Lesson 47. A 30X zoom lens

Lesson 38 showed how to design an 8X zoom lens with no starting configuration. Now we will do a more difficult job, aiming for a zoom ratio of 30X. This exercise will use many of the same tools and introduce yet more powerful options.

Here are the goals:

1. Zoom ratio 30:1
2. Semi-field 14 degrees at wide-angle end
3. Semi aperture 3 mm at that end
4. 11 elements to start with
5. Four groups, two of which will zoom
6. Gaussian image height 5 mm in all zooms
7. Back focus distance approximately 20 mm
8. Total length approximately 600 mm
9. Focus from infinity to five meters.

And this will be the input for ZSEARCH:

```
LOG                  ! to keep track of things later
ON 98
TIME                 ! to see how long this run took
CORE 14
ZSEARCH 3 QUIET      ! save results in library location 3

SYSTEM
ID ZSEARCH TEST
OBB 0 14 3           ! infinite object, 14 degrees semi field, 2.85 mm semi
                     ! aperture.  This defines the wide-field object
UNI MM
WAVL CDF
END

GOALS
ZOOMS 7
GROUPS 2 3 4 2       ! lens has four groups with 11 elements altogether
ZGROUP 0 Z Z 0       ! and groups 2 and 3 will zoom
ZFOCUS 5000 4 90 5       ! also correct range focus at 5 meters
FINAL                ! declare the desired object at the last zoom position,
                     ! which is the narrow field zoom
OBB 0 0.4666 90

ZSPACE NONLIN 1.7 ! other zoom objects will be nonlinearly spaced between the
                  ! first and last
APS 19               ! put the stop on the first side of the last group
DELAY OFF
GIHT 5 5 10 ! the image height is 5 mm for all zooms, with a weight of 10.
BACK 20 .1           ! the back focus is 20 mm and will vary.  A target will be
                     ! added to the merit function with a low weight.
COLOR M              ! correct all defined colors
ANNEAL 50 10 Q       ! anneal the lens as it is optimized in both modes
QUICK 40 40          ! 40 passes in quick mode, 40 in real-ray mode
ASTART 22
```
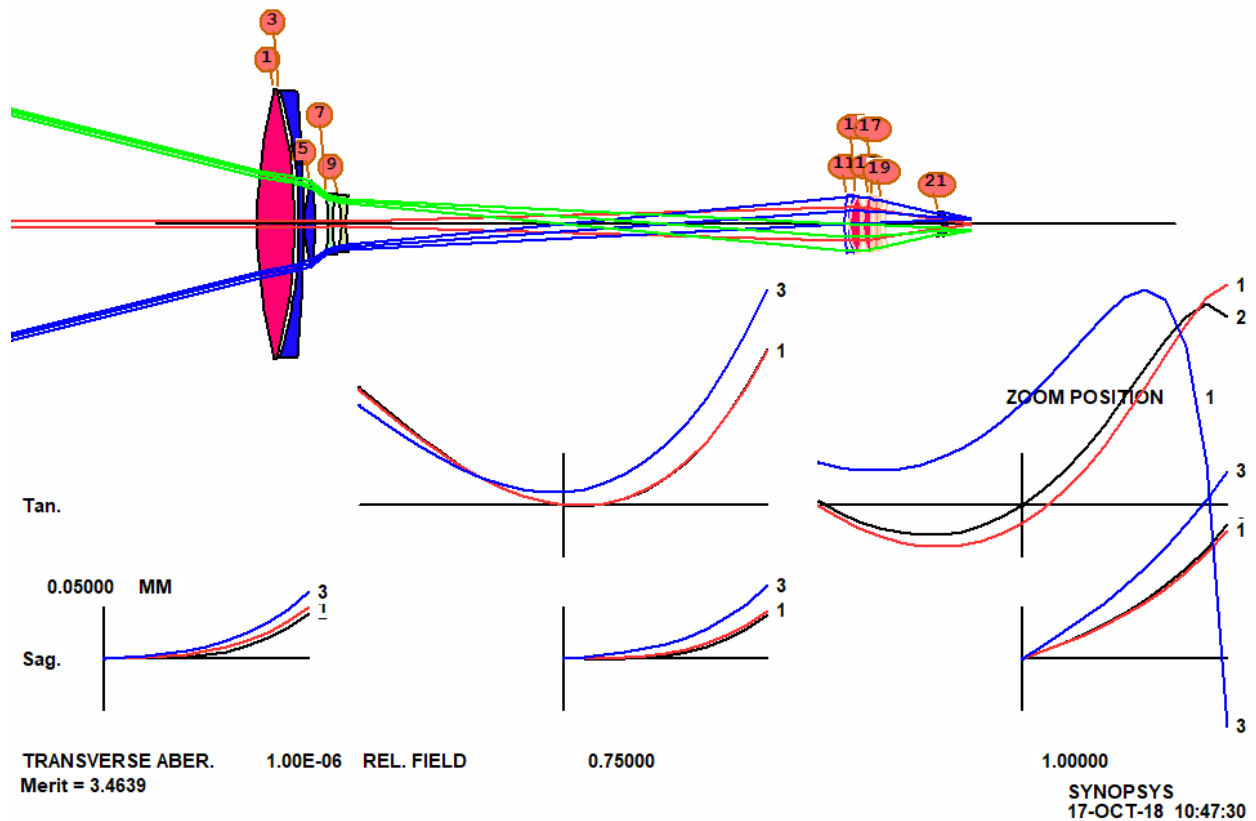
```
TSTART 12
END

SPECIAL PANT
CUL 1.75
FUL 1.75
END

SPECIAL AANT
ACA 55 1 1          ! monitor rays to keep away from the critical angle.
AEC 2 1 1
ACM 4 1 1
ACC 35 1 1

LUL 600 .1 10 A TOTL
END
GO                  ! start ZSEARCH
TIME                ! see how long the run took.
```

We run this input, and in about 26 minutes we get an attractive starting design.

We have corrected only seven zoom positions and will likely need more before we are done, but a lower number makes the ZSEARCH run execute more quickly, and we can adjust things as we learn what works and what doesn't.

The next step is to open the Worksheet and change the APS designation to APS -19. This puts a real pupil into effect, which is clearly needed, since the chief ray found by paraxial raytracing is not close

enough, as shown by the above picture. Then we run the optimization MACro that ZSEARCH has prepared.

Now we are ready to increase the number of defined zooms. Type

> CAM 15 SET

Running the zoom slider shows that the design is fairly well corrected over the zoom range, but it goes out of focus at in-between positions. We expected that, with only seven zooms. Let's look at how the zooms are distributed. Type

> CAM 100
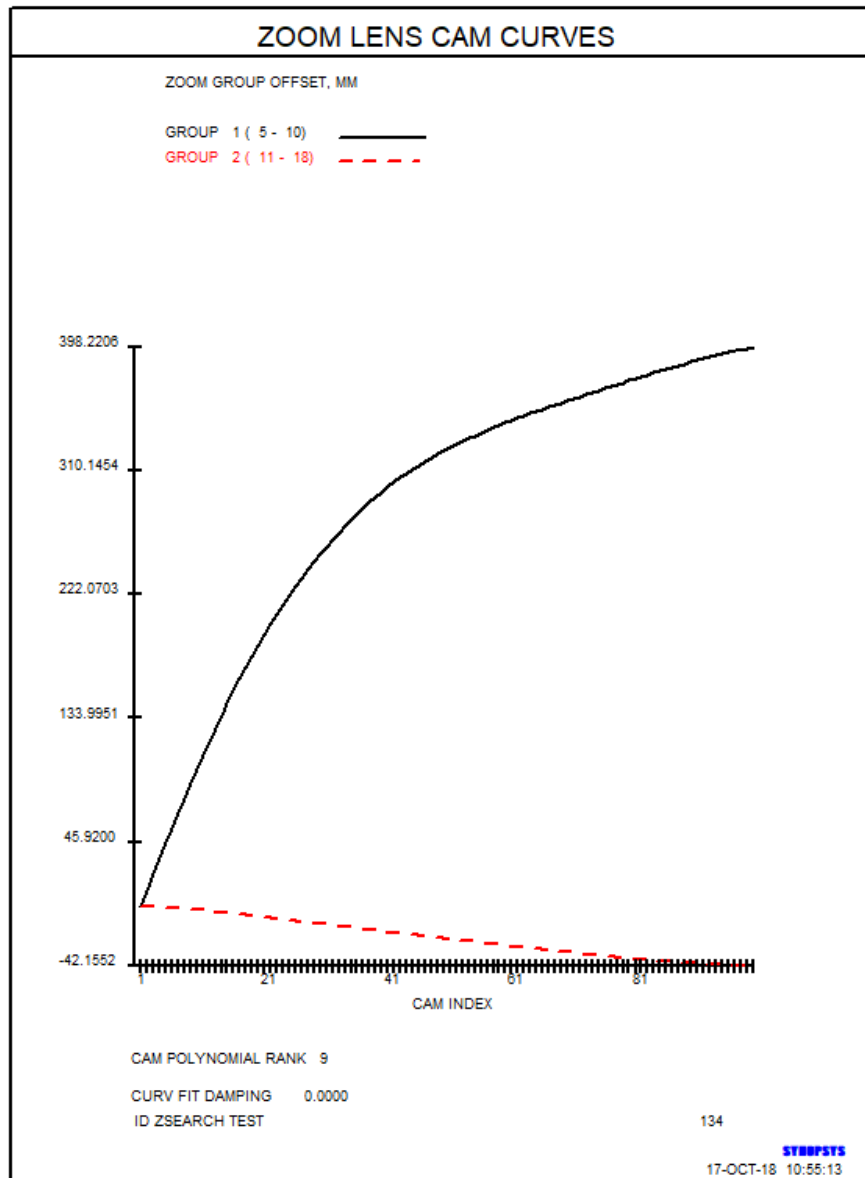
Things are changing most rapidly at the left end of this plot, so it would be a good idea to assign more zoom positions in that region to keep aberrations and focus under control. Where are the zooms assigned now? Enter the command

    CAM 100 APERT
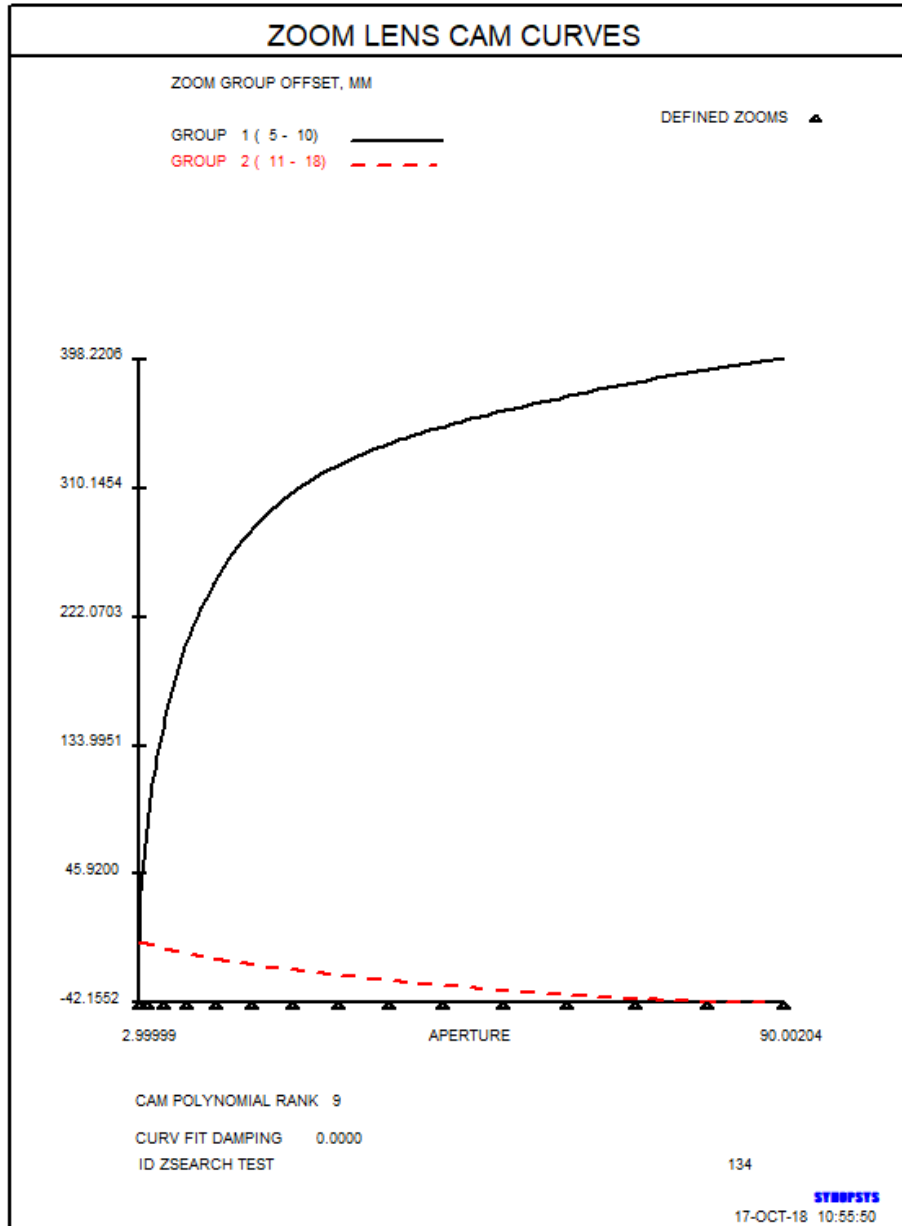
Now the plot is scaled differently. The previous one showed the abscissa scale linear in zoom position. This one is linear in *aperture*, and we see that the current zooms are indeed closer together on the left side than on the right. That was the purpose of the request

    ZSPACE NONLIN 1.7

In the ZSEARCH file, and it is exactly what we want. A larger nonlinear value would cluster them even more, and a value less than 1.0 would cluster them more on the right side, which we do not want here.

Now the lens has 15 zooms defined, also clustered at the left of the cam curves, but not yet corrected, since the zoom motions were interpolated from the original cam curves, which were only accurate at seven zooms.

We have to modify the optimization file that ZSEARCH prepared.

This file, ZSEARCH_OPT.MAC, declared GSR and GNR targets in each of the original seven zooms at the three fields we requested.

```
ZOOM            1
M   0.500000E+01   0.100000E+02 A GIHT
GSR      0.000000      5.000000      4   M      0.000000
GNR      0.000000      3.000000      4   M      0.750000
GNR      0.000000      1.000000      4   M      1.000000
LUL 600 .1 10 A TOTL
  ZOOM            2
M   0.500000E+01   0.100000E+02 A GIHT
GSR      0.000000      5.000000      4   M      0.000000
GNR      0.000000      3.000000      4   M      0.750000
GNR      0.000000      1.000000      4   M      1.000000
LUL 600 .1 10 A TOTL
  ZOOM            3
M   0.500000E+01   0.100000E+02 A GIHT
GSR      0.000000      5.000000      4   M      0.000000
GNR      0.000000      3.000000      4   M      0.750000
GNR      0.000000      1.000000      4   M      1.000000
LUL 600 .1 10 A TOTL
  ZOOM            4
M   0.500000E+01   0.100000E+02 A GIHT
GSR      0.000000      5.000000      4   M      0.000000
GNR      0.000000      3.000000      4   M      0.750000
GNR      0.000000      1.000000      4   M      1.000000
LUL 600 .1 10 A TOTL
  ZOOM            5
M   0.500000E+01   0.100000E+02 A GIHT
GSR      0.000000      5.000000      4   M      0.000000
GNR      0.000000      3.000000      4   M      0.750000
GNR      0.000000      1.000000      4   M      1.000000
LUL 600 .1 10 A TOTL
  ZOOM            6
M   0.500000E+01   0.100000E+02 A GIHT
GSR      0.000000      5.000000      4   M      0.000000
GNR      0.000000      3.000000      4   M      0.750000
GNR      0.000000      1.000000      4   M      1.000000
LUL 600 .1 10 A TOTL
  ZOOM            7
M   0.500000E+01   0.100000E+02 A GIHT
GSR      0.000000      5.000000      4   M      0.000000
GNR      0.000000      3.000000      4   M      0.750000
GNR      0.000000      1.000000      4   M      1.000000
LUL 600 .1 10 A TOTL
```

To make things easier, we will delete all but the first of these, and change that one to a zoom group request. This will create ray aberrations at the requested three fields at all zooms

```
ZGROUP ALL
```

```
M   0.500000E+01  0.100000E+02 A GIHT
GSR     0.000000      5.000000      4  M     0.000000
GNR     0.000000      3.000000      4  M     0.750000
GNR     0.000000      1.000000      4  M     1.000000
LUL 600 .1 10 A TOTL

END
```

The program also has added a ZFOCUS declaration to the AANT file, followed by another set of ZOOM requests, which we again replace with a single ZGROUP ALL. That section changes the object distance, moves the first group out by 90 mm, and again corrects the image in all defined zooms. Note the END line that closes the ZGROUP, and a second END that closes the AANT portion of the file.

```
ZFOCUS    0.500000E+04    4    0.900000E+02    0.500000E+01
ZGROUP ALL
GSR     0.000000      5.000000      4  M     0.000000
GNR     0.000000      3.000000      4  M     0.750000
GNR     0.000000      1.000000      4  M     1.000000

END

END
```
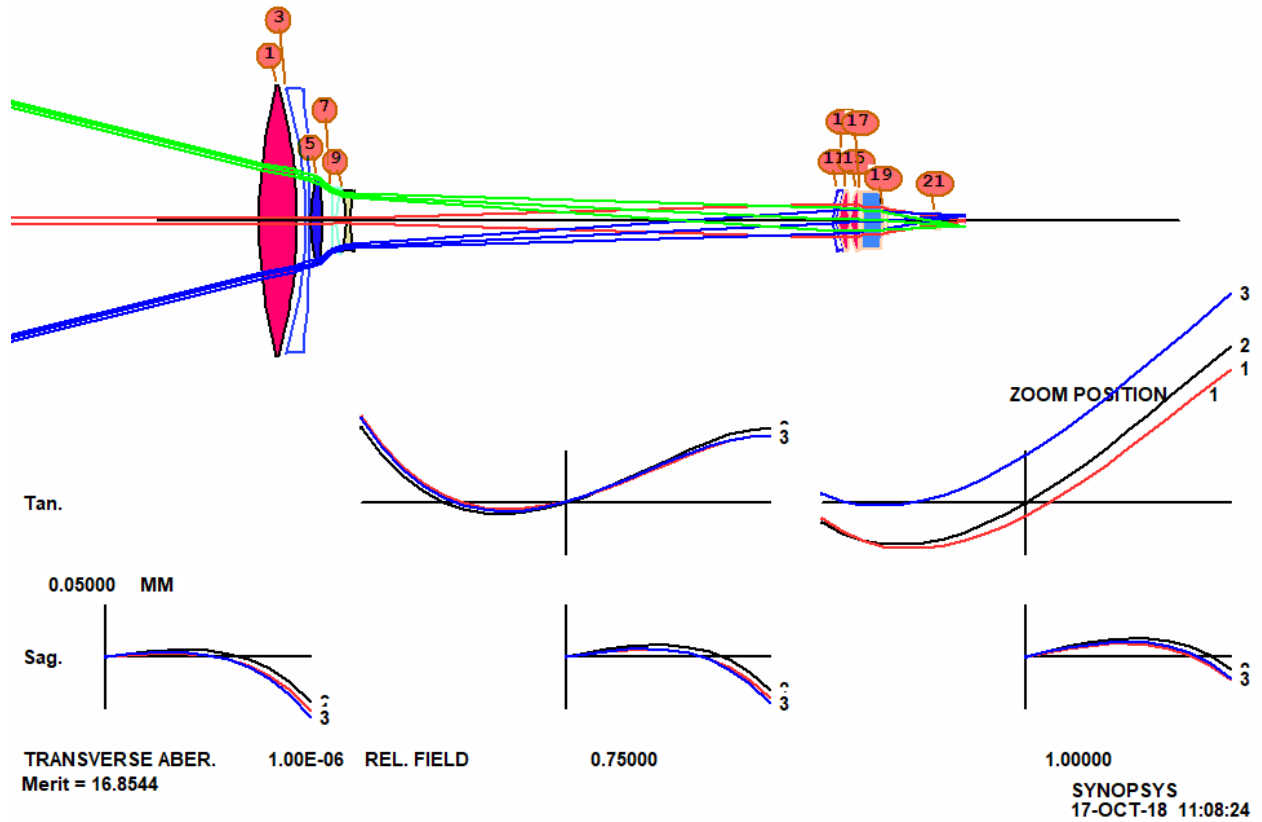
Before we run this, it would be a good idea to tweak up the object zooms. We increased the number from seven to 15, but this option simply interpolated the previous data, which were close but not exact. Type the command

CAM ZMAG 0.0333333 NONLIN 1.7
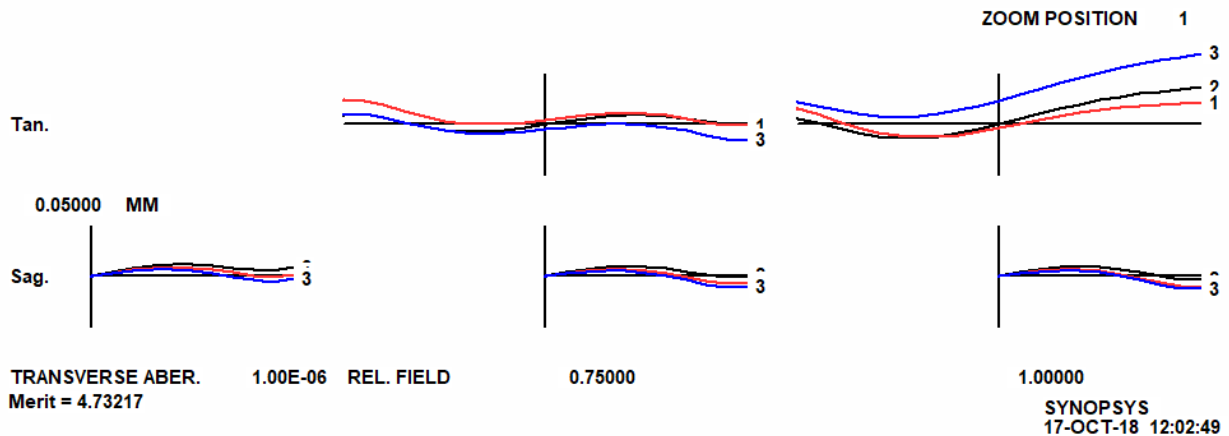
to adjust things properly at the new 15 zooms.

Now run this optimization. The lens is reasonable but needs improvement.

Tan.

0.05000   MM

Sag.

TRANSVERSE ABER.   1.00E-06   REL. FIELD   0.75000   1.00000
Merit = 16.8544
                                                                                    SYNOPSYS
                                                                                    17-OCT-18 11:08:24

Let's see if adding an element helps. Add the line

        AEI 4 1 123 0 0 0 20 2

before the PANT file and run the MACro again. This runs the Automatic Element Insertion routine, which finds the best place to insert. Indeed, the program adds an element in group 4 and the quality is much improved.

ZOOM POSITION   1

TRANSVERSE ABER.   1.00E-06   REL. FIELD   0.75000   1.00000
Merit = 4.73217
SYNOPSYS
17-OCT-18 12:02:49
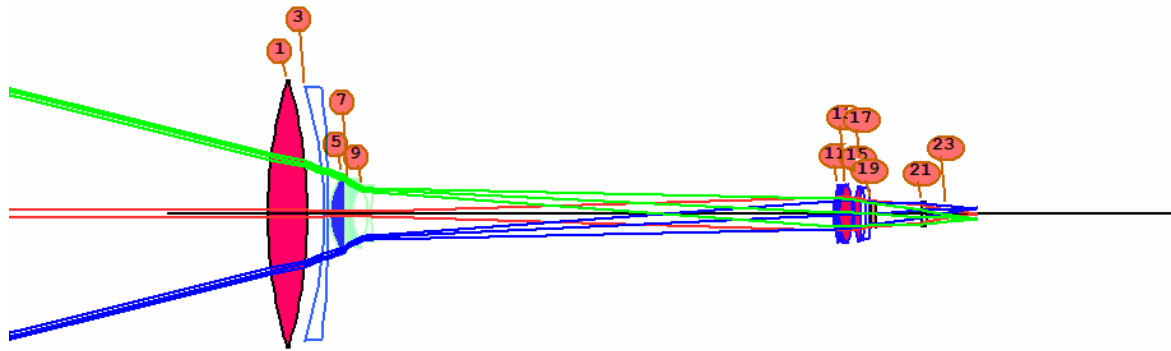
When a design has improved but won't go any further, it is a good idea to figure out why. We are suspicious of the first element, the thickest in the lens, whose edge is very thin. What is the thickness now?

SYNOPSYS AI>1 TH?

 The thickness or spacing of surface number 1 is   35.36316744

Aha! Our MF has a monitor to prevent center thicknesses from growing too large – as they frequently want to do – and we have specified a target of 35 mm. The program wants to make it thicker, but cannot, and is violating both the ACC target (35) and the AEC target (2), which controls the edge. This is a rather large lens, and clearly we need to increase the allowed thickness. Change the ACC monitor to
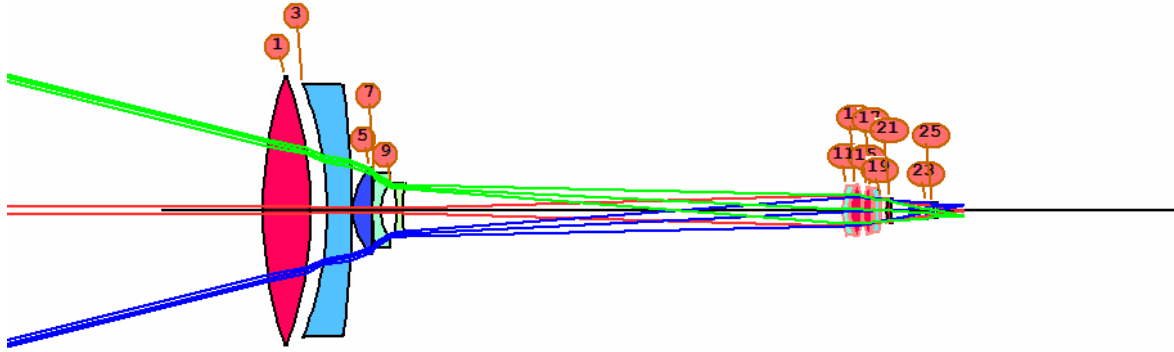
        ACC 50 1 1

comment out the AEI line, and optimize once more and anneal (22,2,50). The MF comes down.
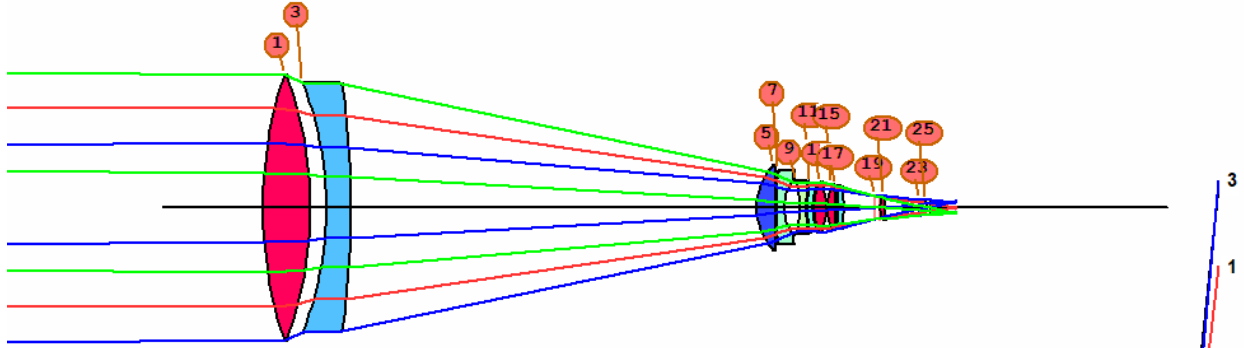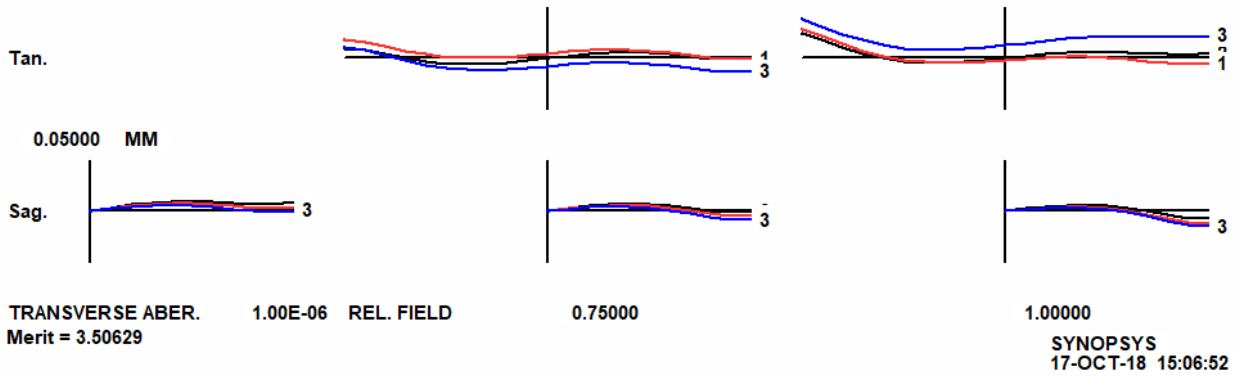
But element 2 is much too thin, so add a new monitor to the MF:

        ADT 7 .1 1

uncomment the AEI line, and reoptimize. This will control the diameter/thickness ratio of every element and add another element. Now the system looks pretty good.

ZOOM POSITION   1

Tan.

0.05000   MM

Sag.   3

TRANSVERSE ABER.   1.00E-06   REL. FIELD   0.75000   1.00000

Merit = 3.50629   SYNOPSYS
                                                                  17-OCT-18 15:06:52

ZOOM POSITION   1

Tan.

0.05000   MM

Sag.

TRANSVERSE ABER.   1.00E-06   REL. FIELD   0.75000   1.00000

Merit = 3.50629   SYNOPSYS
                                                                  17-OCT-18 15:07:17
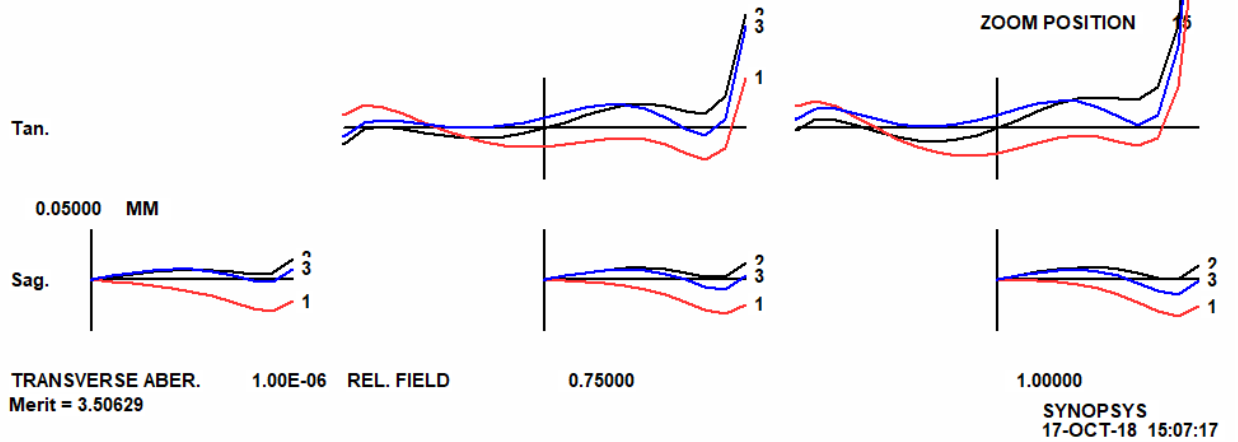
Bump this design into the next ACON, which we are going to use to check the performance at 5 meters focus. Click the button ; then type

  ZFOCUS 5000 4 90 5

You have asked the program to put the object at a distance of five meters and adjust thickness 4 (the airspace following the first group) by 90 mm, adjusting the object height so the Gaussian image height stays at 5 mm. This what we asked ZSEARCH to model, and we want to see how well it worked. Run the zoom slider and look at the performance of this ACON over the zoom range. It is very similar to the performance at infinity, as we wanted. There will be no problems associated with range focusing. The largest aberrations are found in zoom 15, the long focal length setting, which is normal for this kind of lens. (We would likely vignette the tail of the full-field TFAN, to improve that setting.)

Now click the PAD Scan button to check that the aberrations are under control at every field point. We have only optimized at three fields, remember, and it is wise to check whether we need to add more to the AANT file. Do this at both ends of the zoom range and you see that the correction is nicely controlled everywhere. If some intermediate field point showed large aberrations, we would add another GNR request to the AANT file at the offending field point, but it is not necessary in this case.

The Zoom Slider shows the lens almost in focus over the entire zoom range – but we should tweak that up too.

Open the WorkSheet and click the ZFILE button to display the current zoom parameters. Scroll to the top of the edit pane and add two entries, shown in red below:

```
…
OBB  0.000000    14.00000    3.00000   -60.69895    0.00000    0.00000    3.000
ZFILE   2
CAM RANK   9
CAM EXPONENT   0.800000
 5  10
11  18 DFOCUS
RSOLVES
CUBIC
…
```

Now the program will use a piecewise cubic fit to the cam curve (instead of the power-series polynomial used by default so far) and will adjust the zoom position of the second group to maintain a smooth transition of the paraxial defocus at all zooms. Run the Zoom Slider again – and the focus position is essentially perfect everywhere!

Open the MRG menu (Menu, Real Glass), select the Guangming catalog, and click OK. The image has improved, and now there are real glasses everywhere.

ZOOM POSITION 1

Tan.

0.05000 MM

Sag.

TRANSVERSE ABER.   1.00E-06   REL. FIELD   0.75000   1.00000
Merit = 2.89331   SYNOPSYS
                                                                            17-OCT-18 15:40:57

ZOOM POSITION   5

Tan.

0.05000 MM

Sag.

TRANSVERSE ABER.   1.00E-06   REL. FIELD   0.75000   1.00000
Merit = 2.89331   SYNOPSYS
                                                                            17-OCT-18 15:41:19

11
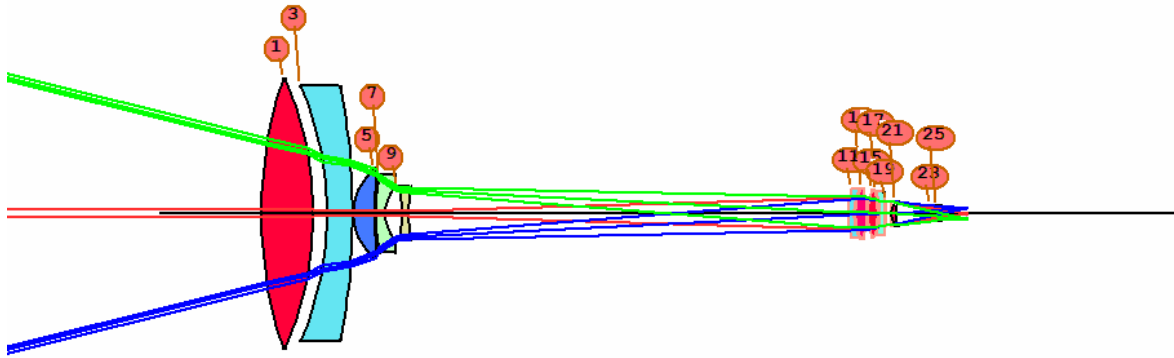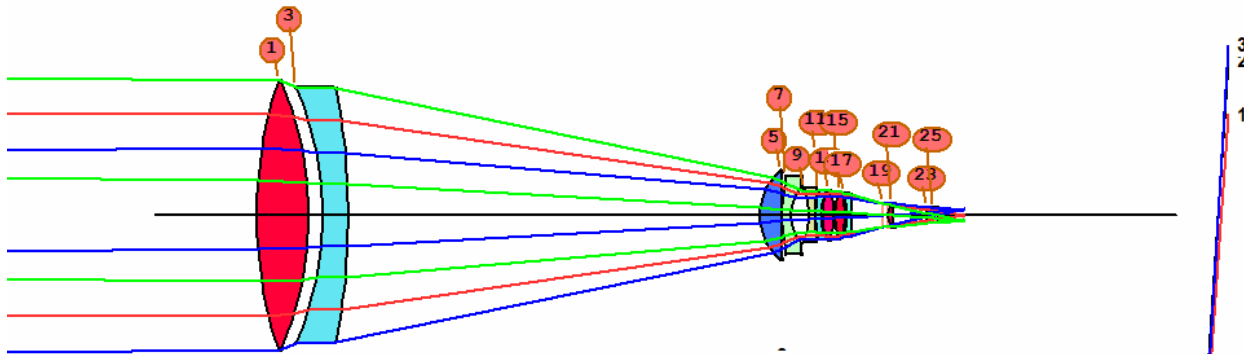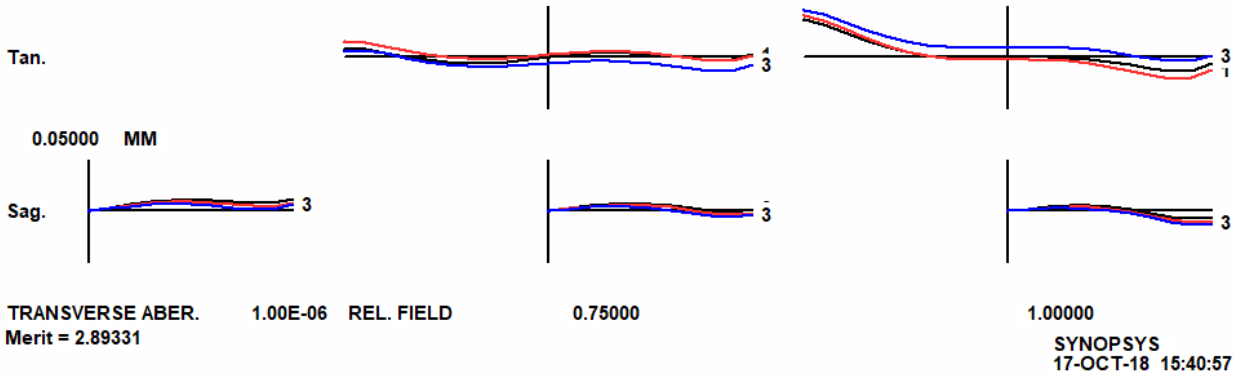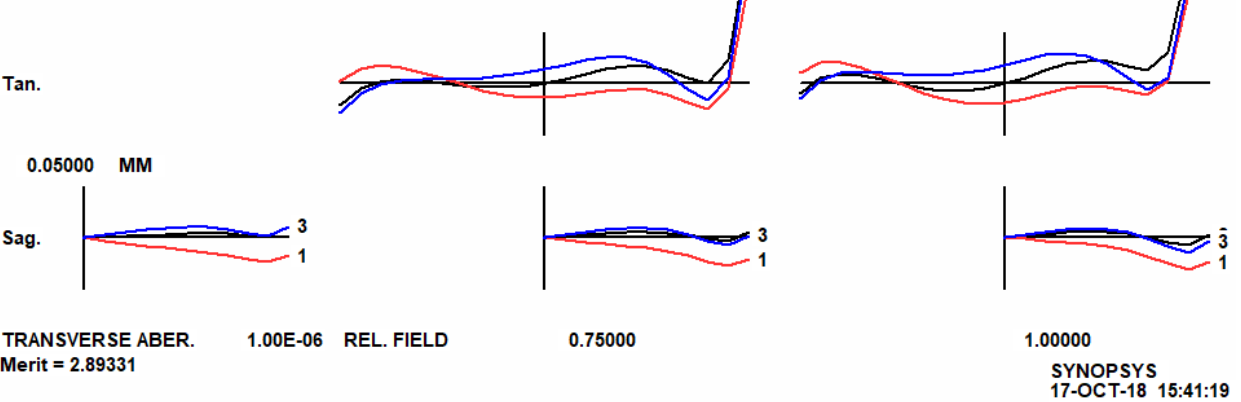
This lesson has made it look easy, and of course it is far easier than it was a generation ago, when a design like this would likely take several months to perfect, using obsolete methods. But there is still a need for human judgement in this process.

In fact, we ran this lesson several times, adjusting parameters until the results were satisfactory. For example, the ZSEARCH input shown above contains entries (the CUL and FUL lines) to limit the highest index of refraction that will be allowed for the glass model variables. In this case, we limited them to 1.75. But there are other glass types whose index is as high as 1.9. Why not use those?

The answer depends on the application. Those glass types, especially those in the flint region, tend to absorb blue light more than glasses with a lower index. If this lens i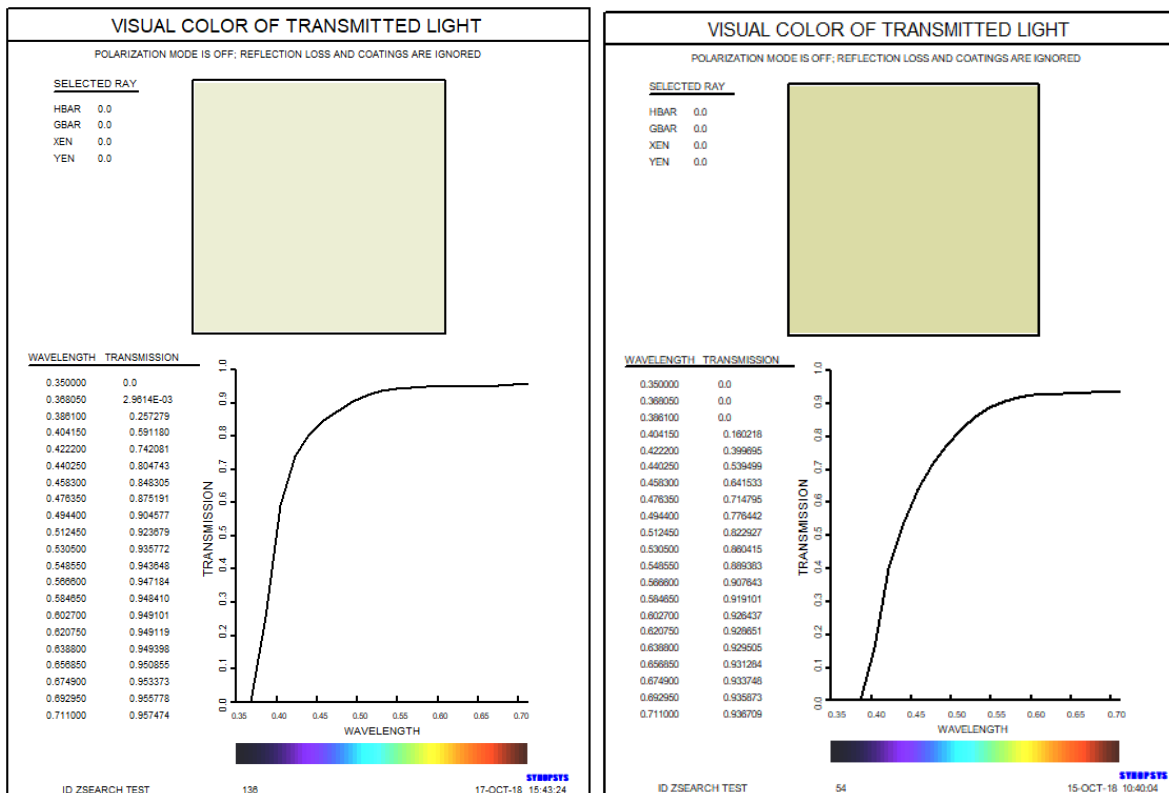s intended for an aerial reconnaissance mission, where one frequently adds a yellow filter to see through haze, then those high-index glasses would be preferred, since one gets better aberration correction that way and the blue light is of no importance. Type

      XCOLOR

to see what colors get through the lens, and you get the picture on the left below. Letting the index go to 1.9, and repeating the whole exercise, we get somewhat better resolution but poorer transmission in the blue, as shown on the right.

VISUAL COLOR OF TRANSMITTED LIGHT

POLARIZATION MODE IS OFF; REFLECTION LOSS AND COATINGS ARE IGNORED

SELECTED RAY
HBAR 0.0
GBAR 0.0
XEN 0.0
YEN 0.0

WAVELENGTH	TRANSMISSION
0.350000	0.0
0.368050	2.9614E-03
0.386100	0.257279
0.404150	0.591180
0.422200	0.742081
0.440250	0.804743
0.458300	0.848305
0.476350	0.875191
0.494400	0.904577
0.512450	0.923679
0.530500	0.935772
0.548550	0.943648
0.566600	0.947184
0.584650	0.948410
0.602700	0.949101
0.620750	0.949119
0.638800	0.949398
0.656850	0.950855
0.674900	0.953373
0.692950	0.955778
0.711000	0.957474

ID ZSEARCH TEST   136   STNOPSYS   17-OCT-18 15:43:24

VISUAL COLOR OF TRANSMITTED LIGHT

POLARIZATION MODE IS OFF; REFLECTION LOSS AND COATINGS ARE IGNORED

SELECTED RAY
HBAR 0.0
GBAR 0.0
XEN 0.0
YEN 0.0

WAVELENGTH	TRANSMISSION
0.350000	0.0
0.368050	0.0
0.386100	0.0
0.404150	0.160218
0.422200	0.399695
0.440250	0.539499
0.458300	0.641533
0.476350	0.714795
0.494400	0.776442
0.512450	0.822927
0.530500	0.860415
0.548550	0.889383
0.566600	0.907643
0.584650	0.919101
0.602700	0.926437
0.620750	0.929651
0.638800	0.929505
0.656850	0.931264
0.674900	0.933748
0.692950	0.935873
0.711000	0.936709

ID ZSEARCH TEST   54   STNOPSYS   15-OCT-18 10:40:04

Another lesson we learned is equally interesting. Our first attempt authorized five groups, three of them zooming. But the cam curves of the final lens showed two of them moving almost in tandem.

That told us we could do the job with only two zooming groups, as we have done. Lens design invariably involves much iteration and adjustments to the goals asked of the software.

We now have a pretty good zoom lens. But can we do better? What else could we aim at?

There are a zillion other requirements that may apply in any given situation. We might need better resolution, and that would call for running AEI yet again, before inserting real glasses. Perhaps we would prefer a shorter lens. That calls for running ZSEARCH again, with a different target on TOTL. What would happen if we ran more cycles in the quick mode? Very likely we would get a different set of 10 lenses. And if switch 98 were turned off and we ran the same job again, the results would likely be different yet. (That switch causes the same random numbers to be recycled for every annealing pass, normally not a good idea, but useful for lessons such as this one, where one expects similar results.)

So this is how it's done. Start with a simple approach, learn what works and what doesn't, increase the complexity as needed, and make use of the many powerful tools that SYNOPSYS provides for the purpose.

Users of more primitive software who switch to SYNOPSYS sometimes ask us to increase the number of allowed zooms. One person wanted to be able to correct at 45 positions – which may indeed be necessary when running an inferior program. But we have shown here that you can get excellent results with only 15 (out of the possible 20) zoom positions for a 30X lens. We once did a 90X zoom this way, with three moving groups, with excellent results. It pays to use the most powerful lens design program in the world. SYNOPSYS.