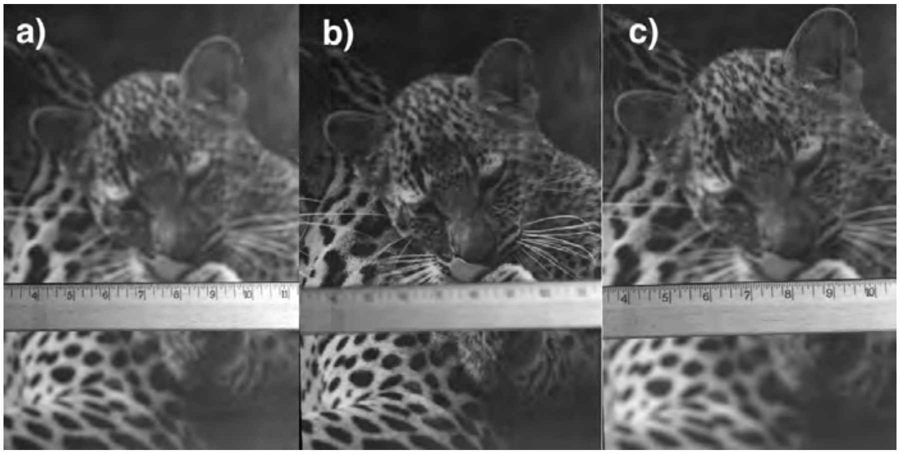

Figure 5: Pictures of a ruler positioned in front of a poster. 5a shows a photo taken with an untilted lens. 5b shows the result of tilting the lens 30° downwards. For Figure 5c the camera back has been extended so as to refocus on the ruler. The image magnification is now 15% larger than before—a result consistent with increasing the focal length of the lens.

times the focal length. The result is that the image distance must be 1.33 focal lengths and the image magnification is thus one-third (Image magnification is equal to B divided by D: 1.33 divided by 4 = 0.33).

In figure 4 the effective focal length has been increased by 15.5%—equivalent to tilting a lens by 30°. The gray lines repeat the conditions described in Figure 3. The black dashed line shows where the lens is now focused if no adjustment is made to the camera back. In this case it is focused beyond the range of our diagram. The dash-dot line shows where the film must be repositioned to focus on the original subject. The back focus distance must be increased by about 20% to do this. And the resultant image magnification has changed to 0.4.

Especially in close-up photography, it will be found that considerable movement of the camera back is required to refocus after the lens has been tilted or swung.

Figure 5 shows an actual example roughly paralleling the conditions described by Figure 4. Figure 5a is the image of a ruler photographed normally at .33 magnification. Behind the ruler is a poster of a mother cheetah and her cub. For Figure 5b I tilted the lens downwards by 30°. Since the effective focal length is increased but the back focus distance has not changed, the camera is now focused on the background. For Figure 5c I refocused using extension of the camera back. You will see that the resulting image is about 15% larger as determined by the ruler. I have effectively zoomed my 9.5 inch Dagor to 11 inches.

The fact that the image of the ruler increased by only 15% instead of the 20% calculated in Figure 4, is due to the fact that the ruler was not originally exactly on the bore sight. The ruler was actually positioned about 5° below the bore sight. Thus when I tilted the lens down by 30°, the effective angle δ for the ruler changed from 5° degrees to 25°. If we recalculate the expected change in magnification for these conditions, we find it should be a 14.5% increase. On the other hand, if I had tilted the lens up by 30° (instead of down), the angle δ would have been 35°, and the image magnification would have been greater than the 20% calculated earlier.

Had I tilted the lens down by only 5°, I would have changed d from 5° to 0°. This would have caused the image magnification to decrease very slightly. In this case I would have shortened the effective focal length of the lens by about one-third of a percent.

Yes, to some extent, every fixed focal length lens is a zoom lens, and the view camera user will discover that fact whenever he tilts or swings his lens. With every tilt or swing of the lens there usually comes a compensating racking to or fro of the

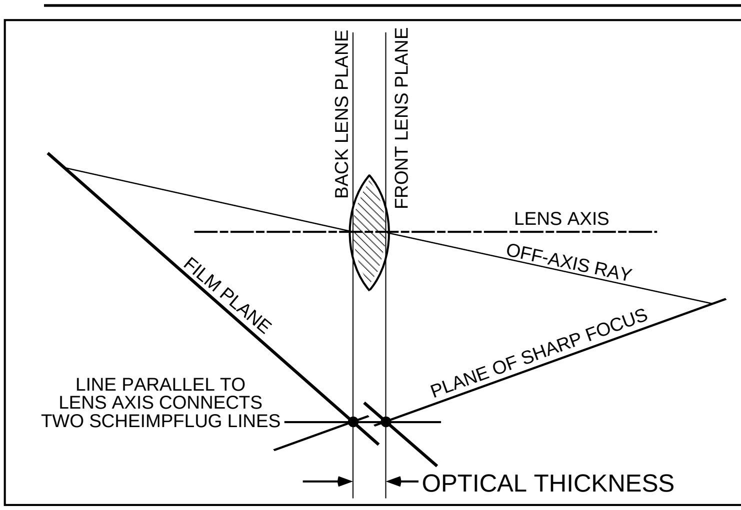

Figure 6: Here we show the relationship of the lens planes, the film plane and the plane of sharp focus for a lens which is "thick". The thick lens has not one lens plane, but two lens planes—a front lens plane and a back lens plane. The two lens planes are separated by the optical thickness of the lens.

camera back. The main point I am trying to make is that swinging or tilting the lens affects focus. It has no effect upon perspective except for the slight change in image magnification which results from the change in effective focal length.

Now for our other problem. I stated in Part I that the Scheimpflug Rule held exactly only for thin, flat-field, rectilinear lenses. But it also holds in slightly modified form for flat-field, rectilinear lenses which are optically thick. And here's how it works. The thick lens effectively has two lens planes. There is a front lens plane passing through the front nodal point of the lens, and a rear lens plane passing through the rear nodal point of the lens. Everything in front of the lens must be referred to the front lens plane, and everything behind the lens must be referred to the back lens plane. A ray passing through the lens effectively passes from the front lens plane to the back lens plane by traveling parallel to the lens axis. A similar story applies for the plane of sharp focus, or an extension of the film plane. Where they pass through the lens planes they effectively travel perpendicular to the lens planes. Figure 6 illustrates.

It is also possible for a lens to have negative thickness. This means that the rear nodal point of the lens is effectively in front of the front nodal point. But again, so long as the nodal point separation is reasonably small (less than a tenth of a focal length or so), the only consequence is that the image on the ground glass shifts a bit as the lens is swung or tilted.

The fact that a lens is optically thick does not usually change things very much. The image shifts a bit on the ground glass as the lens is tilted, and that image shift can easily be corrected if necessary with a shift of the back itself. Only in close-up photography will it normally be necessary to account for these shifts when applying the Scheimpflug Rule.

To summarize Part II, yes, every flat field, rectilinear lens acts something like a zoom lens. The marked focal length of a lens is really its minimum focal length. This is a real effect, and it means that the view camera user will sometimes need a shorter focal length lens than he thought he would. It also means that tilting or swinging a lens has a major impact on focus. It does not affect perspective. We also looked briefly at thick lenses and decided that they don't really change things significantly.

In Part III we'll take a look more closely at perspective. In understanding perspective, a new question will arise: Does every lens act like a pin-hole? Again, the answer is yes, in some ways it does.