Photographer's Aids: A survey*

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Contents

1 Introduction **4**

2 Rodenstock **5**
2.1 Tilt calculation 5
2.2 f-number calculation 7
2.3 Comment 8

3 Focus+, version 1.2 **10**
3.1 Setup 10
3.2 Depth of Field, DOF 11
3.3 Hyperfocal distance 11
3.4 f-number calculation 11
3.5 Conclusion 14

4 Photographe **15**
4.1 Parameters program 15
4.2 DOF Calculator program 15
4.3 Aperture Finder program 18
4.4 Photo Logger 18
4.5 Conclusion 20

5 pCAM **22**
5.1 DOF 22
5.2 f-number calculation 23
5.3 Field of View 23
5.4 Conclusions 25

6 Sushkin Online DOF Plotter **26**

7 Michael Gillett online DOF calculator **27**

8 Simon Walton online DOF calculator **28**

9 Depth of Field 1.0 **29**

10 Schneider Optics tables **30**

11 DFF-1 **31**

12 Michael K. Davis's Not just another depth of field calculator **33**

13 Loyd's C code for DOF **37**

14 Howard Merklinger's books and papers **38**

15 BTZS and ExpoDev **39**
15.1 Introduction . . . 39
15.2 Data entry screen . . . 40
15.3 The Zone System . . . 40
15.4 Input and output . . . 41
15.5 Calculating exposure with reflective meters . . . 43
15.6 Using an incident meter . . . 44
15.7 The constants screen . . . 45
15.8 DOF and Bellows Factors . . . 46
15.9 Conclusion . . . 47

16 Vade Mecum **48**
16.1 What is available . . . 48
16.2 Illustration . . . 49

17 Appendix: Fuzzy numbers **52**

18 Formulas **53**

1 Introduction

There are several devices, tables and programs that may be called "Aids to photographers." The authors offer them as a solution to several practical photographic problems such as DOF and aperture choice. Few authors give the details underling their calculations. Most seem to think that there is no need to do so: which would be understandable if the details had a standard form; but alas they do not, and to this one must add the fact that the authors may err in execution or understanding. One aim of this survey is to tease out the details in order that the Aids may be better used. As part of this, I will check the implementations and comment on the utility of each.

One of the interesting things is the variety of approaches and the different stresses the several authors place on things. Clearly each represents a different approach to the problems, and I am sure all will find kindred spirits somewhere among the readers of this survey. My approach is embodied in Vade Mecum, a suite of programs for several hand held devices, but this may not be to everyone's taste: I do tend to details. I'll try, when I come to it, not to put forward the usual puffery, but to present a brief survey hewing closely to the scheme that I use to survey the other Aids.

Even when authors use the same formulas, they may produce slightly different results. Sometimes this is a numerical problem, but there are two parameters in particular that cause differences: (1) The diameter of the circle of confusion, c. and (2) f-numbers. There are different philosophies about the choice of c, and some unfortunate historical specifications still crop up. For the most part, the differences in the calculations have little practical effect. The f-number scale that we all use is a rounded scale: for example, the f-number which we refer to as f/11 is actually f/11.3. Using 11 in a calculation produces a different result than does 11.3. Most programs take the trouble to translate a user input of f/11 to f/11.3 for internal use; others do not, and thus the answers from the aids will differ slightly.

Several of the aids use the notation f/16 + $\frac{1}{2}$ to refer to the f-number which is one half of the way between f/16 and f/22. In Vade Mecum, I prefer the notation 16_5 which is consistent with the notation used by digital light meters. Both are useful notations.

I give Internet sites in all cases, but since these may change, a backup for many of the Aids is Jon Grepstadt's site at http://home.sol.no/ gjon/depth.htm.

If I err, as being human I tend to do, please let me know. In addition, I would greatly appreciate hearing of any Aid that I have missed, so that I may include it in a future revision.

2 Rodenstock

This calculator is nomographic consisting of plastic disks and cut out windows for setting parameters. It is about 9 cm by 10 cm. It is quite elegant, and comes in an attractive blue pouch. Figure (2) shows the side that is used to calculate lens tilt, and figure (3) shows the side that is used to calculate the f-number. The author is apparently Walter E. Schön. It is distributed by HP Marketing with a list price of $26. Try to obtain it from them directly. They sold me one and took a Visa over the phone. Later, I was informed that their policy is to sell only through photo dealers. I suspect that the left hand does not know what the right hand is doing. The Rodenstock Catalog Number is 260700.

A useful feature, not mentioned in the documentation, is a metric scale and a small hole at the top of the calculator. By placing a pin through the hole and into the bed of a wooden camera, it is possible to measure changes in the positions of a standard. In addition, the calculator may be used with cameras which focus by moving the front lens, except for macro work where the change in the lens position becomes important.

2.1 Tilt calculation

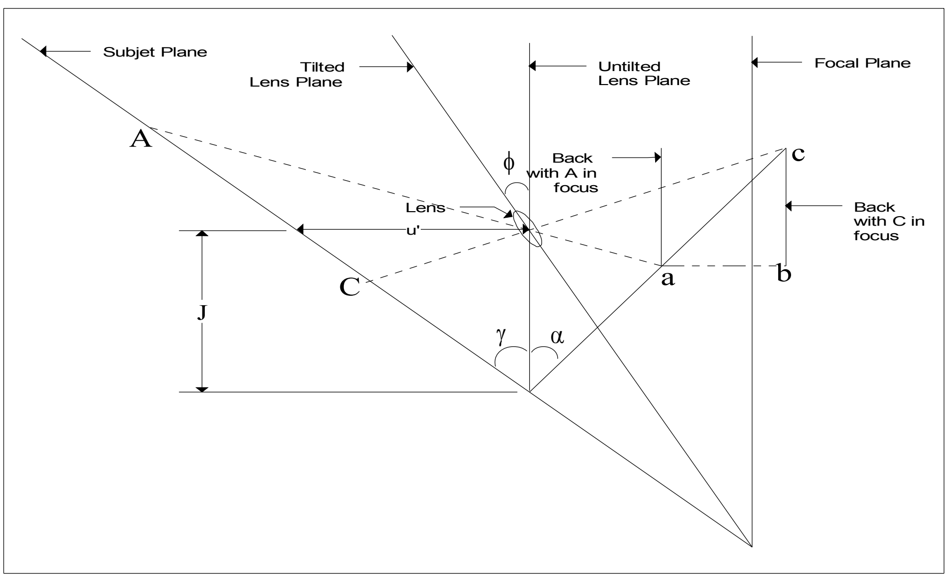


Figure 1: Tilt Diagram

A back focusing procedure[1] is used. Figure (1) shows the situation for a slanted subject plane with two objects A and C. These are successively brought

[1]The front standard may be used to find the *Extension difference*, except for macro distances.

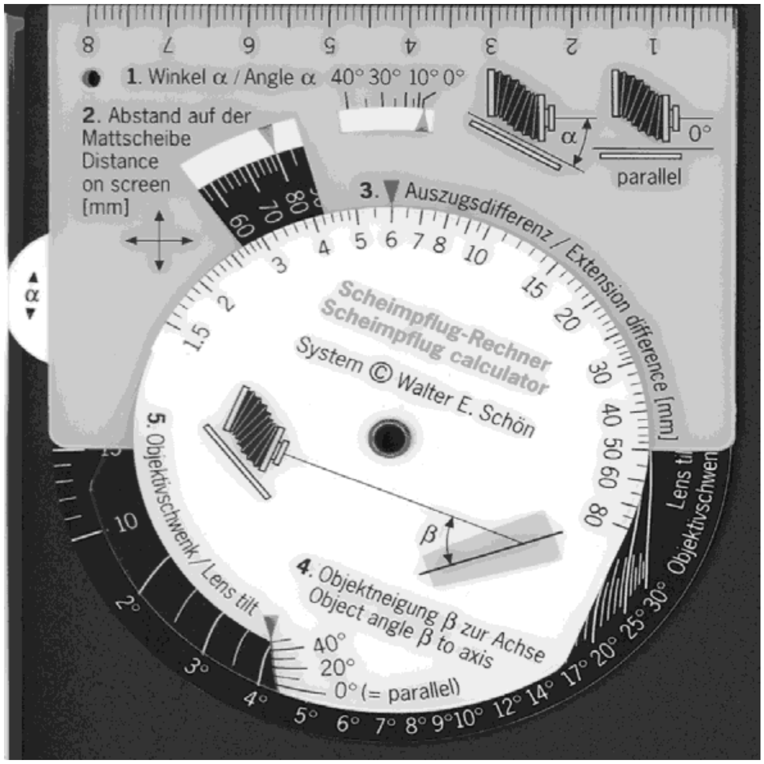


Figure 2: Tilt calculation

into focus by moving the back. The distance $b-a$ is called the *Extension difference* by Schön, and $c-b$ the *Distance on screen*. In figure (2) the *Extension difference* is 6 mm and the *Distance on screen* is 80 mm. From this one may read off the tilt angle at the bottom of the calculator. It is near 4.5°. Wheeler's rule of 60^2 also gives 4.5°.

In practice, nothing else is actually needed to calculate the tilt angle, but Schön has added two things. First he allows adjustment for macro photography by allowing the user to input the angle of the subject plane, β, with respect to the horizontal[3]. The angle β is set at the bottom of the calculator and may be seen to make minor adjustments to the tilt angle. Second, he allows for the fact that sometimes the bed of the camera will not be horizontal when measuring the *Extension distance*. The angle of the bed is *Angle* α at the top of the calculator.

Some may find the adjustment for macro photography awkward to use, since it may be difficult to judge β. The only use of this adjustment is for macro work: otherwise it may be ignored. For macro work it should be possible to measure the distance from the lens to the subject plane at the height of the lens, and

[2] 60(*Extension difference*)/(*Distance on screen*)

[3] $\beta = 90 - \gamma$ in Table (6)

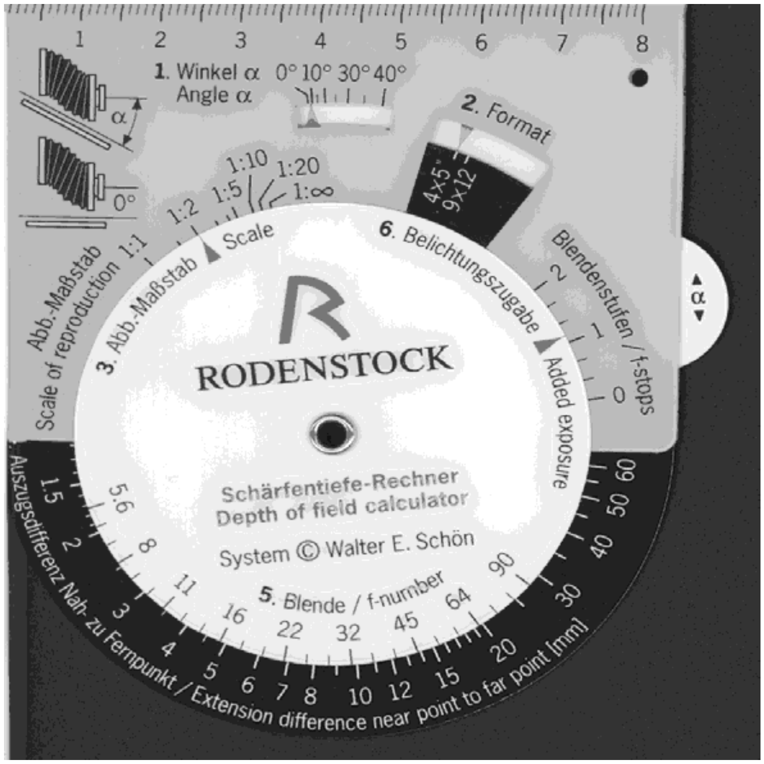


Figure 3: f-number calculation

this with a small amount of calculation will enable β to be determined. As a rule of thumb, take β as approximately equal to 50 times the ratio of the lens height to the subject plane distance. For example, suppose that the horizontal distance from the lens to the plane is 2 m and that the lens is 1 m above the ground, then β is approximately $50(1/2)$ or $25°$. In figure (2) this changes the tilt angle to about $4.2°$.

The basis of Schön's procedure is the second of the two formulas on line 12 of Table (6), which states that the reciprocal of the sine of the tilt angle is equal to the sum of the tangent of β and the ratio of *Distance on screen* to *Extension difference*. This is independent of the focal length of the lens. If however, the focal length is used, then a simpler procedure can be based on the distance between the lens and the subject plane. This is the choice in Vade Mecum which uses the first of the two formulas in line 12 of Table (6).

2.2 f-number calculation

In spite of the words on the face of the calculator, as seen in figure (3), the calculator does not calculate depth of field, DOF. The quantity actually calculated is the f-number required to make two planes in front of the camera, the DOF planes.

As with the tilt calculation, one focuses on two subject points, and measures the *Extension difference* between the two positions of the rear standard. In figure (3), one may read the appropriate f-number from the bottom black dial opposite the Extension difference. An Extension difference of 6 mm, in this case, results in f/16+$\frac{2}{3}$. If f/16+$\frac{2}{3}$ is set on the lens, then the DOF will run from one subject point to the other.

Schön provides several adjustments. He allows for measurements along a sloping bed, as was done for the tilt calculation, and he accommodates several formats. Both are set in the windows in the top part of the calculator. In addition, the bellows factor adjustment, referred to as *Added exposure* is indicated at the right of the calculator, and labeled *f-stops*. The value pointed to is a little over 1 stop, thus the f/16+$\frac{2}{3}$ should be corrected to f/11+$\frac{2}{3}$ to allow for bellows extension[4]. In addition, there is a *scale of reproduction* or magnification dial, which may be used for close-up photography.

The basis for the calculation is the well known geometric optics formula which gives the f-number as the *Extension difference* divided by twice the circle of confusion: the formula is given on line 11 of Table (6). For macro work, one divides the resulting f-number by one plus the magnification. When the lens is tilted, the formula must be corrected slightly to allow for the tilt, but the correction, obtained by multiplying the f-number by the cosine of the tilt angle, has little effect[5], and Schön ignores it.

No doubt, Schön would argue that one can work the calculation backward, starting with the f-number to find the *Extension difference* and then use half of that to locate the two DOF planes by moving the standard and observing the ground glass. This is theoretically possible, but in practice it is quite difficult to locate the in-focus plane on the ground glass. When focusing one ordinarily wiggles the standard slightly to and fro till one finds the best point. This makes use of the eye's ability to detect change: a unique ability not present when the image is viewed as a whole. The procedure described in the previous paragraphs rests on the eye's ability to detect change. The reverse procedure rests on no such substantial foundation since what appears sharp on the ground glass will seldom conform to what appears sharp in a print. Skeptics need only to set up their camera, focus it, and then note that much that is fuzzy on the ground glass is well inside the DOF limits and will appear sharp in a print.

2.3 Comment

This is a well made, inexpensive, useful device which adds no burden to the laden photographer. Its calculations are correct, and the tilt calculation should prove very useful to the large format photographer. The f-number calculation,

[4]The use of this *Added exposure* value is omitted from the documentation.

[5]Even for a large tilt the cosine is near unity. For a 20° tilt the cosine is about 0.93 which changes an f/32 into an f/34, which is a negligible change.

however, is problematical, since the amount of light and degree of subject motion will usually dictate the f-number, and using it to determine DOF will be difficult.

The choice of c is pegged to 0.03 mm for the 35 mm format, and scaled for other formats. Rounding of f-numbers is not a problem.

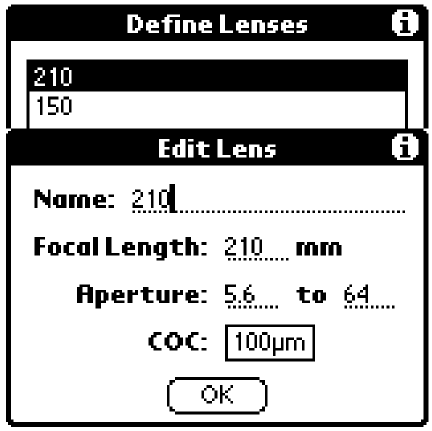


Figure 4: Lens Definition

3 Focus+, version 1.2

This is a program for use on 3Com palm devices. It may be downloaded from http://www.bitwareoz.com/focus.htm or from http://www1.palmpilotgear.com/. It is shareware and priced at $17.95. The latest revision makes it compatible with OS 3.3. The author is Steven Best of Bitware in Australia. It makes a variety of calculations of use to photographers including DOF, hyperfocal, and f-number. It does not deal with tilted lenses.

3.1 Setup

There is a preferences section in which, among other things, the units of measurement may be specified – metric or English.

One may conveniently input descriptions for favorite lenses. Figure (4) shows the dialog for a 210 mm lens used on a 4x5 camera. These are handy, since elsewhere in the program, simply selecting a lens will change the calculations shown on screen. The diameter of the circle of confusion may be input in this dialog by setting a value in the COC box. Best uses μm as a measurement, which is one thousandth of a millimeter, thus 100 μm corresponds to 0.1 mm.

In addition, there is a circle of confusion calculator. Figure (5) shows the calculation for a 4x5 camera. Changing any value results in the instant recalculation of all others. The COC shown assumes that the resulting print will be inspected as closely as possible – at about 25 cm for individuals with normal vision. Usually however, one stands back a bit for larger prints, and the COC can be larger than for close inspection: in general the 8x10 parameters are appropriate.

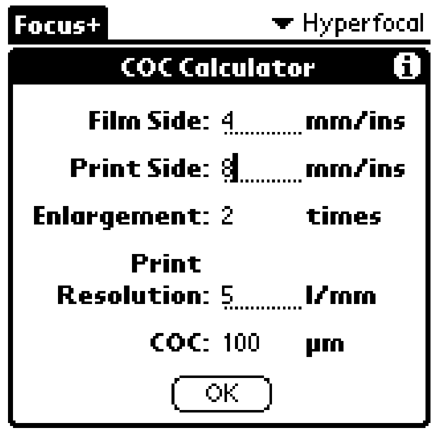


Figure 5: Circle of confusion calculator

3.2 Depth of Field, DOF

Figure (6) shows the DOF output. The values may be displayed at full, half, or third stops by clicking the push button in the lower right hand corner. The distance to the point of focus is shown in the middle, and may be changed by selection. When selected, a pop up window appears, as in Figure (7), allowing the input of a value by clicking on the numbers. The value may also be entered with Graffiti. The lens choice, and the COC may both be changed, and the DOF table will change accordingly. The formulas used are in lines 3 and 4 of Table (6). They apply to all subject distances, although there may not be enough decimals shown for extreme macro distances.

3.3 Hyperfocal distance

The hyperfocal distance display is very similar to the DOF display, and the comments above apply. The screen is shown in Figure (8) and it may be seen that it shows the near DOF limit as well as the hyperfocal distance. The formula from line 1 of Table (6) is used.

3.4 f-number calculation

Figure (9) shows the f-number calculation screen. Near and far values are input, and the program calculates the f-number that will make these the near and far DOF limits. The formula is that in line 10 of Table (6). A handy notation, illustrated in this figure, shows fractional stops. In this case, the appropriate stop is half way between f/32 and f/45. Such stops are only shown if a fraction is chosen in the push button at the lower right hand of the display.

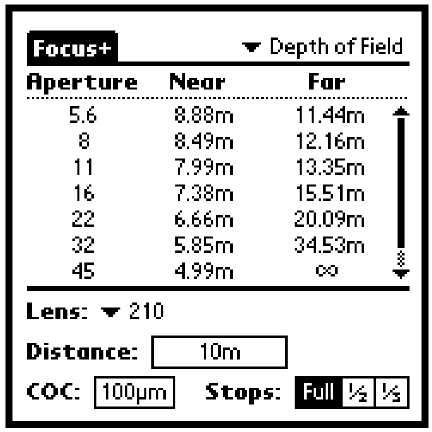


Figure 6: Depth of field

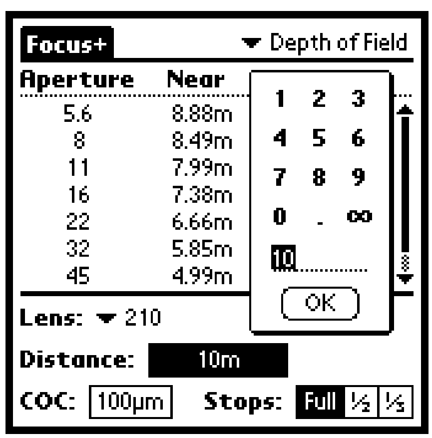


Figure 7: Depth of field with pop up

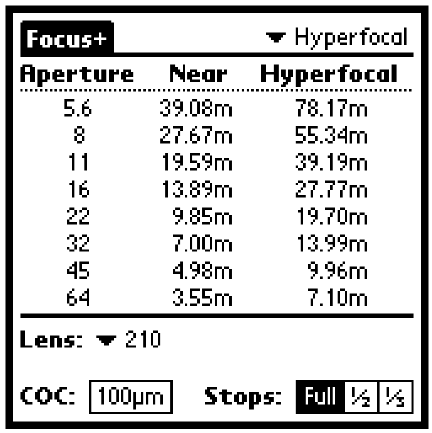


Figure 8: Hyperfocal distance

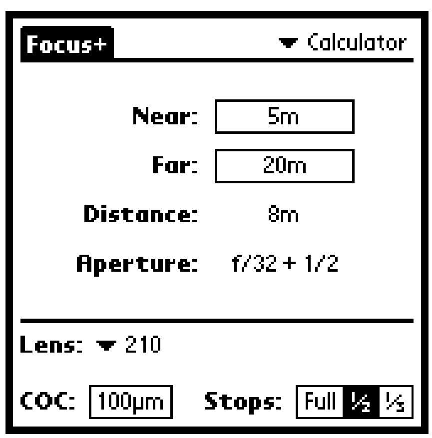


Figure 9: f-number calculation

3.5 Conclusion

The programming is of exceptional quality, and all calculations are correct. The program is extremely useful and most photographers can put it to good use. I am sure that there are some that will buy a 3COM palm device simply in order to use Focus+.

Values of c are basically scaled from 0.03 mm for a 35 mm format, but the user may change them as desired. Rounding of f-numbers is not a problem.

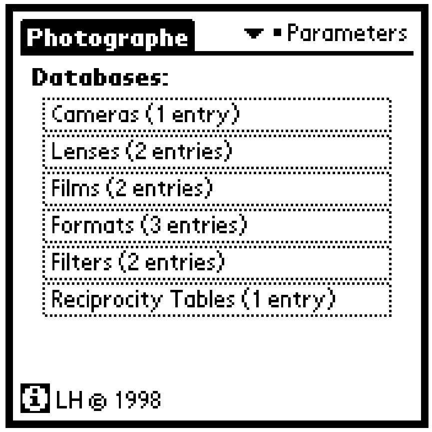


Figure 10: Parameters

4 Photographe

This is a set of programs for use on a 3COM palm device. They are integrated in such a fashion that they may all be accessed from pull down menus in each: i.e., once one has been launched, the others are available from a menu. They may be downloaded from http://www1.palmpilotgear.com/. The author is shy, and only tells us his initials, L.H. In addition, he makes some non-standard calculations for which he offers no documentation or references. Photographe is shareware, and priced at $35 for the set. It has three modules: (1) Sets parameters such as lens and film specifications; (2) Calculates DOF and f-numbers; (3) Saves information about each shot in a log, which can be moved to the PC and printed out. The logging program is more than a simple data sheet, it adjusts exposures for filter factors, bellows extension, and reciprocity.

4.1 Parameters program

Figure (10) shows the *Parameters* screen. Each entry when clicked brings up dialogs allowing the specified type of information to be input. In addition to reminding the photographer of such things as reciprocity factors and filter factors, the information input is used at various places by the other programs when their calculations are made.

4.2 DOF Calculator program

Figure (11) shows the DOF calculation screen. Changing any value in a field will change the DOF limits at the top of the screen. Clicking on the arrows beside the aperture window changes the f-number by the fractional amounts specified for the lens. The f-number input is rounded to the nearest f-stop and fractional stop at which the lens may be set, and this rounded number is used

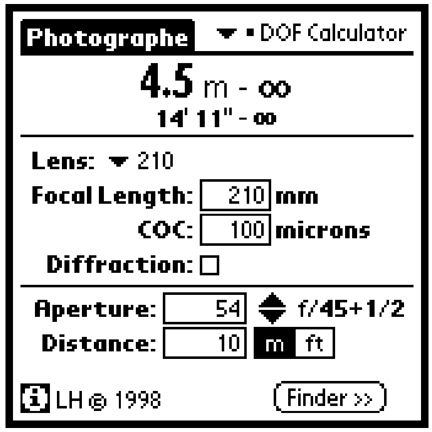


Figure 11: DOF Calculation

in the calculations. This is displayed on the screen at the right of the f-number window.

The calculation appears to use lines 3 and 4 from Table (6).

L.H. has enhanced the calculation in an attempt to allow for diffraction, and this is a questionable procedure. L.H. appears to have been influenced by Peterson (1996) whose idea was to adjust the diameter of the circle of confusion according to the amount of diffraction at the f-number. L.H. does not indicate how this is done in the program, which is a serious error when presenting non-standard material. His procedure appears to produce more reasonable results than Peterson's, but it is difficult to say.

Figure (12) shows the DOF limits with L.H.'s diffraction adjustments. I can get reasonable agreement with this calculation by assuming that L.H. is using a harmonic mean to combine resolutions, but of course, only L.H. knows. I have run tests with real lenses and film under extreme conditions, and have found that the DOF predicted by the formulas in lines 3 and 4 from Table (6) is reliable. This does not mean that L.H.'s adjustments are without merit. They do decrease the DOF slightly, which is the right thing to be doing, but the changes are so small that I cannot distinguish them from predictions by the formulas.

Diffraction is not an important problem, in spite of what many photographers believe: I suspect, too many confuse vibration and other things with it. The greatest diffraction occurs at the largest f-number for a lens, and lens makers are very careful to choose this f-number so that diffraction will have only modest impact even in extreme cases. For example, the case illustrated in Figure (11) is an extreme case. For it the resolution due to diffraction at the DOF limits is 27.3 l/mm[6]. The desired resolution is 10 l/mm since this is a 4x5 camera and the intention is to make an 8x10 print. These combine

[6]lines per millimeter or equivalently line pairs per millimeter

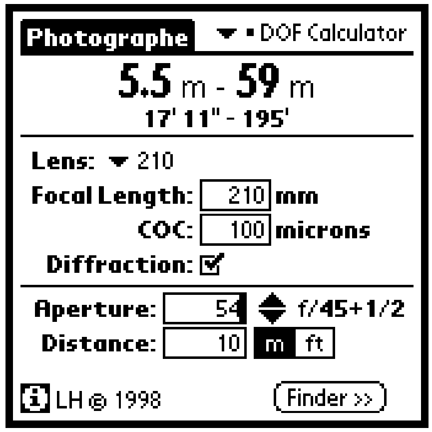


Figure 12: DOF with diffraction

to produce an overall resolution of 9.4 l/mm, which is really quite a negligible change. The normal human eye can resolve about 5 l/mm on a print held at the closest distance of near vision (about 25 cm), and so the DOF limits are chosen to produce resolutions of 5 l/mm at points in the scene corresponding to these limits. Since a 4x5 is enlarged by a factor of two to make an 8x10 print, the film resolution of 10 l/mm becomes 5 l/mm on the print. Allowing for diffraction makes this 4.7 l/mm, which is not practically different from 5 l/mm.

It would be theoretically interesting to adjust the DOF limits to allow for diffraction, and this adjustment should be in the direction of shrinking the DOF, but this is not easy to do. The adjustment depends on how the diffraction resolution is combined with the desired resolution, and there is no simple formula for this, although several empirical formulas appear in the literature. As customarily used, these formulas offer rough guidance in assessing the combined effect of lens and film and other things that affect resolution; and for this purpose they are quite adequate. The problem comes in when an attempt is made to manipulate such formulas. Each will produce a different result, and all are likely to be wrong because the phenomenon depends on the nature of particular lenses, and the formulas apply strictly only to paraxial rays. There are other problems such as the fact that diffraction depends on the wavelength light, and can range from 2/3 to 4/3 of the value calculated for the middle wavelength customarily used.

The upshot is that there is no easy way to adjust DOF for diffraction, and that any DOF calculation should be taken as a rough guide, which is what, I think, is done by most practicing photographers. The correction by L.H. is probably as good as any, but since it makes so little difference, I cannot see bothering.

I would recommend that the *Diffraction* check box be left unchecked.

4.3 Aperture Finder program

The *Aperture finder* may be accessed by a drop down menu or by a toggle at the lower right of the screen. Figure (13) shows the screen set up to find the f-number appropriate for a DOF ranging from 5 m to 30 m.

The calculation is strange. The correct information that should appear at the top of the screen is *8.6 m at f/32* + $\frac{1}{2}$ and not *7 m at f/45* + $\frac{1}{3}$ as it is. Given two DOF limits, the focus should be set at the harmonic mean of the two, which is 8.6 m in this case: see line 9 of Table (6). L.H.'s documentation indicates that he finds this a difficult calculation, apparently requiring iteration. In response to my question to him about this, he indicated that he was adjusting the calculations to use the nearest f-number that could actually be set on the camera. If, say, f/16 + $\frac{2}{5}$ were the calculated result, then L.H. would adjust this to f/16 + $\frac{1}{3}$ if the camera lens were marked in 1/3 stops. If it were marked only in whole stops, it would be adjusted to f/16. The changed f-number might then be used to recalculate the DOF limits. This is what L.H. appears to be doing, but in a strange way.

It is a small matter, since even a half stop will not change a the photograph seriously, but there is no reason why a program should not offer the option if its author feels it important. The program pCAM does it. Unfortunately, L.H. does not tell us what he is doing, and the upshot is that both the f-number and the distance to the subject change in ways the we do not expect.

In addition, a correction for diffraction is offered which has the same problems as before.

A nice feature is found by switching from the *Aperture Finder* to the *DOF Calculator*, where one sees that the focus distance and f-number have been inserted and the appropriate DOF calculated. Unfortunately, the DOF limits are not those that were input to the *Aperture Finder*. Figure (14) shows the DOF screen.

I cannot recommend the calculations from this program without a better explanation of the rationale.

4.4 Photo Logger

The *PhotoLogger* is quite useful. It provides a form in which the conditions of a shot may be recorded, and saves the form as a page in the Note Pad. This form may be moved to the PC and printed in the way one usually does for pages from the Note Pad.

Much of the information about a shot is available from the parameters that were input when the camera, lens, and film was selected, and *PhotoLogger* picks this up and records it on the Note Pad page. In addition, reciprocity, bellows factor, and filter factors are applied to any time-aperture choices, thus minimizing photographic errors: if any such are present, they are shown under the corrected exposure values at the top of the screen. Nothing is done behind the scenes. The parameters are displayed in the middle of the screen. Figure (15) shows the main *PhotoLogger* screen with the *Settings* box in the center. Clicking

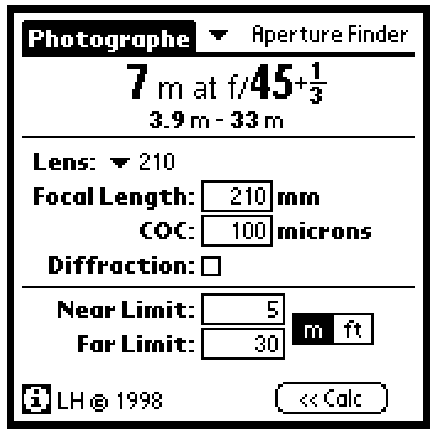


Figure 13: f-number calculation

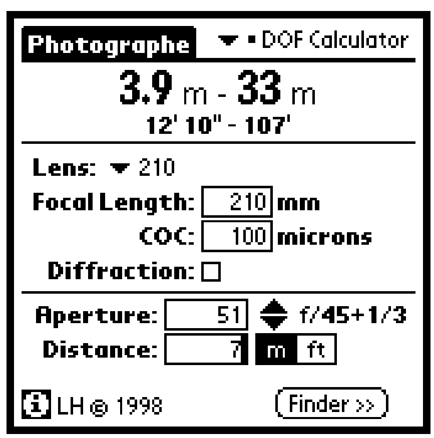


Figure 14: DOF after finding f-number

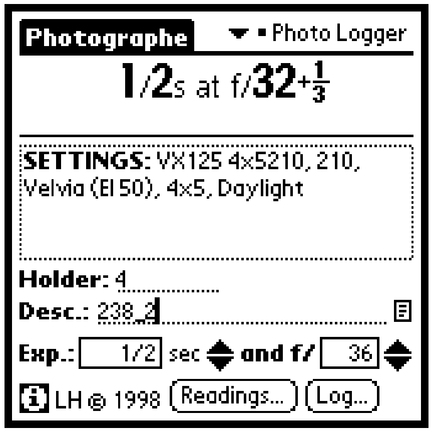


Figure 15: Photo Logger screen

on this box will enable the editing of the parameters for this shot.

Adjustment for the bellows factor is made by clicking on the *Settings* box, and checking a *macro* box which will then bring up a edit field into which the extension (from film to lens) may be input. This is somewhat awkward since the user should be reminded about this most common correction in a more direct fashion. The *PhotoLogger* does not record the distance between lens and subject. This is a serious omission, which were it available would have allowed the program to adjust for the bellows factor automatically. A small flaw in an otherwise useful program.

Subject luminance placement may be recorded by clicking on the *Readings* button. It brings up the record page shown in Figure (16), into which may be entered EV and Zone values. After entering the top two values, other zone values will be calculated for user specified EV values in the *Fall* area by clicking the *Adjust* button. Unfortunately, the fields accept only non-negative input, which may cause problems by those who use different subject luminance methodologies.

Many large format photographers will find that the *PhotoLogger* does not provide for the recording of important information such as tilt angle, shifts and swings, and as mentioned, the distance between subject and lens.

4.5 Conclusion

This is a skillfully made program. The overall idea is quite good. Unfortunately, L.H. the author, has used non-standard procedures that produce unexpected results. The procedures are not documented. He is to be commended for trying to make a photographer's life easy, but unfortunately, I cannot recommend the *Aperture Finder* program. The *Photo Logger* and the *DOF calculation* are both useful: one should make up one's own mind about the *Diffraction* check box, preferably by running tests.

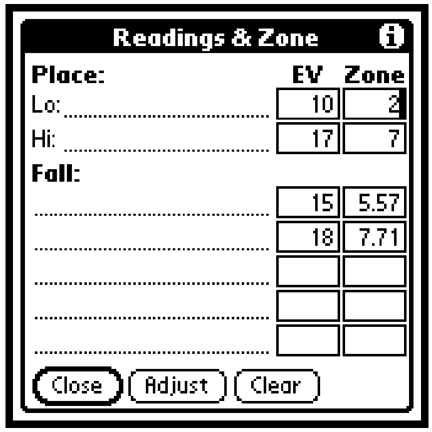


Figure 16: Subject luminances

Values of c are specified by the user for each format. Rounding of f-numbers is not a problem.

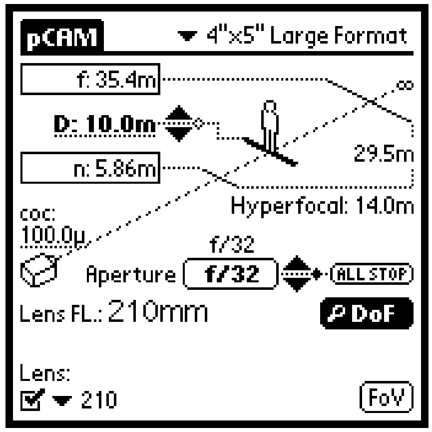


Figure 17: The DOF screen

5 pCAM

This is a program for use on 3Com palm devices. It may be downloaded from http://www1.palmpilotgear.com/. It is shareware and priced at $15. It is authored by Dian Suharto Iskandar who credits David Eubank for the technical details. It is designed for use by cinematographers, CCTV, and photographers, and calculates DOF limits and f-numbers as do Focus+ and other programs. In addition it has a section for field of view calculations, of primary interest to CCTV and cinematographers. It is extremely well done. The program requires several other programs to function, which means that extra memory needs to be allocated. These extra programs are included in the package.

5.1 DOF

Figure (17) shows the DOF screen. It is almost self explanatory. I think that the formulas being used are those in lines 5 and 6 of Table (6), but I am not quite sure apparently due to small numerical errors in the calculation. The formula in line 1 of Table (6) is used for the hyperfocal distance. The near and far limits which pCam calculates in figure (17) should be 5.85 m and 34.53 m. This is not much of a difference and of course makes no difference in practice, except for macro work, where the DOF limits should not be relied upon.

In any case the display shows the near and far DOF limits, the distance to the point of focus, the hyperfocal distance, and the DOF all in a very intuitive visual display. The values change automatically as the f-number is changed. It may be changed with Graffiti or by clicking the arrows beside the f-number box. Each click changes the f-number by the fractional stops chosen at the right of the arrows: the choices are (1) full stops, (2) half stops, or (3) third and half stops.

At the top right hand of the screen may be seen a format specification. A

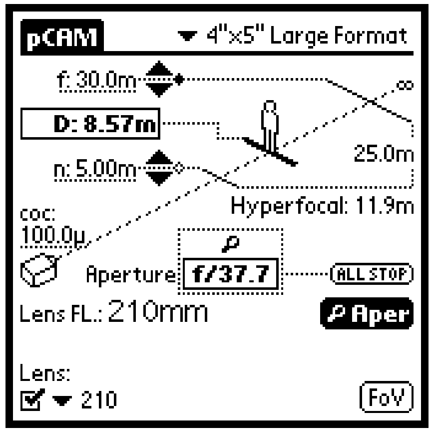


Figure 18: The f-number screen

drop down list allows a choice of others. The latest version of the program includes support for large format photography. The authors express CoC in microns, μ, which is the same as μm used in Focus+.

5.2 f-number calculation

By clicking on the darkened button, it will change to *Aper* and the f-number may be found by setting the near and far DOF limits. Figure (18) shows the screen in which the near and far limits are set to 5 m and 30 m respectively. The resulting f-number is f/37.63 or f/38 when rounded. The focus distance of 8.571 m is correctly calculated by line 9 of Table (6). Note that the hyperfocal distance has changed: this is an error, and a serious one.

When the f-number box is clicked, f/32+$\frac{1}{2}$ appears. This is the nearest actual setting on the camera to f/37.7. The DOF limits are recalculated for this setting. The differences are too small to matter. I fail to see the need for the calculation if for no other reason than that one cannot usually measure the distances precisely enough to discriminate between the two sets of DOF limits; however, this is a personal opinion, and others may well find it useful.

5.3 Field of View

A field of view calculation may be accessed by clicking on the FOV icon. Figure (20) shows the calculation. Either the subject distance or the subject size may be changed and the other parameters adjust automatically. The program apparently takes 4" by 5" as the actual size of 4x5 film. The calculations that I checked seem to be correct.

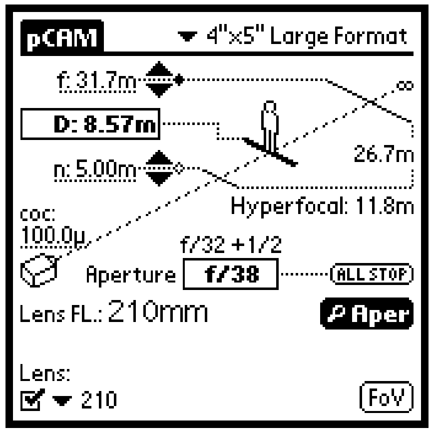


Figure 19: The f-number screen after clicking f/37.7

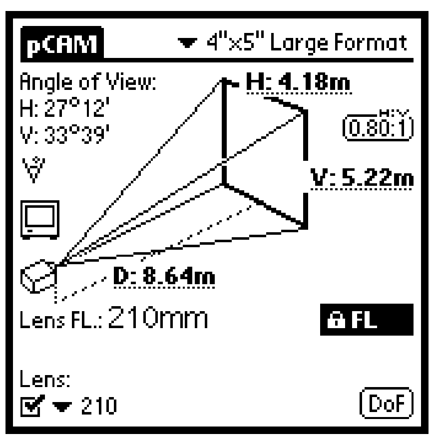


Figure 20: The Field of view screen.

5.4 Conclusions

A nicely done program that should be of use to photographers. The graphical display is quite elegant. It uses approximate formulas and there seem to be errors in its implementation, but except for the hyperfocal distance, the most part the discrepancies are of no practical importance.

Values of c are basically scaled from 0.03 mm for a 35 mm format, but the user may change them as desired. Rounding of f-numbers is not a problem. The author has indicated that he will be adding support for large formats.

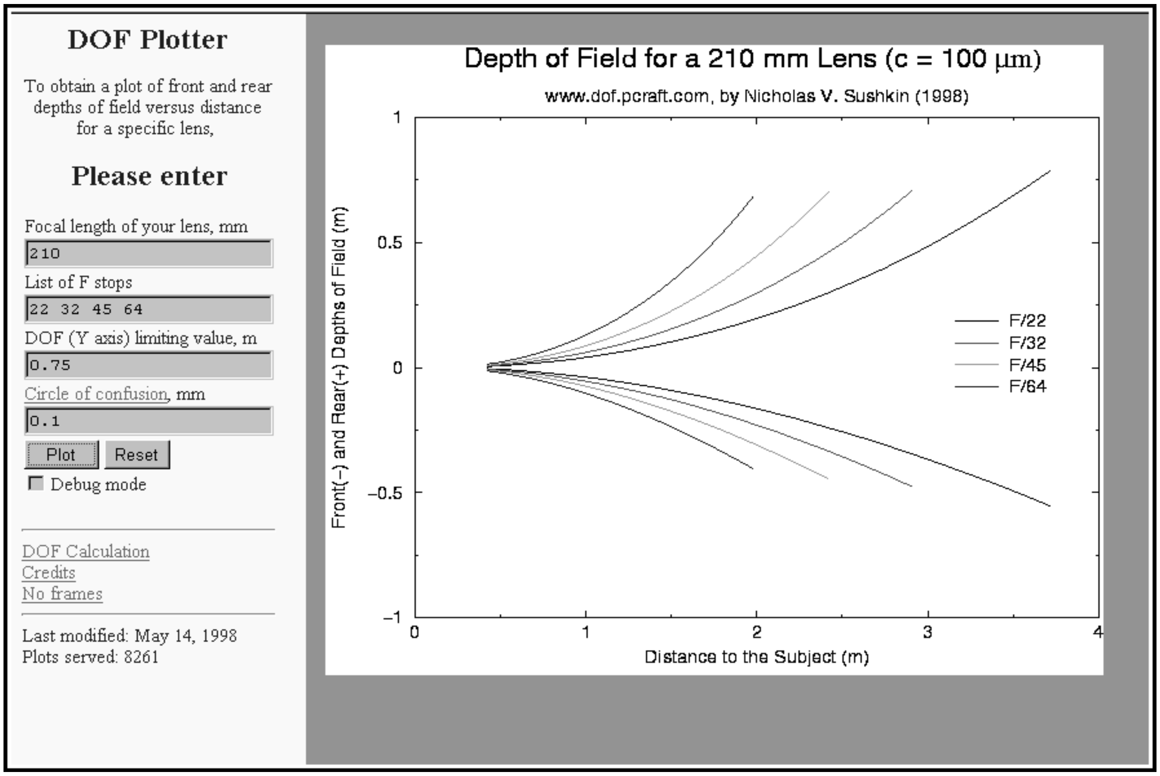


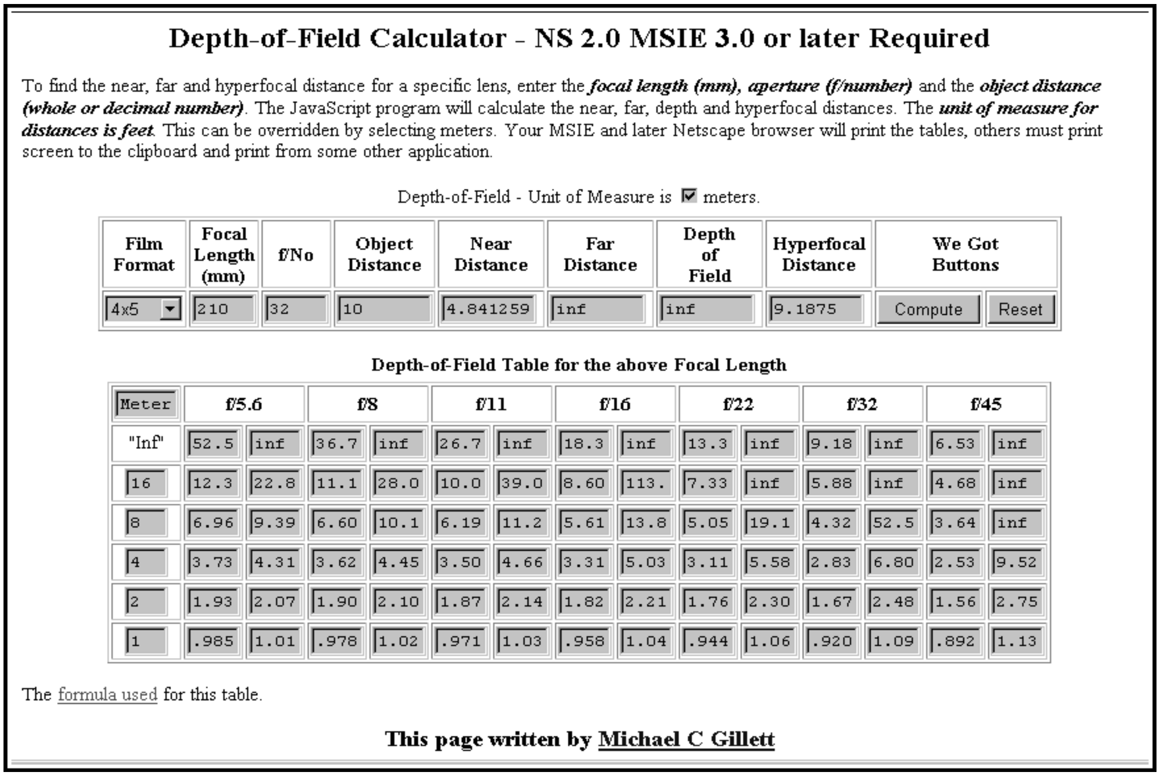
Figure 21: The Plot screen

6 Sushkin Online DOF Plotter

This is an online DOF plotter available at http://www.dof.pcraft.com/. Its author is Nicholas V. Sushkin. It calculates DOF and produces a graph of the FrontDOF and BackDOF values, given in lines 7 and 8 of Table (6). Figure 21 shows the curves for a 210 lens on a 4x5 camera. As many curves are drawn as are specified on the main screen: they are in color on the monitor.

Sushkin gives the derivation of the equations in lines 7 and 8 of Table (6).

The value of c is input by the user. It is not clear whether or not correct rounding is done for f-numbers, since the graphs may not be read that finely. This is not a defect, since the distinction is of little practical interest.



Depth-of-Field Calculator - NS 2.0 MSIE 3.0 or later Required

To find the near, far and hyperfocal distance for a specific lens, enter the ***focal length (mm), aperture (f/number)*** and the ***object distance (whole or decimal number)***. The JavaScript program will calculate the near, far, depth and hyperfocal distances. The ***unit of measure for distances is feet***. This can be overridden by selecting meters. Your MSIE and later Netscape browser will print the tables, others must print screen to the clipboard and print from some other application.

Depth-of-Field - Unit of Measure is ☑ meters.

Film Format	Focal Length (mm)	f/No	Object Distance	Near Distance	Far Distance	Depth of Field	Hyperfocal Distance	We Got Buttons	
4x5	210	32	10	4.841259	inf	inf	9.1875	Compute	Reset

Depth-of-Field Table for the above Focal Length

Meter	f/5.6		f/8		f/11		f/16		f/22		f/32		f/45	
"Inf"	52.5	inf	36.7	inf	26.7	inf	18.3	inf	13.3	inf	9.18	inf	6.53	inf
16	12.3	22.8	11.1	28.0	10.0	39.0	8.60	113.	7.33	inf	5.88	inf	4.68	inf
8	6.96	9.39	6.60	10.1	6.19	11.2	5.61	13.8	5.05	19.1	4.32	52.5	3.64	inf
4	3.73	4.31	3.62	4.45	3.50	4.66	3.31	5.03	3.11	5.58	2.83	6.80	2.53	9.52
2	1.93	2.07	1.90	2.10	1.87	2.14	1.82	2.21	1.76	2.30	1.67	2.48	1.56	2.75
1	.985	1.01	.978	1.02	.971	1.03	.958	1.04	.944	1.06	.920	1.09	.892	1.13

The formula used for this table.

This page written by Michael C Gillett

Figure 22: The DOF calculator

7 Michael Gillett online DOF calculator

This is available from http://www.syspac.com/ gillettm/DOF.html or alternately from http://www.worldphoto.com/depthof.htm.

Figure (22) shows the calculator. Once the values are filled in, the results are calculated by pressing the *Compute* button. Gillett shows the formulas that he uses: They are lines 5 and 6 from Table (6). This calculator will be slightly in error for macro work because of the approximate formulas.

The value of c is fixed to the format size, and although it starts with 0.03 for a 35 mm format, it uses larger than usual values for other formats – 0.15 mm for 4x5. It makes no attempt to correct f-numbers for rounding.

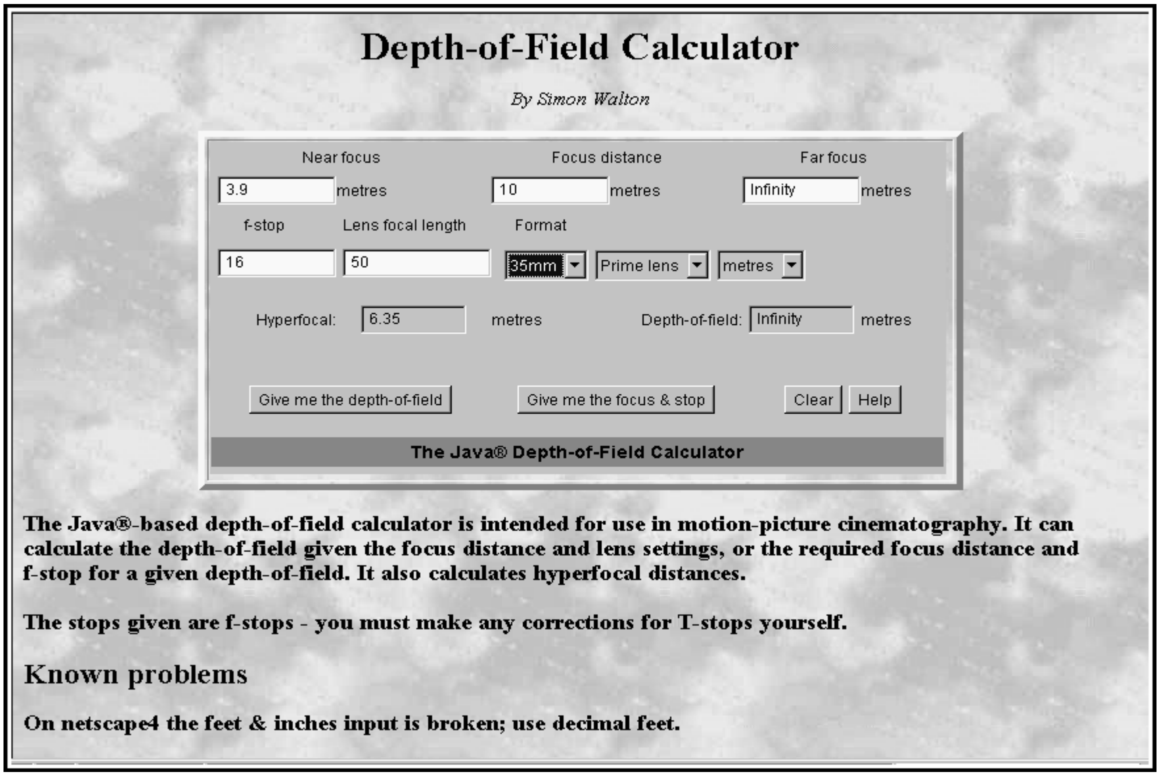


Figure 23: The DOF calculator

8 Simon Walton online DOF calculator

This is available from http://www.cs.ucla.edu/ simonw/DoF/.

Figure (23) shows the calculator. It applies only to 16 and 35 mm formats. The value of c is 0.025. It makes no attempt to correct for f-number rounding. It appears to use the formulas from lines 5 and 6 of Table (6), and probably uses line 2 rather than line 1 in Table (6) .

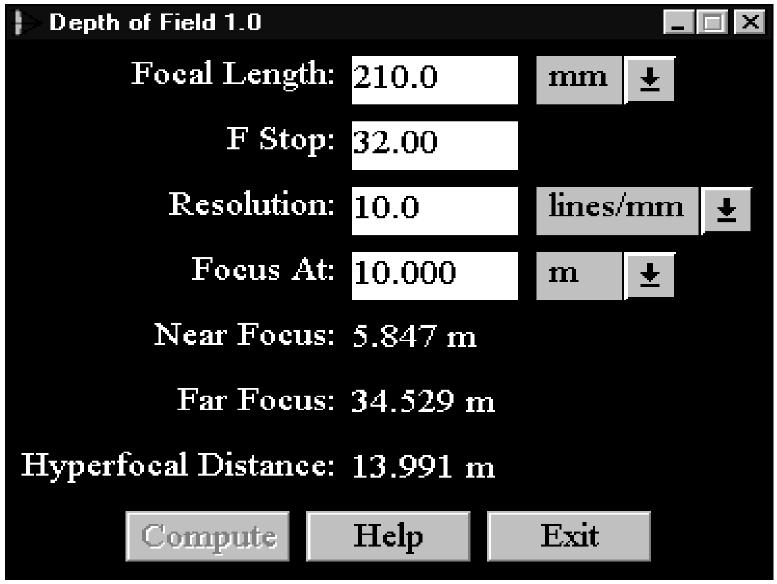


Figure 24: DOF program

9 Depth of Field 1.0

This is a program running under both DOS and Windows. It may be downloaded from http://www.dl-c.com/dl.html. Jonathan M. Sachs is the author. Figure (24) shows the calculator. Filling in the white boxes and pressing the *Computer* button produces the near and far DOF values and the hyperfocal distance. The calculations are correct and Sachs gives his formulas: they are lines 1, 3, and 4 in Table (6). The only white box that may cause pause, is the one for resolution. He intends that this should hold the on-film resolution which is the reciprocal of the circle of confusion desired.

He makes two fluffs in his documentation:

(1) He says, "Note: enter the f stop as marked on the lens – do not attempt to correct for any extension due to macro focusing as this is already taken into account by the formulas used to compute the depth of field." which is not correct. Adjusting the f-number for bellows extension, changes the DOF, and if one needs to know the correct values, then they should be recalculated using the bellows adjusted f-number.

(2) He says, "Some film manufacturers have begun rating their film's resolution by publishing an MTF curve instead of listing lines per mm. You can infer the resolution in lines per mm for high contrast subjects by looking at where the MTF curve drops to about 20%." This is a typo. He meant to say low contrast.

The program makes no adjustment for f-number rounding.

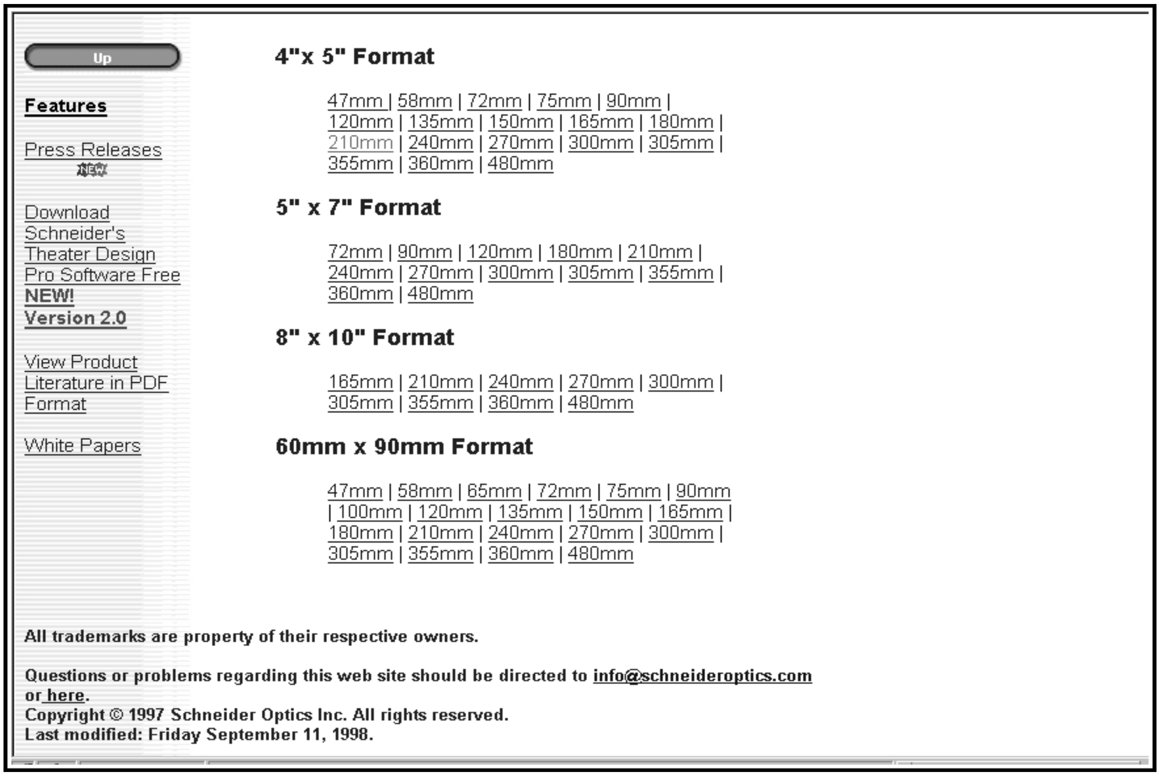


Figure 25: Schneider DOF index

10 Schneider Optics tables

These are on line tables giving hyperfocal distances, and DOF limits in feet for a large number of focal lengths and medium and large formats. They are available at http://www.schneideroptics.com/large/depth/depthof.htm. An index of the lenses and formats is shown as Figure (25). They are calculated using lines 5 and 6 from Table (6), which are not completely accurate for macro photography. They seem to use $c = 0.075$ mm for 6x9, $c = 0.1$ mm for 4x5, about $c = 0.145$ mm for 5x7, and $c = 0.2$ mm for 8x10.

The program makes no adjustment for f-number rounding.

11 DFF-1

This is a 20 inch ruler with a plastic slider, in appearance not unlike a slide rule. The author is apparently Jim Egan. The finder may be obtained from B&H for $29. It may be used for 4x5 cameras only. Measurements are in feet and inches.

The finder imitates the DOF scales found on medium and small format prime lenses. Figure (26) shows parts of the two sides set up for a 150 mm lens with a 10 foot lens to subject distance. As may be seen on side B, the slider has vertical lines indicating the DOF limits about the focus distance, just as on lens barrels. The distance scales on small cameras are such as to show the lens to subject distance corresponding to a given lens extension. The same thing is done on the finder.

Side B is simply a magnification and alignment of side A, making it easier to read some of the tightly packed values. The slider on side A could also have been marked with vertical lines, but they would have been quite close together. The nomogram is constructed by using the Gaussian lens equation.

To use the finder, the ground glass to lens extension is measured. The diagram on side A shows how this is done. The value under the line on the side A slider in the appropriate focal length row will then be the lens to subject distance. In Figure (26) it may be seen that 10 feet appears under the line in the 150 mm row on side A, and so the lens is focused at 10 feet.

Transferring this 10 feet to side B, shows that the DOF runs from about 7 feet to 17 feet for f/32.

The hyperfocal distance for f/32 may be read by aligning the upper f/32 line on the slide with infinity.

The rear nodal plane of the lens is needed for the measurement describe by Egan. He suggests focusing on infinity, measuring one focal length in front of the ground glass, and marking the lens at that point. An alternate procedure is to first focus on infinity, and then measure the extension difference as the focus is moved to the subject. Set the slide this far to the left of the infinity symbol, on side A to get the lens to subject distance. The advantage of this is that one may use arbitrary marks on the standards instead of the precise location of the film and nodal planes.

The finder is bulky and liable to misuse. I find it easy to confuse inches with feet because the author uses apostrophes to denote the units, and it is quite easy to read values using the wrong focal length on the slider.

The value of c is 0.004 inches, or about 0.1 mm.

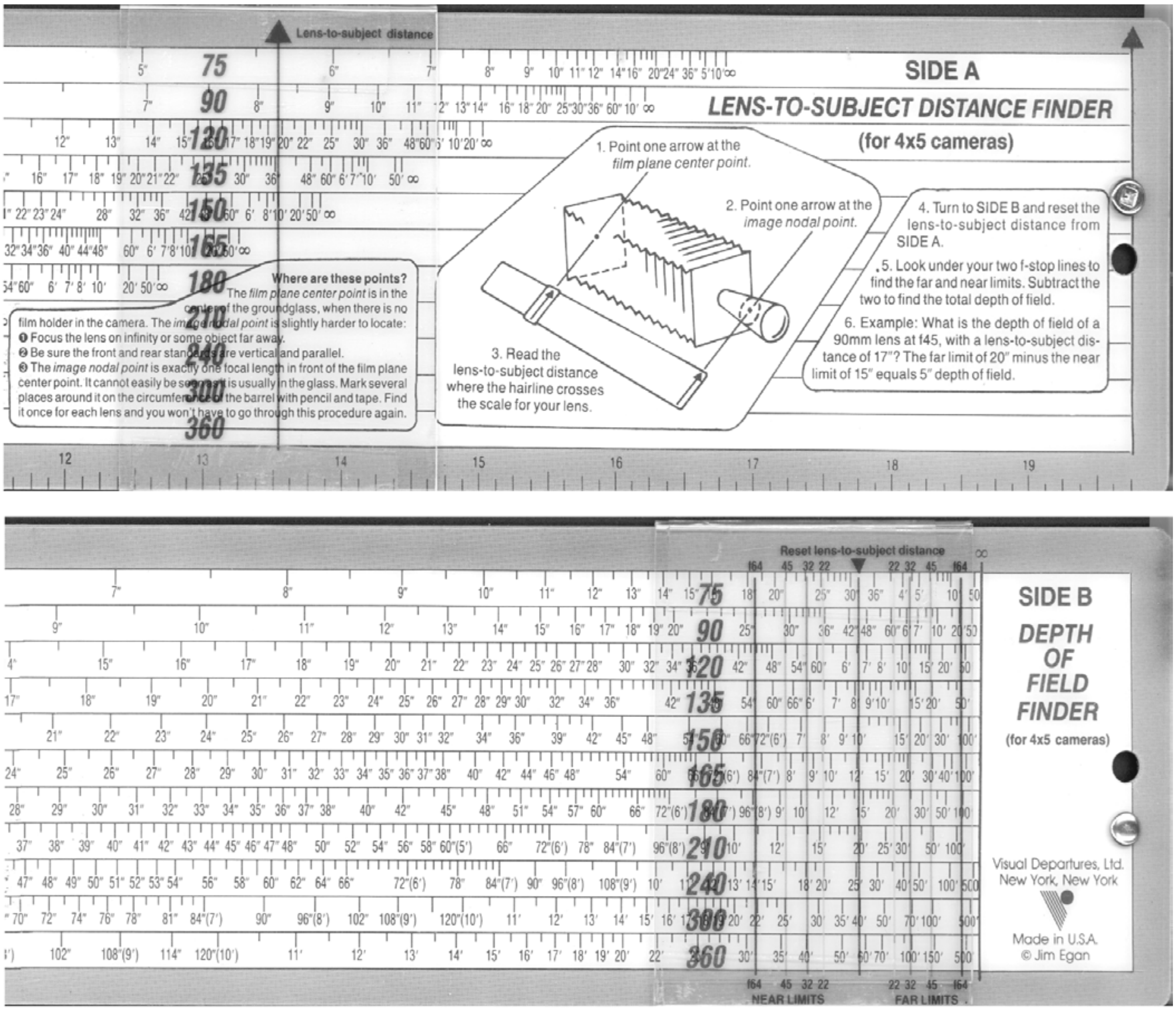


Figure 26: DFF-1 Depth of field finder

12 Michael K. Davis's Not just another depth of field calculator

This is an Excel spreadsheet that may be downloaded from http://home.sol.no/~gjon/depth.htm. Its author is Michael K. Davis.

Davis is right, it is not just another spreadsheet. He chooses to define the circle of confusion with respect to resolution on a print instead of on the film, and then uses precise calculations involving the ratio of print to film diagonals. His idea is that since a half plate is about 6x8″, that this should be the basis for setting on-print resolution. It does of course correspond roughly to the angle of vision of the human eye when viewed at distance equal to the 10″ diagonal, which is about the closest distance of distinct vision for the normal human eye. He winds up with the rule that the on-film resolution should be equal to 1/1750 the of the print diagonal. For 4x5, this is about 0.087 mm, which is reasonably close to the usual 0.1 mm. His rule corresponds to assuming that the normal human eye can discriminate about 7 l/mm at the distance of closest vision. A more usual number is 5 l/mm, but his number is not unreasonable.

However, it doesn't matter much and having to deal with the different print diagonals is a nuisance. Quite satisfactory results are obtained from computations which peg everything to a c of 0.03 for 35 mm, and scale to other formats by the ratio of sides instead of diagonals. In my opinion, his calculations are precise mathematical results based on fuzzy input – garbage in, garbage out, so to speak.

The spreadsheet is shown in Figures (27), (28), and (29). As a comparison, the usual calculation for a 210 mm lens at f/32 with $c = 0.1$ and $u = 10$m gives a hyperfocal distance of 14 m, and DOF limits of 5.8 m and 34.5 m. Davis gives 15.7 m, 6.1 m, and 27.6 m respectively. These are hardly practical differences. Davis appears to be using lines 2, 5, and 6 from Table (6).

Finally, Davis calculates the f-number at which the diffraction disk equals c. Unfortunately, he uses the wrong constant in the calculation, with the result that what he calls the "diffraction limited maximum aperture" should be twice what he cites. For 35 mm format with a 50 mm lens, he cites f/18, when it should be f/36. Since the maximum f-number for 35 mm lenses is f/16 or f/22, this "diffraction limited maximum aperture" has no meaning. The same may be said for other formats. In order to experience diffraction problems one must use the maximum aperture on a lens in a macro mode.

The program makes no adjustment for f-number rounding.

In conclusion, I cannot recommend this spread sheet. He does things in an unusual way, which is not a bad thing, but it does not lead to an improvement over what is customarily done

Not Just Another Depth of Field Calculator!

Michael K. Davis
zilch0@primenet.com

Step 1)	Specify Focal Length (mm):	210.00
	Converted to inches:	8.27
Step 2)	Specify Image Diagonal (mm)	153.67
	Converted to inches:	6.05

If you know in advance what aspect ratio print will be produced, use a calculated cropped diagonal instead of the full image diagonal. Use the following calculator as a guide, or enter your own value by measuring the diagonal directly from image area. You can change the Length x Width values, below, after measuring image dimensions produced by your cameras. (Length should be entered as the greater dimension, if length is not equal to width.) You can use the last column of this calculator to specify an aspect ratio other than 4:5, 5:7 or 11:14, to get that aspect ratio's diagonal.

Image Diagonal Calculator for Full Format and Crops to Various Aspect Ratios

Format Name	Full Image Width (mm)	Full Image Length (mm)	Full Image Diagonal (mm)	Diagonal @ Max. Crop to 4:5 ratio (mm)	Diagonal @ Max. Crop to 5:7 ratio (mm)	Diagonal @ Max. Crop to 11:14 ratio (mm)	Max. Crop to Other Aspect Ratio Short Axis: 1.00 Long Axis: 1.00
APS	16.70	30.20	34.51	26.73	28.73	27.03	23.62
35mm	24.00	36.00	43.27	38.42	41.29	38.85	33.94
4.5x6cm	41.50	56.00	69.70	66.43	68.82	67.17	58.69
6x6cm	55.00	55.00	77.78	70.43	67.59	69.95	77.78
6x7cm	55.00	68.00	87.46	87.08	83.57	86.48	77.78
6x9cm	55.00	86.00	102.08	88.04	94.63	89.02	77.78
4x5in	96.00	120.00	153.67	153.67	147.47	152.61	135.76
5x7in	121.00	170.00	208.66	193.69	208.18	195.85	171.12
8x10in	194.00	245.00	312.51	310.55	301.08	311.58	274.36
10x12in	245.00	295.00	383.47	377.78	362.53	375.17	346.48
11x14in	276.23	352.43	447.78	442.18	433.10	447.10	390.64
Other	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Step 3) DEPTH OF FIELD CALCULATION

Specify the Permissible Diameter (1/nth inch) of Circles of Confusion:	175

Specify the denominator for a fraction of an inch. For example, a value of 175 would specify a diameter of 1/175th of an inch. (See Note 2, below.)

Figure 27: Davis top of output

Step 4)	DIFFRACTION-LIMITED MINIMUM APERTURE			
For diagonal of:	153.67 mm and	CoC of 1/ 175	avoid >= f/	64.86

The effects of diffraction will become visible at this and smaller apertures. (See Note 1)

For maximum DOF including Infinity, focus at the Hyperfocal Distance given in this table:

DEPTH OF FIELD WHEN FOCUSED AT HYPERFOCAL DISTANCE

Focal Length (mm): 210.00 Image Diagonal (mm): 153.67

Calculated to Limit Diameter (inch) of Circles of Confusion to 1/ 175

f Num	Near Sharp (meters)	Hyperfocal Distance (meters)	Far Sharp (meters)	Near Sharp (feet)	Hyperfocal Distance (feet)	Far Sharp (feet)
1	251.11	502.21	Infinity	823.84	1647.68	Infinity
1.1	228.28	456.56	Infinity	748.94	1497.89	Infinity
1.2	209.26	418.51	Infinity	686.53	1373.07	Infinity
1.4	179.36	358.72	Infinity	588.46	1176.91	Infinity
1.8	139.50	279.01	Infinity	457.69	915.38	Infinity
2	125.55	251.11	Infinity	411.92	823.84	Infinity
2.8	89.68	179.36	Infinity	294.23	588.46	Infinity
4	62.78	125.55	Infinity	205.96	411.92	Infinity
5.6	44.84	89.68	Infinity	147.11	294.23	Infinity
8	31.39	62.78	Infinity	102.98	205.96	Infinity
11	22.83	45.66	Infinity	74.89	149.79	Infinity
16	15.69	31.39	Infinity	51.49	102.98	Infinity
22	11.41	22.83	Infinity	37.45	74.89	Infinity
32	7.85	15.69	Infinity	25.74	51.49	Infinity
45	5.58	11.16	Infinity	18.31	36.62	Infinity
64	3.92	7.85	Infinity	12.87	25.74	Infinity
90	2.79	5.58	Infinity	9.15	18.31	Infinity
128	1.96	3.92	Infinity	6.44	12.87	Infinity

Figure 28: Davis middle of output

To focus at a specific Object Distance, specify distance in meters:						10.000
Use this converter if you need it:			Feet to Meters:		6.000	1.829
DEPTH OF FIELD WHEN FOCUSED AT OBJECT DISTANCE (meters): 10.00						
Focal Length (mm): 210.00 Image Diagonal (mm): 153.67						
Calculated to Limit Diameter (inch) of Circles of Confusion to 1/ 175						
f Num	Near Sharp (meters)	Distance Focused (meters)	Far Sharp (meters)	Near Sharp (feet)	Distance Focused (feet)	Far Sharp (feet)
1	9.80	10.00	10.20	32.17	32.81	33.47
1.1	9.79	10.00	10.22	32.11	32.81	33.54
1.2	9.77	10.00	10.24	32.04	32.81	33.61
1.4	9.73	10.00	10.29	31.92	32.81	33.75
1.8	9.65	10.00	10.37	31.67	32.81	34.03
2	9.62	10.00	10.41	31.55	32.81	34.17
2.8	9.47	10.00	10.59	31.08	32.81	34.75
4	9.26	10.00	10.87	30.39	32.81	35.65
5.6	9.00	10.00	11.26	29.52	32.81	36.93
8	8.63	10.00	11.89	28.30	32.81	39.02
11	8.20	10.00	12.80	26.91	32.81	42.01
16	7.58	10.00	14.68	24.88	32.81	48.15
22	6.95	10.00	17.80	22.81	32.81	58.38
32	6.11	10.00	27.56	20.04	32.81	90.43
45	5.27	10.00	96.19	17.30	32.81	315.57
64	4.40	10.00	Infinity	14.43	32.81	Infinity
90	3.58	10.00	Infinity	11.75	32.81	Infinity
128	2.82	10.00	Infinity	9.25	32.81	Infinity

Figure 29: Davis bottom of output

13 Loyd's C code for DOF

Eric C. Loyd gives C code for DOF. It may be found at
http://www.algonet.se/ bengtha/photo/software/dof.txt.
His code produces the FrontDOF and BackDOF given by lines 7 and 8 of Table (6). One needs both *dof.c* and *dof.h* to compile the code. The value of c is a built in constant that must be changed to whatever is appropriate. The code makes no adjustment for f-number rounding.

14 Howard Merklinger's books and papers

I mention these because they contain tables pertinent to both DOF and lens tilt. A source site is http://www.trenholm.org/hmmerk/index.html.

Merklinger deals with both lens tilt and DOF for tilted lenses.

To calculate lens tilt, he assumes that the photographer can estimate the distance from the lens downward to the sloping lens plane: this is J in Figure (30). If this can be done, then the sine of the tilt angle is given by f/J. I personally find J very difficult to estimate, but each individual should try for themself by comparing the results with the results from some other Aid such as the Rodenstock calculator or Vade Mecum which make use of back focusing.

For DOF, Merklinger provides tables which give the orthogonal depth of the DOF wedge, and others that give the angles of the two planes. Figure (30) shows the distances Merkinger cites as *LowerDOF* and *UpperDOF*. I find these difficult to use when looking at a scene. For myself, the distance to the near and far planes is of more interest, just as it is when the lens is not tilted. If I look at the scene along a ray from the camera, I would like to know the DOF along this ray about the focus plane, since then I can estimate whether or not a tree branch along the same ray will be sharp or not. Figure (30) illustrates such a ray and shows the FrontDOF and BackDof regions.

I cannot exactly reproduce the values in his tables, although the agreement is good enough for all practical purposes. I used line 13 in Table (6), which is derived in my notes. He often gives important results without derivation, and sometimes it is hard to work them out.

I have mixed feelings about Merklinger's approach. It seems very complicated and odd, but apparently many find it useful, and after all that is the proof.

He chooses c in an awkward way, and I cannot tell whether he is making an adjustment for f-number rounding because of the numerical differences between our calculations.

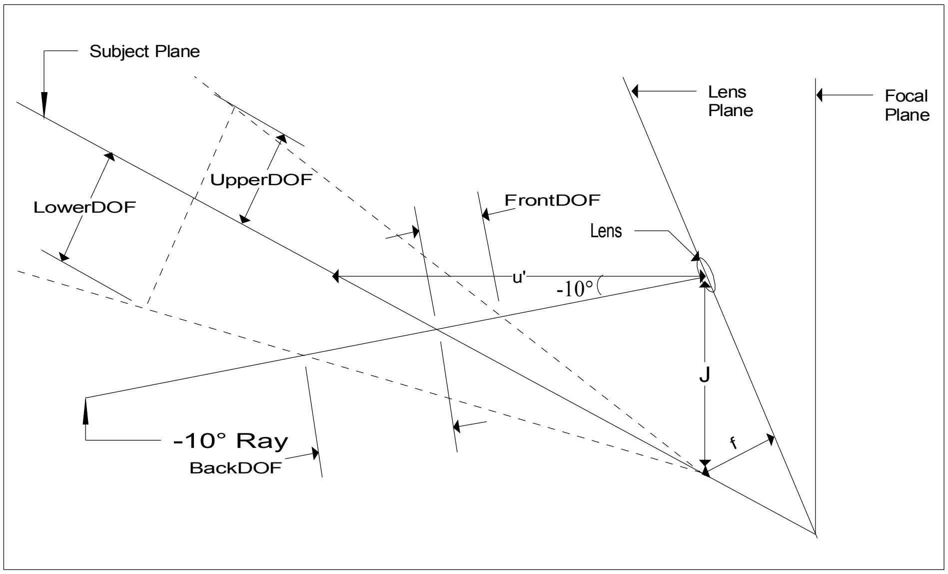


Figure 30: DOF for tilted lens

15 BTZS and ExpoDev

15.1 Introduction

ExpoDev is a 3COM palm program which supports Phil Davis's book *Beyond the Zone System*. It is available from Darkroom Innovations http://www.darkroom-innovations.com/ for $129. I understand that other computing devices have been supported in the past, and may still be. To use ExpoDev one needs to read Davis's book or take one of the courses that he teaches. I will discuss ExpoDev as a stand-alone entity, but please remember that there is more to the system than this one program.

The program is an integrated environment for the photographer. It accepts input describing the scene and the film processing parameters and outputs information about exposure and other things needed to make a photograph. It has a built in timer for extended exposures, and a data logging mechanism which will produce files that may be transferred to a PC and then printed as a permanent record. There are several screens, but I have chosen not to describe them all because most are self evident or well documented. However neither the documentation nor Davis's book really lays out the details of the calculations: some formulas are given at the rear of Davis's book. I will describe the bases of the calculations in a way that I hope will be clear to all.

First this methodology is applicable only to black and white photography, since its rationale lies in the ability to control contrast by varying development times. Photographic paper has a limited range, but scenes have both larger and

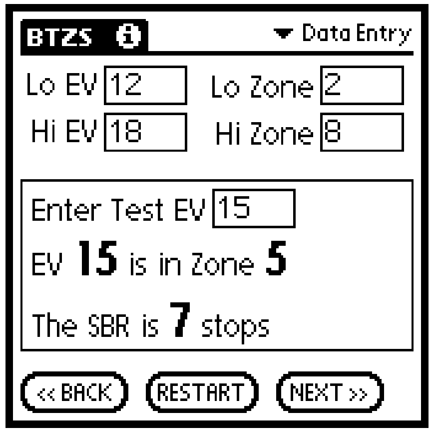


Figure 31: Data entry screen

smaller ranges. The problem is to map the scene range into the paper range. If a scene has a short range, then it must be expanded to fit in the paper range. If a scene has a long range then it must be contracted to fit. This can be controlled by changing the development time of the film.

> **What ExpoDev does:** Subject luminance is measured with a light meter and assigned to zones. From this the program calculates the exposure and a constant which may be used to find the appropriate developing time.

15.2 Data entry screen

That is basically all there is to it, but of course there is a haze of obscuring detail. The data entry screen is shown in figure (31). One enters light meter readings into this screen, and the results of the calculation appear on the working data screen, shown in figure (32), where one can see the proper f-number and shutter speed. In addition, a parameter, $\overline{G}$, is shown giving a key to the appropriate development time[7]. The two lines in the middle represent the same exposure: the first one is adjusted to match actual speeds that may be set on a lenses.

15.3 The Zone System

I will assume a passing familiarity with the Zone System, but to refresh memories, there are usually 10 zones designated with Roman numerals. Each zone

[7] $\overline{G}$ is the average slope of the characteristic curve, and the user must find, by testing, the appropriate development times needed. It should be noted that the base value of $\overline{G}$ is 0.47 which is approximately the reciprocal of 2.1, corresponding to a seven step exposure range. There is a companion program called GBar which enables the user to plot $\overline{G}$ against development times.

represents twice the density of the preceeding one. Table (1) is similar to a table in Davis's book. An extended description with illustrations may be found in "the Bible," Adams (1981).

0	Pure paper black
I	Black; virtually indistinguishable from 0
II	Near black; texture but no detail
III	Very dark gray
IV	Dark gray
V	Middle gray
VI	Light gray
VII	Very light gray
VIII	Near white; texture but no detail
IX	Pure paper white

Table 1: Zone definitions

15.4 Input and output

The values entered into the data entry screen are exposure values, EV, obtained with the ISO speed set to 100. For this one pretty much has to use a spotmeter, since two separate luminances are required. At the right of the screen are two corresponding boxes for the specification of zone values. The program will map the EV's into the specified zones on the print. In figure (31), EV=12 is mapped into Zone II, and EV=18 is mapped into Zone VIII. These EV values cover a seven step range, and so do the corresponding Zone values, but other ranges are possible, and in fact the two ranges do not have to be the same. If the Zone range is shorter than the EV range, one must compress the range to fit on the paper, and if it is larger, one must expand it. The program adjusts for this automatically. Figure (33) shows an expansion when EV=18 is placed on zone VII. When this is done, one sees that the exposure, shown in figure (34), increases and the $\overline{G}$ decreases. The decreased $\overline{G}$ implies a decrease in development time.

The SBR shown in figure (33) is the subject luminance range in EV's. It is found from r, the ratio of the zone range ΔZ to the EV range ΔE; that is $r = \Delta Z/\Delta E$. In this figure $\Delta Z = 5$, and $\Delta E = 6$ so $r = 5/6$. This means that there are 6/5 EV's per zone, and thus the SBR must be $7/r = 7/(5/6) = 8.4$ EV's, where it is assumed that seven is the zone range for a normal subject[8]: that is a normal subject will range from zone II through zone VIII.

[8] Actually seven is pretty much built into photographic standards. For example, light meters are calibrated for values in the middle of a seven step range.

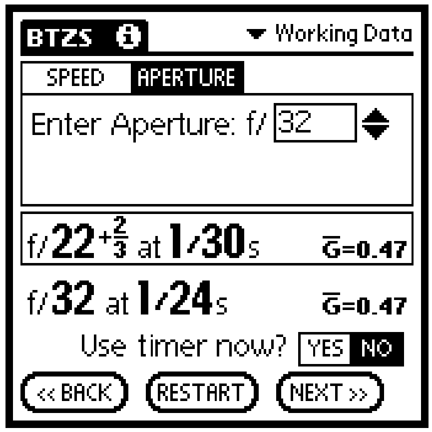


Figure 32: Working data screen

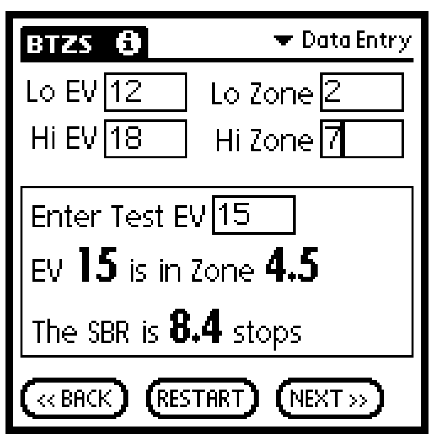


Figure 33: Shortened Zone range

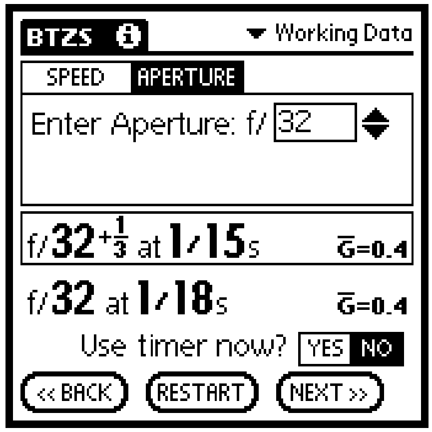


Figure 34: Exposure for expanded SBR

15.5 Calculating exposure with reflective meters

The exposure EV is calculated as

$$EV = (loEV) - (loZone - 1/2)/r + 4, \tag{1}$$

and of course by definition $2^{EV} = N^2/t$, where N is the f-number and t the time in seconds. As shown in figure (34), this gives 12-1.5/(5/6)+4=14.2, and for $N = 32$, one finds $t = 1/18$ seconds.

One cannot simply use the light meter reading at the EV value corresponding to zone V in figure (33) because it is valid only for standard processing. Light meter calibration adjusts EV's by -3.6 to produce mid gray tones on a seven stop scale. This calibration adjustment must be removed to obtain the correct base level. This is done by adding 3.6 to observed EV's: the result is an exposure which will place the tone at the beginning of zone I. From this base level, the exposure must be increased to bring the tone up to the lo Zone value. Since each increase by one zone requires an increase of $1/r$ EV's, it is necessary to subtract[9] $(loZone - 1/2)/r$ to move the exposure from the start of zone I to the lo Zone.

Davis adds 4 instead of 3.6 to obtain equation (1). A fair question would be, "why does Davis choose 4 instead of 3.6? Doesn't this result in an underexposure?" It does indeed, but that is what he does. I suspect that he is concerned about the placement of an 18% gray card, and chooses a half stop correction for this purpose. ExpoDev allows this choice to be changed by the user on the constants screen.

It is possible to adjust the film speed using equation (1). The nominal ASA 100 speed should be changed to $1600 \div 2^{(loZone-1/2)/r}$. Table (15.5) gives the adjusted speeds. If S is the actual speed of the film, multiply the entries by

[9] EV and exposure are opposite effects. Low exposure implies a bright object and a large EV.

$S/100$. With this adjustment, meter readings will give correct values for non-standard processing.

	SBR							
lo Zone	4	5	6	7	8	9	10	11
I	1600	1600	1600	1600	1600	1600	1600	1600
II	1076	975	883	800	724	656	594	538
III	724	594	487	400	328	269	220	181
IV	487	362	269	200	149	110	82	61

Table 2: Reflectance method adjusted film speed table.

The program requires EV's with the meter to be set to ASA 100. The recommended exposure is adjusted for the value input in the Constants screen. The instructions nowhere note that the film speed to be used depends on the subject luminance range. Davis makes much of the fact that the proper film speed depends on the subject luminance range, with careful testing and graphing techniques laid out in excruciating detail; however, the program seems to make no use of these speeds. Of course one can input a custom film and specify its speed on the Constants screen, but I think that few users will be aware that this is something that they must do, and must do for each subject luminance range. The effect of this omission is that users will make non-optimum exposures and for short subject luminance ranges, will find that the densities produced are larger than they anticipate. I suggest that equation (2) would be more appropriate, where the meter is set to the ASA speed which produces a seven stop subject luminance range. This equation assumes that the ASA values obtained from tests may be obtained by multiplying the ASA value for a seven stop subject luminance range by r.

$$EV = (loEV) - (loZone - 1.5)/r + 3.6 + \log_2(r). \quad (2)$$

In addition, Davis apparently assumes that the density corresponding to 0.1 plus background and fog falls on zone I-1/2. It would seem more reasonable to assume that it falls on zond I+1/2, which is incorporated in equation (2).

15.6 Using an incident meter

Davis has developed an ingenious method by which one may use an incident meter instead of a reflective meter. He argues that the subject luminance range arises from two things, the reflectance of the subject and the illumination that falls thereon. If one assumes a range of reflectance for the subject, then one need only measure the illumination to discover the subject luminance range. Figure (35) shows the data entry screen for incident readings. The incident readings are for the most highly and least illuminated areas.

A five stop range of reflectance is assumed, and Davis argues both that this is normal, but that even if it is not, "... camera exposure should generally provide

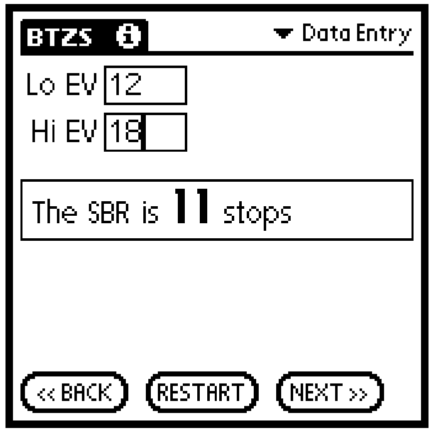


Figure 35: Data entry screen for incident readings.

for all the tones, from black to white, whether they are actually present in the subject or not."

He adds the range of the incident readings to this five stop reflectance range to get the subject luminance range, SBR, and argues that the low meter reading should fall on zone $1.5+2.5\frac{7}{SBR}$, and the high meter reading should fall on zone $8.5-2.5\frac{7}{SBR}$. The zone difference is thus $7-5\frac{7}{SBR}$, which is zero for a five stop SBR. He then applies[10] equation (1) to the resulting low value. Making the substitution gives equation (3).

$$EV = loEV + (1.5 - \frac{SBR}{7}). \tag{3}$$

Davis prefers to express this correction in terms of film speed, which means that the nominal ASA 100 film speed must be changed to $100 \times 2^{1.5-SBR/7} = 283 \div 2^{SBR/7}$. Table (3) gives these speeds. To adjust to an actual speed S, multiply the entries by $S/100$. Using these adjusted speeds will give correct EV's for the low reading when using non-standard processing.

SBR							
4	5	6	7	8	9	10	11
190	172	156	141	128	116	105	95

Table 3: Incident method adjusted film speeds

15.7 The constants screen

The first screen is the constants screen shown in figure (36).

[10] Davis's calculations differ very slightly from those given by this equation.

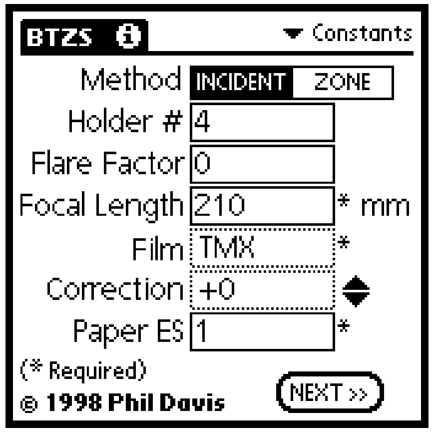


Figure 36: The constants input screen.

Most of the input is obvious, but a couple of items may be puzzling to those who have not taken Davis's course – perhaps even to those who have only read his book, since he never defines *flare factor*. The flare factor has a standard definition in photography: it is the ratio of the subject luminance range to image luminance range, and is typically about 2 or 3. Davis uses this value to adjust exposure by the base two log of the flare factor. If, for example, the flair factor is 2, the exposure will be increased by one stop, moving the shadow region up the characteristic curve. Flare adds exposure mostly to the shadows, decreasing the tonal separation. By moving up the curve, the degradation is reduced.

Davis offers a choice of five common black and white films to choose from:TMX 100 & 400, TXT 320, Delta 100, FP4+ 125. He allows the user to specify other films by inputting their film speeds. He uses the reciprocity behavior of the built in films to correct the exposure, but of course he can use only some standard rules for reciprocity correction with other films.

A correction factor may be inserted in a box on this screen. If 1/2 is inserted, the exposure calculation will use 3.5 instead of 4.0 in equation (1) and 1 instead of 1.5 in equation (3).

The paper ES is the exposure range of the paper which is equated to the density range of the film. Davis divides the exposure by ES in order to adjust the units of film density. He also multiplies $\overline{G}$ by ES, which means that larger paper ES's require longer development times.

15.8 DOF and Bellows Factors

ExpoDev is a completely integrated system, in that any specifications that are entered are incorporated in the final exposure recommendation. In particular, for close up work, the bellows factor is accounted for when necessary. The bellows factor information is obtained from screens that calculate DOF since it depends on the distance between lens and subject.

The DOF calculation is not satisfactory. Davis uses the correct formulas, lines 3 and 4 of Table (6), but he chooses $c = 1/1720\times$ Lens focal length. This is appropriate only for normal lenses. Davis might have used the diagonal of the film size as did Michael K. Davis in Section (12), since then 1/1720 would have been an appropriate multiplier. The magnitude of the error is of practical importance. For example, with an 800 mm lens focused at 50 m, Davis gives DOF limits of 23 m and infinity. The correct values are 40 m and 56 m.

He also uses this value for c in the calculation of f-numbers from the near and far DOF limits. For the 800 mm lens with near and far DOF limits at 40 m and 56 m, ExpoDev gives $f/4 + \frac{2}{3}$, when the correct value is f/22. This is a very serious discrepancy.

15.9 Conclusion

This is an impressive program, both in its global aims, and in its execution. The aim is obviously to support Davis's methodology, which the program does admirably. It integrates the various factors that must be considered in making a photograph and provides the photographer with the information needed to both take and process the photograph. After having studied the program, I find it hard to imagine a practicing photographer using the Zone System without its aid. It is clearly worth buying a 3COM palm device in order to use ExpoDev.

There are flaws with respect to DOF calculations and the EV calculation formula. The DOF calculations may be relied upon only when normal lenses are used. The results for long lenses and wide angles will be disappointing. Users would be well advised to use equation (2) instead of the values suggested by the program. Using the exposure recommended by the program will tend to block the whites.

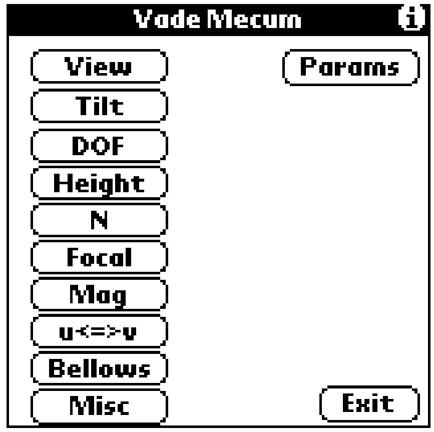


Figure 37: Main Vade Mecum screen

16 Vade Mecum

This is a collection of programs for hand held devices, or one program with many functions, depending on the device. At the present time, the HP48GX, and the TI89 calculators and the 3COM palm devices and Windows CE palm size devices are supported. Figure (37) shows the main Vade Mecum screen for the 3COM device. The same options are offered on each device, although the screens will differ. Detailed documentation is supplied for each device using appropriate screen captures. Vade Mecum may be obtained from ftp://208.219.63.253/public/photo, and from resources for each particular device. It is freeware.

16.1 What is available

The interface is quite straightforward for all devices, allowing the choice of focal length, format etc. One starts by setting up the parameters. Figure (38) shows the parameters input screen that appears when one clicks the *Params* button on the main screen. The information is saved when the *OK* button is clicked, but it is not associated with a lens or format as is done in Format+ or Photographe. If you want a different lens or format, the parameters must be changed here.

Once the parameters are set, one may click on any of the items to bring up a menu of functions that may be performed. All have a standard format which makes it easy to remember what is expected. Clicking on *DOF*, for example, brings up the menu shown in Figure (39). Choosing *DOFu* from the menu brings up the dialog in Figure (40). The dialog picks up the f-number, N, from the *Params* dialog. The user must fill in, u, the distance from the lens to the subject, or change N as desired. A handful of parameters, such as u and N, are designated by symbols in order to save space on the display. They are listed at the start of the documentation, and should cause little problem even for those who find symbols uninteresting.

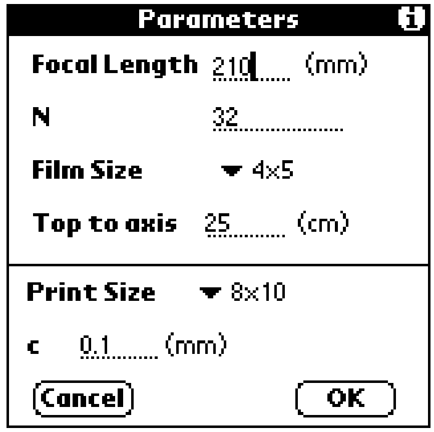


Figure 38: Parameter screen

Clicking on the *Calc* button fills in the lower half of the screen. Note the *FrontDOF* and *BackDOF* are given as opposed to the *near* and *far* values. Many of the calculations show an *Adjusted N*, which is the f-number adjusted for the bellows factor. Forgetting the bellows factor is a common cause of misplaced exposure – at least I tend to forget it in the heat of the moment so to speak, and need reminding.

The available functions are shown in Table (4).

16.2 Illustration

As an illustration, the calculation of lens tilt and the DOF determination for a tilted lens will be shown. Figure (41) shows the dialog for calculating lens tilt from two focus points as was done with the Rodenstock calculator. One fills in the distance along the rail between the two focusing positions, *Rail d*, the distance between the two images on the ground glass *Glass d*, and an estimate of the horizontal distance from the lens to the sloping subject plane, u'. Schön uses *Extension difference = Rail d* and *Distance on screen = Glass d* in the Rodenstock calculator.

It may be seen that the tilt angle is 4.2°, and for those who do not have degree scales on their camera, the distance that a mark on the top of the front standard should move during tilting is also given.

Figure (42) shows the DOF calculation along a ray which is $-10°$ below the horizon. This is illustrated graphically in Figure (30). It may be seen that the distance of the plane from this ray is about 6 m and that the DOF extends about 2 m in front and 5 m behind along this ray.

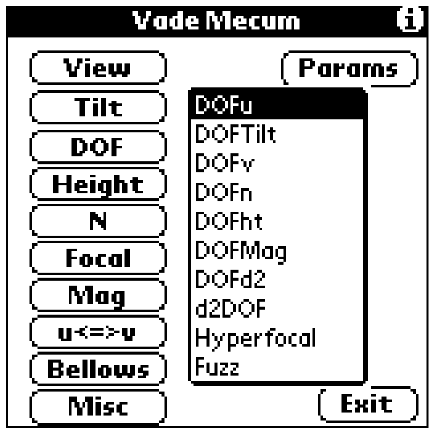


Figure 39: DOF menu

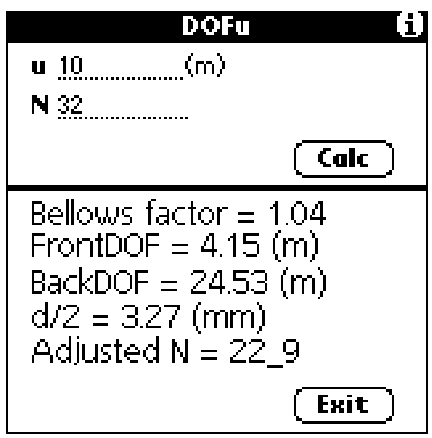


Figure 40: DOFu dialog

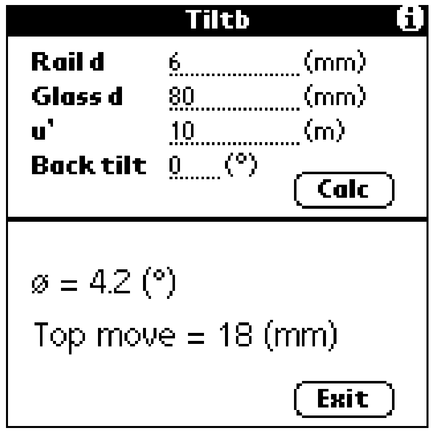


Figure 41: Tilt by back focusing

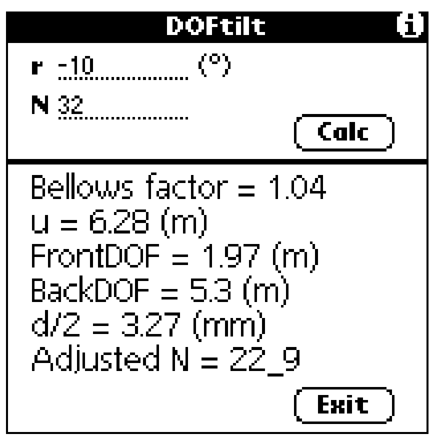


Figure 42: DOF along a ray

17 Appendix: Fuzzy numbers

The calculations made by any of these aids should be taken as approximations only: it is not wise to over-interpret their output. The problem is not usually with the calculations themselves, but rather with the input values, which are quite fuzzy. The value of c, for example, is far from a fixed, well-agreed upon constant. Compelling arguments can be made for values over a wide range. The usual argument ties it to the resolution of the normal eye on a print held at the nearest distance of clear vision. When I have tested it, I have obtained a resolution of about 5 l/mm; but I will not dispute those who say it should be 7 l/mm, nor will I dispute those, of a conservative bent, who think it should be closer to 3 l/mm. With this range of input, DOF calculations may reasonably range over a $\pm 40\%$ range. The fact that many of the aids, including mine, output numerical values to one or more decimal places is simply an artifact of the calculation, and should not obscure the fact that the values are fuzzy. Davis's results on page 33 provide a case in point. His values differ considerably from those obtained by other aids, but they are not wrong, just different plausible values. They are in fact guesses and the careful photographer will factor their nature with other considerations when making a composition.

Diffraction is another vexing issue. Aids that treat it cite Rayleigh's criterion, which was obtained from observations of self-illuminated objects such as stars. There are other criteria, Sparrows's for example, but all of them involve, somehow, the wavelength of light, usually assumed to be blue-green in the formulas cited. In my experience, the world is not uniformly blue-green, and calculations based on that assumption are fuzzy. The wavelength of visible light ranges from 2/3 to 4/3 of the blue-green wavelength, hence a diffraction calculation based on blue-green cannot be completely accurate. It is probably not as bad as the 2/3 to 4/3 range would suggest, but the photographer should be prepared for an increase in diffraction when the composition tends to the violet. The wavelength appears in the denominator of the criteria, so the criteria values will range from about 75% to 150% of that for blue-green, with the 150% at the violet end of the spectrum.

As with any other aspect of photography, the photographer should run tests, and determine from these what is best. There is no greater authority than that of a photographer's own darkroom.

18 Formulas

The several formulas used by the aids are given in Tables (5) and (6). More details can be obtained from my notes at ftp://208.219.63.253/public/photo.

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2. Peterson, Steven. (1996) Image sharpness and focusing the view camera. *Photo Techniques.* 17-2, 51-53.

3. Davis, Phil (1999) Beyond the zone system, Focal Press, Boston.

Directory	Program Name	Description
	Params	Set and display parameters
View		Viewframe information
	Viewv	u,FrontDOF,BackDOF from v
	Viewu	u,FrontDOF,BackDOF from u
Tilt		Calculates tilt angle
	Tiltb	By back focusing
	Tiltd	From distances and angles
	TilJ	From u and J
	Tiltg	From subject plane slope
DOF		Depth of field
	DOFu	From u
	DOFTilt	From ray angle, for tilted lens
	DOFv	From v
	DOFn	From near
	DOFht	From height of the subject
	DOFmag	From magnification
	DOFd2	From $d/2$
	d2DOF	$d/2$ from DOF
	Hyperfocal	The hyperfocal distance
	Fuzz	Blurred subject size
Height		Subject height
	Hu	From u
	Hv	From v
	Hm	From magnification
	HDOF	From DOF
	Hd2	From $d/2$
N		Calculates F-numbers
	NNearFar	From near and far values
	Nd2u	From $d/2$ and u
	NDOFu	From DOF and u
Focal		Focal length
	FNearFar	From near and far DOF limits
	Fd2u	From $d/2$ and u
	FDOF	From DOF and u
	Fmu	From DOF and magnification
	Fmv	From v and magnification
Mag		Magnification
	Magu	From u
	Magv	From v
	Magh	From subject height
	Magd2	From $d/2$
u <=> v		u and v
	utofromv	u to v or v to u
	uvh	u and v from subject height
	uvm	u and v from magnification
	uvd2	u and v from $d/2$
Bellows		Bellows factors
	BFm	From magnification and N
	BFext	From extension and N
Misc		Various utilities
	AOView	Angle of view from magnification and focal length
	StopMotion	Shutter spread to stop motion
	StopDifference	Stop difference for two light distances
	Ttianuglate	Triangulates to find subject distance
	Resolution	Theoretical resolution
	Resolutionu	Resolution at the DOF limits

Table 4: Vade Mecum functions

u	Horizontal distance between lens and subject.
f	Focal length
N	The f-number
c	The diameter of the circle of confusion
ϕ	Tilt angle in degrees
m	magnification $= \frac{f}{u-f}$
δ	Extension difference
$tan(\alpha)$	$(b-a)/(c-d)$ from Figure (1)
γ	Angle of subject plane: see Figure (1)

Table 5: Symbols used in the formulas

1	Hyperfocal distance	$H = \frac{f^2}{Nc} + f$
2	Hyperfocal distance	$H_a = \frac{f^2}{Nc}$
3	Near DOF	$Z_n = \frac{uf^2}{f^2+(u-f)Nc} = \frac{u(H-f)}{H+u-2f}$
4	Far DOF	$Z_f = \begin{cases} \frac{uf^2}{f^2-(u-f)Nc} = \frac{u(H-f)}{H-u} & \text{for } u < H \\ \infty & \text{for } u \geq H \end{cases}$
5	Approximate Z_n	$Z_{na} = \frac{uH_a}{H_a+u}$
6	Approximate Z_f	$Z_{fa} = \begin{cases} \frac{uH_a)}{H_a-u} & \text{for } u < H_a \\ \infty & \text{for } u \geq H_a \end{cases}$
7	FrontDOF $D_n = u - Z_n$	$D_n = \frac{u(u-f)Nc}{f^2+(u-f)Nc} = \frac{u(u-f)}{H+u-2f}$
8	BackDOF $D_f = Z_f - u$	$D_f = \begin{cases} \frac{u(u-f)Nc}{f^2-(u-f)Nc} = \frac{u(u-f)}{H-u} & \text{for } u < H \\ \infty & \text{for } u \geq H \end{cases}$
9	Harmonic mean	$M_h = \frac{2Z_nZ_f}{Z_n+Z_f}$
10	f-number from Z's	$N = \begin{cases} \frac{f^2}{c(M_h-f}\frac{Z_f-Z_n}{Z_f+Z_n} & \text{for } f < M_h \\ \infty & \text{for } f \geq M_h \end{cases}$
11	f-number from δ	$N = \frac{\delta\cos(\phi)}{2(1+m)}$
12	tilt angle	$\sin(\phi) = \frac{\tan(\alpha)}{1+m} = \frac{\tan(\alpha)\tan(\gamma)}{\tan(\alpha)+\tan(\gamma)}$
13	Angles of near, γ_+, and far, γ_-, DOF planes	$\frac{1}{\tan(\gamma_+)} = \frac{1}{\tan\gamma} + \frac{Nc}{f}\left(\frac{1}{\tan\phi} + \frac{1}{\tan\gamma}\right)$ $\frac{1}{\tan(\gamma_-)} = \frac{1}{\tan\gamma} - \frac{Nc}{f}\left(\frac{1}{\tan\phi} + \frac{1}{\tan\gamma}\right)$

Table 6: Formulas