Posts to a Thread at the Analog Photography Users Group Forum

"Using hyperfocal distance effectively in the field"

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Hey guys!

I'm kind of late to the party, but I'd like to throw in my two cents...

I contend that the number one reason for disappointment with DoF calculations is the failure to specify an appropriate maximum permissible CoC diameter.

Many DoF calculators, including the aforementioned, clever-at-first-glance, Rodenstock DoF Calculator, only permit the user to specify the "format" of their camera - as if to say that, for any given format, everyone produces the same print dimensions, optimized for the same viewing distances - which is ludicrous.

So... Shame on Rodenstock and every other maker of DoF calculators, software-based or otherwise, that prohibit the user from specifying a maximum permissible CoC diameter of their own choosing - more specifically, a maximum permissible CoC that has been calculated, by the user, to satisfy his or her personal requirements for final image resolution in lp/mm, for an anticipated enlargement factor and viewing distance.

Hint: My requirements for print resolution are likely different from yours or the next person's. My print sizes produced from any given format are likely different from those you or someone else produces. And my willingness to assume that no one will stand any closer than a given distance from my prints could be different than the requirements you might impose in this regard.

Let's start by throwing away that Rodenstock calculator and any other DoF tool, including the DoF scales engraved on lens barrels, that FORCE you to use the designer's choice of maximum permissible CoC diameter for any given format.

I think, at this point, we can all agree it's foolish to assume that any single CoC diameter can satisfy every possible combination of desired print resolution, enlargement factor and viewing distance, for any given format, in the hands of multiple users having different requirements.

So: Use a DoF calculator that allows YOU to specify a maximum permissible CoC diameter YOU have calculated to satisfy YOUR requirements.

To calculate the Maximum Permissible CoC diameter to be used in your DoF calculations:

Max. Permissible CoC Diameter (mm) = anticipated viewing distance (cm) / desired final image resolution (lp/mm) for a 25cm viewing distance / anticipated enlargement factor / 25

Source: https://en.wikipedia.org/wiki/Circle_of_confusion

It is generally agreed that healthy human eyes can resolve at least 8 lp/mm when viewing a high contrast target at a viewing distance of 25cm (9.84 inches). This equates to an angular resolution of 0.86 arcminutes (86/100ths of 1/60th of 1 degree of azimuth or inclination). This is the generally agreed limit of human acuity.

(THX uses a rounded-up figure of 1.0 arc-minute instead of 0.86 arc-minute, in performing their recommended calculations for home theater viewing distances relative to screen resolutions. 1.0 arc-minute equates to a less demanding resolution goal of 6.88 lp/mm in a target viewed at 25cm.)

To employ the equation provided above, it's up to YOU to select and specify a desired print resolution that would be appropriate for a 25cm viewing distance. It's actually your privilege to do so.

Note that most "pro lab" digital prints of significant size are produced with digital image densities as low as 150 dpi (not to be confused with the much higher ppi of inkjet droplets (i.e. 1440 or 2880 ppi). I realize I'm departing from analog nomenclature, but it's for the sake of helping with selection of a "desired final image resolution (lp/mm) for a 25cm viewing distance." And besides, this comes into play, whether we like it or not, when scanning our analog chromes to produce digital prints.

At the moment, I just want to convey that an image density of 150 dpi equates to a 3 lp/mm print resolution. That will be found to convey plenty of detail, by most people, at a viewing distance of 50cm (about 20 inches), but not at a viewing distance of 25cm, for healthy or corrected vision that can actually focus that closely. 3 lp/mm is less than half the 8 lp/mm limit of human acuity at a viewing distance of 25cm.

Truly, most people have never laid eyes on a print that delivers even 5 lp/mm worth of true subject detail. Such prints are RARE, as there are several obstacles that must be consciously, willfully, deliberately overcome, with excellent planning and technique. The variables that must be controlled are finite in number and they actually can be controlled. The question becomes: "Do you have sufficient desire, passion and self-discipline to control these variables - in addition to using the best optics, a good tripod, ensuring film flatness, avoiding camera and subject motion, using mirror lockup with SLRs or DSLRs, etc.?"

Anyway, I recommend you start out calculating your CoCs for a fairly aggressive goal of 5 lp/mm in a print viewed at 25cm. You can always adjust this "throttle" later, if you find you are personally willing to secure lower resolutions in your prints. It's your choice, but whatever you desire in the way of a final print resolution, you have to be REALISTIC in terms of what your camera system can record on film (or at the sensor), prior to enlargement to your anticipated print size.

A post-enlargement goal of 5 lp/mm equates to securing a minimum of 30 lp/mm at the film or sensor plane, even in the corners of the frame, prior to suffering a 6x enlargement factor. I'll leave it to the reader to work that out, but the point is, your maximum possible enlargement factor is ultimately determined by the resolving power of your camera system, not by your DESIRED final print resolution.

For the best color films and lenses, it's generally best to assume a maximum resolution of no better than 32 lp/mm in the corners. Higher resolutions are possible at the center of the frame [especially at the PSF (Plane of Sharpest Focus)]. But again, I'll leave this determination to the reader.

For digital sensors, the math is a little less ambiguous. Consider these steps for determining the maximum print size you can produce from a given CMOS sensor [assuming lens performance is not a limiting factor]**:**

1) Select your desired print resolution. Again, it's your choice, not mine, but let's assume you want to go with 5 lp/mm, for example.

2) Multiply your desired print resolution by 72 to calculate the minimum number of CMOS pixels required per linear inch of print dimension. But for the losses caused by the AA filter and RGBG Bayer algorithm, you could multiply your desired print resolution by 50.8, as each line in a line pair could be resolved by one pixel and there are 25.4mm to an inch. But we have to take into account the 30% loss of resolution suffered by CMOS sensors. So... for 5 (actual) line pairs per millimeter of desired print resolution, your sensor will have to deliver 5 * 72 pixels = 360 dpi. Meaning, you would select an image resolution of 360 dpi, without resampling, when resizing the image for print output (if you are to achieve a desired resolution of 5 lp/mm), independent of your printer's droplet density of 1440 or 2880 ppi, for example.

[Note that CCD sensors and CMOS sensors lacking AA filters can deliver actual resolutions that are closer to the resolutions suggested by their pixel counts – they don't suffer the typical 30% loss of resolution suffered by most CMOS sensors.]

3) Divide the pixel dimensions of your sensor by the dpi calculated in Step 2. For a 4608 x 3456 pixel CMOS sensor (15.9 MP), your realistic maximum print size, to support a desired resolution of 5 lp/mm worth of genuine subject detail, will be (like it or not), only 12.8 x 9.6 inches. [i.e. 4608 pixels / 360 dpi = 12.8 inches] And that's only if you do not crop the capture. (Hint: 16MP is roughly equivalent to using 35mm film.)

If that's too small a print for your tastes, you'll need a [CMOS] **sensor with more pixels -OR- you'll have to reduce your "desired" print resolution, joining the masses of people who can't tell the difference between resolution and acutance, anyway.**

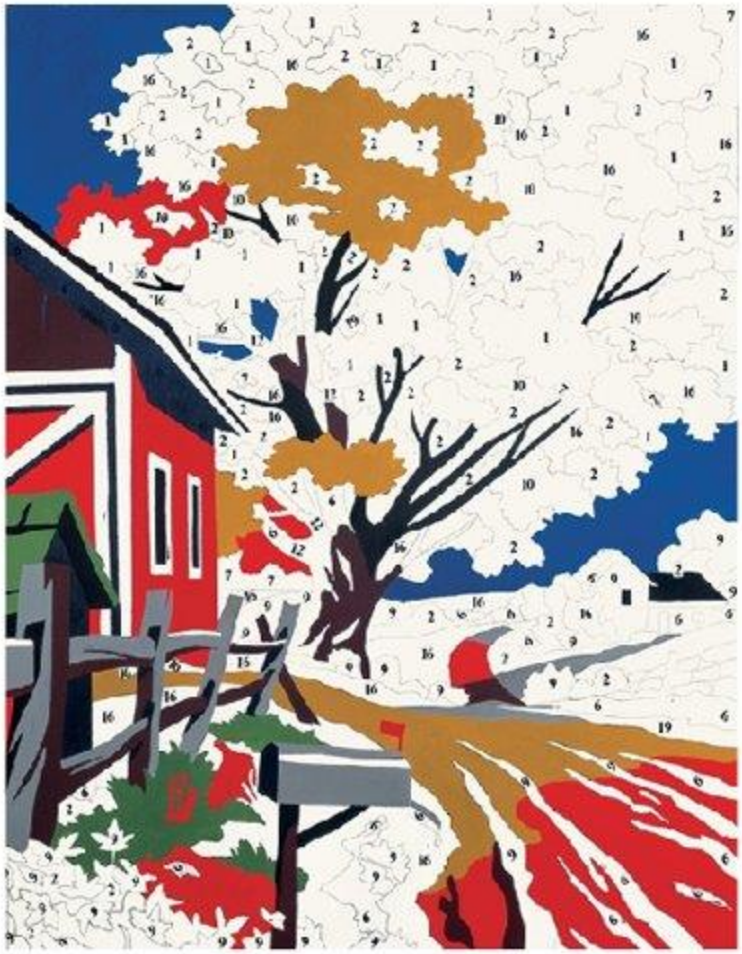
[Resolution equates to recorded subject detail. Acutance equates to edge sharpness, which is often misinterpreted as resolution.

See Sean McHugh's Sharpness tutorial.

Most people are completely content to look at a low-resolution print that has high acutance, because they have very little experience looking at prints that are high in both edge sharpness (acutance) AND subject detail (resolution). Look no further than Joe Consumer's contentment with "4k" flatscreen televisions, which deliver less than 9MP, as most owners of "4k" TVs make the mistake of sitting at too great a viewing distance to even resolve the resolution which is displayed.

See my Excel spreadsheet: Ideal Viewing Distances for 16:9 HDTVs.

A low-resolution, high-acutance photographic print is akin to a very carefully executed "paint by numbers" painting, where all of the colors are precisely applied within the boundaries of each cell, but where the painting, by nature of the medium, has very poor detail – making it best viewed at greater distances than would be necessary otherwise.



Andy Warhol's *Paint by Numbers*

(an example of a potentially high acutance at a very low resolution)

Source: https://thelyingtruthofarchitecture.wordpress.com/2010/09/08/andy-warhol-and-the-deep-surface/

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Going back to the CoC equation, let's run an example for 5 lp/mm at 25cm, when the actual viewing distance we hope to satisfy is actually greater, at 50cm, for an anticipated enlargement factor of 13.33:

Max. Permissible CoC Diameter (mm) = anticipated viewing distance (cm) / desired final image resolution (lp/mm) for a 25cm viewing distance / anticipated enlargement factor / 25

Max. Permissible CoC Diameter (mm) = 50 / 5 / 13.33 / 25 = 0.04 mm

Take note that I'm suggesting you select your enlargement factor and viewing distance, on the fly, prior to calculating DoF - i.e. prior to making an exposure. For some people, this is a showstopper. If that's the case, go ahead and do all of your DoF calculations with a maximum permissible CoC diameter that will accommodate your worst-case combination of largest anticpated print dimension and closest viewing distance, combined with whatever print resolution goal you're willing to accommodate.

The sad thing about resigning to such an approach is that you might always find yourself composing for shortened [shallower] subject spaces and/or using larger f-Numbers than necessary, with correspondingly longer exposures, with correspondingly greater risk of camera or subject motion, ALL BECAUSE you are unwilling to adopt on-the-fly calculation of CoC diameters.

I personally consider my choice of print resolution to be carved in stone, so to speak. I will not compromise my personal preference for subject detail secured at my anticipated viewing distance of 25cm. (Hint: It's next to impossible to enforce greater viewing distances, short of erecting a barrier that keeps your audience at bay.) What do you hope to achieve? Make up your mind and stick to it.

With print resolution and viewing distance treated as constants, the enlargement factor variable becomes your friend, as it's the last variable [in the Max. Permissible CoC equation] with which you can exercise some control. If your camera lacks movements, but you want to shoot a really "deep" subject space with a given FL, willfully choosing to make a SMALLER than usual print, PRIOR to performing CoC and DoF calculations, can be very empowering. [For example,] deliberately choosing to make a print that's half as large as what's otherwise possible, effectively gives you two additional stops worth of DoF, without violating your desired print resolution goal for your anticipated minimum viewing distance. (You might also [choose to] make a smaller print to indirectly secure a faster shutter speed, by opening up, with no impact on final print resolution.)

All you have to do is pre-calculate the CoC diameters for the multiple print size/viewing distance combinations you expect you might make. Then, in the field, you can start out calculating DoF with the smallest CoC, the one that equates to your most stressful combination of print size (large) and viewing distance (close). If the resulting f-Number required for sufficient DoF is untenable, either because it's not available on your lens, or more likely, because it would cause diffraction's Airy disk diameters to exceed the CoC diameters (more on this in a moment), or more likely still, because you just can't shoot at the shutter speed required for that f-Number under the prevailing light and ISO rating, then... your choices are to make a smaller print (which allows the use of a larger, less aggressive, maximum permissible CoC diameter), to move the camera farther away from the nearest subject using the same FL (which changes the composition), to go to a shorter FL without moving the camera (which also changes the composition), or get this: DON'T take the shot! That's always an option for someone who treats desired print resolution as a constant that must not be violated.

What's NOT an option, in my opinion, is shooting your desired composition without consideration of these factors. That's what everybody and his kid brother is doing and it's why they end up being disappointed when the Nears or Fars are too soft for their own liking [after enlargement], again, because they ROLLED THE DICE brainlessly, instead of THINKING their way through the image-making process.

I apologize for my dogmatic tone, as I realize this level of CONTROL isn't for everyone, especially for people who are shooting subjects that demand a less deliberate approach for lack of time to setup a shot. It's best suited to control freaks, like me, who are shooting [relatively static] landscapes or architecture, interiors, tabletop, etc.

I use a Bosch GLM700 laser rangefinder for measuring the nearest subject distance that falls within my intended frame and for finding targets on which to focus that [DoF calculators will typically indicate] reside at about 2x that Near distance. I sometimes have to swing the tripod-mounted camera around to focus on a target, that resides *outside the frame,* at [the DoF calculated distance, which is typically 2x the Near distance, when Infinity is included in the frame]. I then return the camera to my original framing, after focusing. Subject distances that lie beyond [my laser rangefinder's] practical maximum range of about 50 meters, don't have to be measured with the accuracy of the Nearest subject in the frame. You can estimate any Far distances that exceed 50 meters, without much impact on DoF calculations. Some people say that, for the purpose of DoF calculations, "Infinity" resides at 200x the FL, but I prefer to always assume an Infinity distance of 10,000 ft. [for landscapes taken with short FLs], as that seems far more reasonable than telling a DoF calculator that the mountains I can see in the distance are only a few hundred inches away!

I've beaten to death the subject of controlling defocus, including aperture selection and focus distance determination, with acknowledgement of and accommodation for enlargement factor, desired print resolution, and viewing distance, but **diffraction gets worse as we stop down to secure greater DoF.**

The f-Number at which diffraction will just begin to inhibit your desired final image resolution, for an anticipated enlargement factor and viewing distance, can be calculated as follows:

Max. Permissible f-Number = Max. Permissible CoC / 0.00135383

Source: http://photo.net/learn/optics/lensTutorial (in the section on diffraction)

Notice, that calculation of both the CoC diameter and the f-Number at which diffraction would begin to inhibit a desired final image resolution are dependent on only two variables: enlargement factor and desired print resolution (which itself incorporates consideration for viewing distance).

Thus, revisiting digital photography for a moment...

It's the higher enlargement factors that can come with like-sized sensors having a higher pixel count that force the use of smaller apertures (smaller Airy disks at the sensor) before magnification, to produce like-resolution prints that will be viewed at the same distance.

If you don't use the extra pixels to make larger prints, you don't have to shoot at a wider aperture to prevent diffraction from inhibiting your desired final image resolution, because there will be no change in the enlargement factor.

If, however, you do use the extra pixels to make larger prints, but you are content [really?] with the assumption that people will increase their viewing distance proportionately, you don't have to shoot at a wider aperture to prevent diffraction from inhibiting your desired final image resolution, because your desired final image resolution will itself have been reduced to the same degree as the enlargement factor (inversely proportional) [assuming you stick to using the aforementioned equation for calculating Max. CoC.]

OK, getting back to analog (or digital) application of the diffraction equation...

Contrary to popular misunderstanding, there is no single f-Number at which diffraction will begin to inhibit a desired print resolution for any given camera.

In other words, there is no single f-Number at which diffraction "becomes a problem" for any camera at ALL combinations of enlargement factor and desired print resolution!

Consider that an image shot for an enormous roadside billboard does not have to be shot with a 10,000 Megapixel camera because the associated viewing distance is typically hundreds of feet. A 24x36-inch print viewed at a distance of 20 inches can similarly appear to have every bit as much subject detail as when the same file is printed to a 12x18-inch print for viewing at half that distance.

Yet somehow, anticipated enlargement factor and specification of the resolution one personally hopes to record in the final print are, more often than not, completely ignored in discussions of aperture selection for controlling either diffraction or defocus.

[Excuse this seemingly arrogant statement, but read any online photography forum and you'll find a nearly universal ignorance prevails when it comes to properly qualifying statements and opinions regarding "acceptable sharpness" and how to achieve it. The most common error I see is that made by pixel-peeping "100% crops" of digital captures to (incorrectly) determine the f-Number at which diffraction begins to take effect – despite the fact that these people might never make prints with enlargement factors as high as the crops they are viewing on their computer monitors, for whatever viewing distances they are using! They then very confidently proclaim that a given camera's sensor demands one never stop down below that single f-Number. Sigh…]

For each CoC you have calculated to accommodate your personal, desired print resolution goal at various combinations of enlargement factor and viewing distance, you MUST calculate the f-Number at which diffraction's Airy disk diameters would begin to exceed your maximum permissible CoC diameters. Securing your desired print resolution when diffraction gets into the picture (pun intended) is actually more complicated than simply ensuring that your Airy disk diameters do not exceed your maximum permissible CoC diameters, but I'm trying to make this easy, believe it or not!

In truth, you are better off shooting closer to the f-Number at which diffraction would begin to inhibit your desired print resolution, than shooting at some smaller f-Number that is calculated as [being only nominally] sufficient to secure adequately small CoC diameters, but doing so always means having to make longer exposures.

In the end, the [more] complicated math required to optimize defocus against diffraction isn't really necessary, if you just pay attention to the results you're getting with a given "desired print resolution," while *religiously* adhering to your DoF calculations, using the appropriate CoC diameters, as already discussed above. If you don't like what you see, you can just increase your "desired print resolution" to start working with smaller CoC diameters, and thus, smaller Airy disks, that will be forced to the same diameter, as long as you don't shoot at f-Numbers exceeding those calculated with this [aforementioned] equation:

Max. Permissible f-Number = Max. Permissible CoC / 0.00135383

OK, I'm spent. Have fun!

Mike

[With cameras having] parallel lens and film planes, as with most roll-film cameras, you can rely on the previously mentioned Bosch GLM700 laser rangefinder to determine the distance from the film plane or sensor to the closest subject in the frame. That becomes your Near distance for DoF calculation. As stated, earlier, Far distances aren't nearly as critical for DoF calculations, so if the Farthest subject resides beyond the effective range of your laser rangefinder (20m for the Bosch unit I recommended), you can just estimate the Far distance.

I'm almost always shooting with short FLs so, this is a reasonable approach that wouldn't work with really long FLs without using two rangefinders - one that's accurate for short distances and another for long distances (i.e. a golfer's [laser] rangefinder, perhaps). Warning: Laser rangefinders made for long distances aren't accurate enough to use for measuring landscape or architecture Nears.

You can then use the laser rangefinder(s) to locate a subject that resides at the focus distance indicated by your DoF calculator. Once you've focused the lens on that target found with the laser rangefinder (even if it's behind you or off to one side of the frame), you can then restore the originally intended composition, without touching the focus, and shoot at the DoF calculator's indicated minimum f-Number to secure sufficient DoF (more specifically, the minimum f-Number to secure CoC diameters no larger than those calculated with the formula I provided - a maximum permissible CoC diameter that takes into account your anticipated enlargement factor and personal print resolution goal (which itself takes into account the closest viewing distance you hope to support).

As long as the DoF calculation doesn't recommend an f-Number that exceeds that indicated by the diffraction equation I provided, or that leaves you compromised for subject motion due to insufficient shutter speed in the prevailing light for your ISO rating, you're good to go. Diffraction's Airy disk diameters will be [made] **equal to or less than your carefully calculated maximum permissible CoC diameter -AND- you'll be shooting at the fastest possible shutter speed with an f-Number that delivers CoC diameters at the Near and Far limits of your subject space that will actually satisfy your desired print resolution. Tada!**

If you can't shoot at the calculated f-Number, you'll have to back away from the Nearest subject and recalculate the DoF, go to a shorter FL and recalculate the DoF, do a combination of both and recalculate the DoF, make the conscious decision to produce a smaller print and recalculate both the CoC and the DoF (this doesn't sit well with most people, but it's a powerful way to increase the range of distances you can capture without compromising a given print resolution goal), or somehow enforce a greater viewing distance and recalculate both your CoC and your DoF. But the LAST thing you should do is what most people do - allow their print resolution goal to be compromised, assuming, of course, they even HAVE a print resolution goal. Most people have never considered working backwards from a stated print resolution goal. Only weirdos like me actually take control of as many variables as possible to consistently achieve a desired print resolution.

Once again, there are many other factors that can prevent a "desired print resolution" - I'm only talking about controlling the spread functions of defocus and diffraction, here [under the ceiling imposed by a camera system’s total resolution, as discussed above].

My approach tightens up the process considerably, for the sake of faster shutter speeds. Stopping down farther than necessary to accommodate imprecise distance estimates and focusing has indeed worked just fine for over 100 years, using the same DoF equations I'm using (I've invented nothing), albeit with greater vulnerability to camera and subject motion, due to unnecessarily longer exposures and, potentially, loss of resolution due to diffraction - not to mention soft Nears and Fars born of nothing more than specifying too large a CoC diameter in the DoF calculations - CoC diameters that ignore actual enlargement factors and viewing distances, much less any specification of a desired minimum print resolution.