Tutorial

GENERAL INFORMATION - Welcome to the program! At this point, I assume that you have completed installation, opened your reference manual and said, "Oh, my! What do I do next?" Well, keep reading.

THE USER'S REFERENCE MANUAL - User's Reference Manual which you received is the program book of all knowledge. All features and commands are documented there. Keep the User's Reference Manual with you whenever you use the program. You will need it until you start to remember command names and syntax. If you need additional copies you may make your own copies.

THE PROGRAM STATEMENT - tHE program has a powerful command driven interface and a well written reference manual. As time goes on, a full and optional GUI interface will be added. Read the manual! This program provides a vast assortment of immediate mode and programmable functions for use in the design and analysis of optical systems. It is not just an optical design program, it is also a powerful optical design programming language. All commands may be issued from the keyboard in an immediate mode, may be issued from an ASCII text file in a batch mode or may be included in a programmable macro or macro function. The macros and macro functions, once written, operate exactly as if they were hard coded program commands.
RUNNING THE PROGRAM - After installation, you can go to the PRG directory and double click on the file PRG.EXE. You can make an alias of this file and move it to your desk top.

EXITING THE PROGRAM - When you need to leave the program, you should always exit from the CMD level. If you don't know what level you are at, a simple press of the ENTER key without any preceding command will cause the current level to be displayed on the screen. If you are not at the CMD level, then one or more issuances of the "EOS" command will always bring you to the CMD level. You may then exit by issuing the "EXI" or "EXIT" command. This is the only proper way to leave the program. This is the only way the program will know that it should save its current lens and close all of its files. Exiting the program in any other manner will produce unpredictable results and you will lose data! You may also exit the program using the close window option or by chossing EXIT from the FILE menu.

COMMANDS TO BE INPUT DURING THE TUTORIAL - Only commands shown **in BOLD, GREEN UPPERCASE, TIMES NEW ROMAN** are meant to be input during this tutorial. All other type is to be considered explanatory only.

LESSON #0 - Read the User's Reference Manual - Since the program is a command-driven program, you must eventually become familiar with the commands. Reading the User's Reference Manual once from cover to cover isn't the only way to get started but all other methods work less well. Just as you need to learn the words of the language you speak, you need to learn the command language in order to speak to the program.

LESSON #1 - Inputting a known lens prescription - The first lesson will be the input of a known lens prescription using the LENS INPUT mode. While you are performing this task, have your User's Reference Manual open to the LENS section. Look up each command in the User's Reference Manual as you enter it. The lens prescription which we will be inputting is that of a Cooke Triplet (U.S. Patent #2,453,260). This lens is the only lens in the lens library when you first install the program. We will use this prescription throughout this tutorial. The prescription of the design is given in the following table:

RADIUS	THICKNESS	MAT'L	INDEX	V-no	sa
40.940	8.740	SSK4	1.618	55.1	18.5
inf.	11.050	air	-	-	18.5
-55.650	2.780	SF2	1.648	33.8	14.9
39.750	1.000	air	-	-	14.4
inf.	6.630	air	-	-	14.1
107.560	9.540	SSK4	1.618	55.1	15.5
-43.330	78.739	air	-	-	15.5

The units are millimeters. The half angle of the field of view is 20.81 degrees. The effective focal length will end up at 99.4 mm. The f-number is 2.7. The entrance pupil diameter is 36.947 mm. We will assume that we do not know the names of the glass manufacturers.

WHAT I DID - I first input the prescription into the program just as you will. I then reset the output device from TP (screen) to ED (edittext.dat file) using the "OUTPUT ED" command and listed the prescription with the CMD level "LENO" command. This resulted in a prescription being written to the disk file "EDITTEXT.DAT". The format of this type of "LENO" produced prescription is such that if each line were read back into the program, the lens would be recreated as the new "current lens". The "LENO" output is verbose. When you type the prescription into the program, you won't need to type everything which "LENO" output. I have trimmed down the full "LENO" output to the list of commands which you should now input from the keyboard. The following string of commands, input exactly as shown, will result in the above Cooke triplet prescription becoming the current lens. If you make mistakes during this input, don't worry. We will fix errors using the UPDATE LENS level in the next lesson. If you wish to stop during this input process and start over, just issue an "EOS" command and then repeat the input of these following commands. Issue each of the next commands from the keyboard:

LENS
LI, COOKE TRIPLET U.S.# 2,453,26Ø
UNITS MM

SAY 18.4735
SCY FANG 2Ø.81
TH 1.ØE2Ø
AIR
AIR
RD 4Ø.94
TH 8.74
CLAP 18.5
GLCAT SSK4
TH 11.Ø5
CLAP 18.5
AIR
RD -55.65
TH 2.78
CLAP 14.9
GLCAT SF2
RD 39.75
TH 1
CLAP 14.4
AIR
TH 6.63
CLAP 14.1
REFS
ASTOP
AIR
RD 1Ø7.56
TH 9.54
CLAP 15.5
GLCAT SSK4
RD -43.33
TH 78.739
CLAP 15.5
AIR
AIR
AIR
EOS

The original "LENO" output, from which this trimmed down command list was made, is now listed for completeness. Commands which you did not input would have only set parameters to their already default LENS INPUT mode values. You could, of course, always input the full list if you so desired. If your listing looks a little different, it is because your current version of the program has been augmented, fixed or improved since this example was generated.

```
ANGLES MIXED
LENS
LI, COOKE TRIPLET U.S.# 2,453,260
WV, 0.5876000E+00, 0.4861000E+00, 0.6563000E+00, 0.0000000E+00, 0.0000000E+00
WV2, 0.0000000E+00, 0.0000000E+00, 0.0000000E+00, 0.0000000E+00, 0.0000000E+00
UNITS MM
PCW,2,3
SCW,2,1
CW,1
SAY, 0.18473500E+02
SAX, 0.18473500E+02
SCY,-0.38006410E+20,-0.10155457E+02
SCX,-0.38006410E+20,-0.10155457E+02
CV, 0.00000000E+00
TH, 0.10000000E+21
NORMAL   REGULAR
AIR
CV, 0.00000000E+00
TH, 0.00000000E+00
NORMAL   REGULAR
AIR
CV, 0.24425989E-01
TH, 0.87400000E+01
CLAP, 0.1850000E+02  0.0000000E+00  0.0000000E+00
NORMAL   REGULAR
GLCAT    SSK4
CV, 0.00000000E+00
TH, 0.11050000E+02
CLAP, 0.1850000E+02  0.0000000E+00  0.0000000E+00
NORMAL   REGULAR
```

```
AIR
CV,-0.17969452E-01
TH, 0.27800000E+01
CLAP, 0.1490000E+02  0.0000000E+00  0.0000000E+00
NORMAL   REGULAR
GLCAT   SF2
CV, 0.25157233E-01
TH, 0.10000000E+01
CLAP, 0.1440000E+02  0.0000000E+00  0.0000000E+00
NORMAL   REGULAR
AIR
CV, 0.00000000E+00
TH, 0.66300000E+01
CLAP, 0.1410000E+02  0.0000000E+00  0.0000000E+00
NORMAL   REGULAR
REFS
ASTOP
AIR
CV, 0.92971365E-02
TH, 0.95400000E+01
CLAP, 0.1550000E+02  0.0000000E+00  0.0000000E+00
NORMAL   REGULAR
GLCAT    SSK4
CV,-0.23078698E-01
TH, 0.78739000E+02
CLAP, 0.1550000E+02  0.0000000E+00  0.0000000E+00
NORMAL   REGULAR
AIR
CV, 0.00000000E+00
TH, 0.00000000E+00
NORMAL   REGULAR
AIR
CV, 0.00000000E+00
TH, 0.00000000E+00
NORMAL   REGULAR
AIR
EOS
AIMRAY YES
MODE FOCAL
SPTWT, 0.100000E+01  0.100000E+01  0.100000E+01  0.000000E+00  0.000000E+00
SPTWT2, 0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00  0.000000E+00
```

When you type the "EOS" command at the end of lens input, the lens prescription becomes the "current lens". If you exited now, a copy of this "current lens" is stored in the file LENSTEXT.DAT in the CURLENS directory which sits just beneath the PRG directory. When you run the program again, this file is read in and automatically becomes the "current lens". Before you exit, you should save your work in the lens library by issuing the command:

LIB PUT - This command will store your lens in the lens library (described in the LENS section of the User's Reference Manual). The library entry name will be the lens identifier which you entered with the "LI" command. The lens library entry will be time and date stamped. The lens library provides a good way to save and recall lens prescription. The library has room for 999 optical systems as long as you have enough disk space. At this point, look up and try out the lens library commands "LIB P" and "LSTAT". This is the end of Lesson #1. In Lesson #2, we will learn how to list and modify the lens system we just entered using the UPDATE LENS mode.

LESSON #2 - Listing and modifying the "current lens" - In the first lesson, we learned how to use the LENS INPUT mode to input a lens prescription and how to save what we input to the lens library. If you are among the 99.99% of us who are not perfect, you probably made some input errors during lesson #1. I will now show you how to list your lens and fix errors without re-inputting the entire prescription from the start. The LENS section of the manual describes a number of lens database or "current lens" output commands. Let's try a few. At the CMD level, issue the command:

RTG ALL

The Radius, Thickness and Glass materials associated with the "current lens" will be displayed on the screen.

RIN ALL

For a complete list of the "current lens" in a readable format, issue the command:

LEPRT

which stands for Lens PRinT. If you want to print this list, issue the commands:

OUTPUT LP
LEPRT
OUTPUT TP

PRINT

These four commands set the default output device to the file PRINTER.TXT, output the lens prescription to that file, reset the default output device to the screen and then print the PRINTER.TXT file to the current printer attached to the LPT1 printer port. "LEPRT", as described in the LENS section of the User's Reference Manual, is a composite of a number of other lens output commands which are described in the same section. Try them all. See what the output looks like. As long as you saved the prescription in the library, you can't break anything. In the Reference Manual and at the end of this lesson, I show you how to use the built-in full screen editor to change a lens. For the tutorial, we will use the UPDATE LENS level commands. So much for listing the current lens. Now, let's change something. All changes to the lens database or "current lens" are made at the LENS UPDATE level. At that level, most of the LENS INPUT level commands may be issued. There are three additional commands, "CHG", "INS" and "DEL", which are unique to the LENS UPDATE level. These commands are described in the User's Reference Manual. In order to change an existing value in the current lens prescription, use the "CHG" command. If, for example, the radius of curvature of surface number 2 had been input as 4.094 instead of 40.94 and the thickness of surface 3 had been left equal to the default (0.0) instead of input as 11.05, the following commands would be used to make the corrections:

U L
CHG 2
RD 4Ø.94
CHG 3
TH 11.Ø5
EOS

If you had failed to type the second "AIR" command in the listing, the dummy surface would not have been inserted as surface 1. To fix that, simply type:

U L
INS 1
EOS

If you had typed three "AIR" commands instead of two "AIR" commands near the top of the input command list, you would now have surface 1 and surface 2 as dummy surfaces. To remove surface 2, just type:

U L
DEL 2
EOS

Experiment with other changes to the lens using other UPDATE LENS level commands described in the LENS section.

QUERY OF LENS VALUES DURING LENS INPUT AND UPDATE - During LENS INPUT and LENS UPDATE, typing a lens parameter name followed by a space and a question mark will result in the current value of that parameter being displayed on the screen. For example, while at surface 3, typing:

RD ?

will result in the radius of curvature of surface 3 being displayed on the screen.

FULL SCREEN EDITTING YOUR LENS - If you wish to use the full screen edit method to modify a lens prescription, do the following:
1. Make sure the lens you want to edit is your current lens.
2. Type:
OUTPUT ED
LENO
OUTPUT TP
EDIT
The result will be a full screen edit display of your current lens using either the default program full screen editor or the editor you you have designated with the "EDITOR" command described in the reference manual. Modify the lens as you desire and then file the lens. The program will return from the editor to the CMD level. Then type:
INPUT ED
Your full screen edit modified lens is now the current lens. This is the end of lesson 2.

LESSON #3 - Paraxial Rays and 3rd, 5th and 7th Order aberrations - To make this lesson easier, turn on full headings with the CMD level "HEADINGS ON" command. See the description in the reference manual. Issue the following command:

HEADINGS ON

The paraxial ray trace is automatically performed each time the lens is updated. It is performed in both the XZ and YZ-planes. It ignores tilts, decentrations and special surface definitions. To display YZ-plane paraxial ray data, issue the command:

PXTY ALL

A table displaying the YZ-plane paraxial marginal ray height (PY), paraxial marginal ray slope tangent (PUY), paraxial chief ray height (PCY) and paraxial chief ray slope tangent (PUCY) will be generated. The output is always calculated at the current control wavelength. Look up and read about the "PXTY" command. Try the other paraxial ray output commands described in the same section. The commands are in the CMD section of the reference manual. Try the single surface modes of these commands, like:

PXTY 3

This form of the command just lists the paraxial ray data at surface 3. With "HEADINGS OFF", no heading would appear in single surface output. There are also paraxial output commands which display paraxial incidence angle tangents rather than slope tangents. Try them.

The 3rd, 5th and 7th order aberration values calculated are based on the work of Buchdahl. To calculate and display the 3rd, 5th and 7th order spherical aberrations, issue the command:

SA357 ALL

It must be remembered that, except for third order aberrations, all higher order aberrations are made up of an intrinsic surface dependent part and a transferred part due to lower order aberrations at preceding surfaces. The program not only calculates and displays the sum of the intrinsic and the transferred part of 5th and 7th order aberration values but also can calculate and display just the intrinsic surface dependent component part of each aberration. These intrinsic surface dependent parts of the higher order aberrations can lead to great insight into the aberration makeup of an optical system. To look at the intrinsic components of spherical aberration, for example, issue the command:

SA357I ALL

Now, experiment with the other 3rd, 5th and 7th order aberration output commands discussed in the CMD section of the reference manual.

LESSON #4 - Chromatic Differences - When the paraxial ray trace and 3rd, 5th and 7th order aberrations are calculated at wavelengths other than the control wavelength, the differences in these values characterize the 1st, 3rd, 5th and 7th order chromatic behavior of an optical system. The commands in this lesson are described in the CMD section of the reference manual. The first order YZ-plane chromatic characteristics of the current lens are calculated and displayed by issuing the following command:

FCHY ALL

This command displays the primary and secondary axial and lateral chromatic aberration of the lens based upon the definitions of the primary and secondary wavelength pairs as set with the "PCW" and "SCW" command at the lens input level.

To query the wavelength numbers of PCW and SCW at the CMD level, issue the following two commands:

PCW ?

SCW ?

To calculate the primary chromatic differences for 3rd, 5th and 7th order spherical aberrations, issue the command:

PCDSA ALL

Try the other primary and secondary chromatic difference commands described in the CMD section.

LESSON #5 - Tracing Individual Real Rays - Individual real trigonometric rays are traced using the two commands,"FOB" and "RAY". The "FOB" command is used to specify the location of the current object point from which all subsequent rays are to be traced. Input consists of the relative Y, X, and Z coordinates, measured in the current object surface and in relative units of the reference object heights. Reference object heights were input in the current lens prescription using the "SCY/SCX" or "SCY FANG/SCX FANG" commands. The "FOB" command, in many cases, also causes a central or "chief" ray to be traced. This ray starts at the specified object point, is iteratively aimed so as to pass through the center of the current reference surface, and then proceeds through the rest of the current lens. The "RAY " command is used to specify and trace all general "non-chief" rays by specifying the relative Y and X coordinates of the ray in the current reference surface (see definition of reference surface in the reference manual). The "FOB" and "RAY" commands may also be used to specify that the rays be traced at wavelengths other than the default control wavelength. You should go to the reference manual at this point, and read the full descriptions of the "FOB" and "RAY" commands and also read about ray aiming. After a ray has been traced, the ray data may be displayed in a textual sense or plotted in a graphical display or individual ray data may be transferred to the macro accumulator (x-register) for further manipulation. The following three commands trace the axial, full marginal ray in the YZ-plane and then display the X, Y and Z coordinates at each surface and also the ray slope angles.

FOB
RAY,1
PRXYZ ALL

There are quite a few different ray data display commands described in the reference manual. You should go look them up in the CMD section and read about them. This is the end of lesson #5.

LESSON #6 - Draw the Lens - There are a great many graphics options. You don't need to know them all to draw the lens. To see XY, XZ, YZ and orthographic projections of the current lens, just issue one of the following commands:

VIE XY 3 (You must enter an explicit scale factor when an XY view is requested and 3 is a good value using this lens.)

VIE XZ

VIE YZ

VIE ORTHO

Each of these commands creates a graphics file containing a picture of the current lens system with marginal rays traced from on-axis and at the limits of the field of view as specified by the SCY and SCX values stored in the lens database. To see the pictures, just type:

DRAW

To clear the screen, just press ENTER. If you want a hard copy, either do a graphics screen dump or use the "GRAOUT" command described in the GRAPHICS section of the reference manual.

LESSON #7 - Automation, Writing a Macro - The best feature of this program is that most of the hundreds of commands can be put together to form a macro which then looks just like any other command. We will first do something useful but not too complex. Then, we will do something useful and complex. The first macro we will write will be named MYMAC1. It will change the output device to ED, which stands for the EDITTEXT.DAT output file, will do a LENO to output the lens in a program readable ASCII form and will change the output device back to TP, which stands for the display screen. To write the macro using the macro input mode, type the following commands:

MACRO MYMAC1
OUTPUT ED
LENO
OUTPUT TP
EOM

If you wish to use the full screen macro edit mode of macro creation, type these alternate commands:

MEDIT MYMAC1

The next macro adds the first and second numeric word entries issued with the macro and displays the result. The result is also placed in the accumulator or X-register. The macro is named ADDER. We will use the macro input mode to enter the macro. Follow each command in your reference manual.

MACRO ADDER
NSUB DV Ø Ø
NSUB Ø 1
STO 1
NSUB Ø 2
STO PLUS 1
RCL, 1
FORMAT F13.6
WRITE X
FORMAT D23.15
EOM

The first line defines the macro, names it ADDER and causes the program to enter the macro input mode. The second line causes the default values for numeric words #1 and #2, which are input when the macro is run, to be set to 0.0. The third line moves the first numeric word into the X-register. STO 1 stores that value in numeric register #1. Next, numeric word #2 is moved to the X-register and then added into numeric register #1 with the STO PLUS 1 command. Next, the sum in register 1 is recalled into the X-register. The output format is set to F13.6. The sum is output with a label X=. The format is reset to the program default of D23.15. The last line files the macro.

To add 4.5 and 6.7, just type:

ADDER 4.5 6.7

The answer displayed will be:

```
X = 11.200000
```

Macros are powerful. They can do just about anything you can imagine you wish to do. If macros cannot be made to do something which you need to do, call me and I will attempt to modify their behavior to satisfy your needs.

LESSON #8 - Optimization with Predefined Operands - There are several examples of optimization files in the reference manual. Here is another simple one. We are going to vary the last surface curvature and its conic constant of the current lens so as to change the system focal length to 100 mm while at the same time driving the 3rd order spherical aberration to 0.0. We will keep the system paraxially focused with a PY solve on the second to last surface. First, put on the PY solve by typing:

U L
CHG 9
PY
EOS

This causes surface #9 to take on the value 0.174770E-02 mm as can be seen by doing an RTG 9 command.

Next, set up the operands with the following commands:

MERIT
FLCLTH 1ØØ 1 Ø 1Ø
SA3 Ø 1
EOS

The first command causes the program to enter Merit creation mode. The next command indicates that the paraxial focal length be targeted to 100 with a weight of 1 for surfaces 0 to 10 (the entire lens). The next command targets the 3rd order spherical aberration to 0.0 with a weight of 1. Finally, EOS saves these definitions and causes a return to the CMD level. Next, set up the variables with the following commands:

VARIABLES
CV 8
CC 8
EOS

The first command causes the program to enter Variables creation mode. The next two commands define the curvature and conic constant of surface 8 to be variables. Finally, EOS saves these definitions and causes a return to the CMD level. First type:

VB

This lists the current variables. Next, type:

OPRD

This lists the current operands with their current and targeted values. The focal length is currently 99.4030 mm and the SA3 value is -0.437230. This optimization problem can be solved with damped least squares or directly since we have two variables and two operands which happen to be linearly independent. We will do a combination of the two techniques. Type:

ITER
PFIND
ITER

After these optimization cycles, the FMT (Figure of Merit) will be much smaller than it was. Before we started, it was 0.13095. The new focal length and SA3 values will be very near their target values. Further cycles could drive the values closer to their targets. The new curvature and conic values can be seen by issuing another VB command or by issuing an RTG ALL or an RTG 8 command. The thickness of surface 9 has now changed to 0.474615 mm in order to maintain paraxial focus. There are other optimization methods described in the reference manual which you should try.

LESSON #10 - A Merit Function using Predefined and User-defined Operands - Here is a simple example of a senseless (not intended to be a meaningful figure of merit) merit function which is made up of ray based and non-ray based user-defined and predefined operands. We will make up a merit function which consists of the following aberrations:

Predefined: The Y-height on the image surface of the full marginal Y-ray for an on-axis image position The PY marginal paraxial ray height on surface 3

User-defined: The PY marginal paraxial ray height on surface 3 squared and added to the PCY chief paraxial ray height on surface 3 squared. The difference between the X-ray heights of the FOB 1, RAY 0 7 ray and the FOB 1, RAY 0 -8 ray at surface 5.

First, the user-defined aberrations. We write the following macro function named FUN01 by entering the following commands at the CMD level:

```
MACRO FUN01
C FIRST THE SUM OF THE SQUARES OF PY AND PCY AT SURFACE 3 (STORE IN #1)
GET PY 3
ENT
GET PY 3
C MULTIPLY
*
STO 1
GET PCY 3
ENT
GET PCY 3
C MULTIPLY
*
C STORE PLUS INTO REG 1
STO PLUS 1
C SECOND THE DIFFERENCE IN RAY HEIGHTS (STORE IN #2)
C SET THE OBJECT POSITION
FOB 1
C TRACE THE FIRST RAY
RAY 0 7
C GET THE X POSITION ON SURFACE 5
GET X 5
C STORE IN REGISTER 2
STO 2
C TRACE THE SECOND RAY
RAY 0 -8
C GET THE X POSITION ON SURFACE 5
GET X 5
C STORE MINUS INTO REG 2
STO MINUS 2
EOM
```

Now macro function FUN01 exists and sets up the user-defined operands. now set up the merit function by entering the following commands:

```
MERIT
Y 0 1,,1 2
PY 0 1 3
FUNC01 UOP1 0 1 1
FUNC01 UOP2 0 1 2
EOM
```

Line #1 enters the MERIT sub-level
Line #2 targets the Y height of Ray #2, Field #1 (predefined fields and rays list in OPTIM) to zero height on the image surface with weight of 1.0.
Line #3 targets the PY paraxial ray height to 0.0 with weight 1.0 on surface #3
Line #4 targets the first user-defined operand in FUN01 (stored in register #1) to zero with weight 1.0. The user-defined name is UOP1. You can use any name here.
Line #5 targets the second user-defined operand in FUN01 (stored in register #2) to zero with weight 1.0. The user-defined name is UOP2. You can use any name here as well.
Line #6 ends MERIT definition and returns the program to the CMD level.
You can now define variables and proceed to optimize. User-defined operands can be anything that the program can calculate in a macro function. It is just that easy.

LESSON #11 - Basic Aberration Analysis - Many types of aberration analysis are available. This next lesson should get you started with some of the more common types.

ABERRATION FANS AND THEIR PLOTS - To generate transverse fan data at a specific point in the field of view, issue an "FOB" command which specifies that fractional field of view location. In our example lens, the SCY FANG value was 20.81 degrees. To use "FOB" to specify that analysis is to be performed at a Y-object angle of 2.5 degrees and an X-object angle of 1.25 degrees, issue:

```
FOB 0.1201, 0.060067
```

since these are the relative fractional object heights corresponding to the two angles. Now generate a YZ-plane, transverse aberration fan at the control wavelength with eleven rays in the fan by entering the following command:

```
YFAN, -1, 1, 1, 11
```

The next command will graphically display this fan.

DRAWFAN

The "FANS" command can be used to generate more complex ray fan aberration graphics. The next two commands generate YZ and XZ-plane, transverse ray aberration plots at three pre-selected field of view positions.

FANS or **FANS YFAN**

and

FANS XFAN

There is an extensive list of commands in the CMD section of the reference manual which can be used to generate useful types of aberration fans. There is an extensive aberration fan plotting capability described in the GRAPHICS section of the reference manual. Experiment with these.

DISTORTION, FIELD CURVATURE and ASTIGMATISM - Unlike all other optical design programs, this program correctly calculates distortion, astigmatism and field curvature for off-axis, decentered systems. It does this by basing its calculations on a "generalized paraxial ray trace" instead of on the paraxial ray trace based upon simple algebraic relationships. This so-called "generalized paraxial ray trace" is based upon a finite difference, differential ray trace along the chief ray and it accounts for all optical system parameters including tilts and decenters. For centered systems, the results of this "generalized paraxial ray trace" agree exactly with the conventional paraxial trace. There are many more types of aberration analysis available than can be described here. Read the CMD and GRAPHICS sections for the complete story. Look up these next commands in the reference manual to see how they can be customized. To generate tabular and graphical output of distortion, astigmatism and field curvature, issue the following sequence of commands:

DIST
PLTDIST
AST
PLTAST
FLDCV
PLTFLDCV

Remember that after a graphic is displayed, it may be printed with a screen dump or it may be printed in high resolution using the "GRAOUT" command.

SPOT DIAGRAM GENERATION - Spot diagrams are easy to generate. Specify the fractional object position with an "FOB" command and then issue the "SPD" command. For a graphical display, follow up with a "PLTSPD" command. Try the following sequence:

FOB, .1 .1
SPD
PLTSPD

DIFFRACTION MTF - Diffraction MTF generation and plotting is almost as easy. Try the following commands to generate DOTF data at fractional object point Y=.1 and X=.2:

FOB, .1 .2
CAPFN (generates the complex aperture function)
DOTF (generates the MTF)
PLTDOTF (plots the MTF)

LESSON #12 - Basic Tolerance Analysis - This next lesson describes how to perform a simple tolerance analysis upon the Cooke triplet lens of example 1. In this analysis, we will determine how two aberrations, third order spherical aberration (SA3) and third order coma (CMA3) change when manufacturing tolerances are applied to the first element of the design. Before the impact of these manufacturing tolerances are evaluated, the lens will be refocused using an automatic adjustment of the thickness of surface #8 so that the paraxial marginal ray height, PY, at the image surface is restored to its original value prior to the application of the manufacturing tolerances. It's really very easy to do. Simplicity itself. Read the TOLERANCE section of the reference manual before you run this lesson and look up each command as you enter it. This is a simple example. The power and flexibility of the tolerance analysis is superior to most other commercial optical design programs.

LIB GET 1 (GETS LIBRARY 1 LENS INTO THE CURRENT LENS)

RESTORED LIBRARY LENS NO. 1

(THE NEXT THREE COMMANDS SET UP COMPENSATOR VARIABLES)
COMPVAR

TH 1 8 (Compensator 1 is the thickness of surface 8)
EOS

(THE NEXT THREE COMMANDS SET UP TOLERANCE VARIABLES)
TVAR
RD 2 .2 (Radius of surface 2 changes by .2%)
CV_FR 3 4 (Curvature of surface 3 changes by 4 fringes of power)
TH 2 .005 (Thickness of surface 2 changes by 0.005 lens units)
EOS

(THE NEXT THREE COMMANDS SET UP THE FOCUS CRITERIA)
FOCRIT
PY 1 (PY height is focus criteria #1)
EOS

(THE NEXT THREE COMMANDS SET UP THE TOLERANCE OPERANDS)
TOPER
SA3 1,,,,.003 (Third order spherical is operand #1, inverse value to be 0.003)
CMA3 2,,,,.003 (Third order coma is operand #2, inverse value to be 0.003)
EOS

(If you have a macro named TOLDEF, delete it with the command)
MDEL TOLDEF

(Now save the current tolerance definitions in a macro named TOLDEF by typing:)
TOLDMP TOLDEF

(You may review the compensator, tolerance variable, focus criteria and tolerance operand definitions by entering the next four commands. Try them now.)

COMPS (Displays current compensator definitions)

```
CURRENT COMPENSATION VARIABLE DATA (COMPS)
COMPVAR #  VARIABLE  SURF#   CURRENT VALUE  DINCR VALUE
        1    TH        8      78.7390       0.100000E-04
```

TVB (Displays current tolerance variable definitions)

```
CURRENT TOLERANCE VARIABLE DATA (TVB)
TVAR #  VARIABLE SURF# CURRENT VALUE  DELTA VALUE
     1    RD       2    40.9400       0.200000
     2    CV_FR    3   0.000000        4.00000
     3    TH       2    8.74000       0.500000E-02
```

CRITS (Displays current focus criteria definitions)

```
CURRENT FOCRIT DATA
FOCRIT #  FOCRIT NAME       NW2          NW3          NW4
                            (I)          (J)          (K)
  1           PY           9.00        1.000        -----
```

TOPS (Displays current tolerance operand definitions)

```
CURRENT TOPER DATA
TOPER #   TOPER NAME        NW2          NW3          NW4          NW5
                            (I)          (J)          (K)
  1           SA3         10.00        -----        -----      0.3000E-02
  2           CMA3        10.00        -----        -----      0.3000E-02
```

Starting on the next page, we perform the three tolerance analyses available.

Now perform the analyses.

SENSI (GENERATES THE FOLLOWING SENSITIVITY OUTPUT)

```
****** SENSITIVITY ANALYSIS ******

******************************************************************************
TOLERANCE VARIABLE NAME    = RD       TOLERANCE VARIABLE # =   1
TOLERANCE VARIABLE SURFACE #  =   2
TOLERANCE VARIABLE % CHANGE =  0.20000000
```

```
TOLERANCE VARIABLE CHANGE VALUE =  0.81880001E-01 MM
(TOLERANCE OPERAND SENSITIVITIES)
TOLERANCE OPERAND(#  1) = SA3     *CHANGE =   0.11054431E-01
TOLERANCE OPERAND(#  1) = SA3       VALUE =  -0.45566641
TOLERANCE OPERAND(#  2) = CMA3    *CHANGE =   0.78866589E-02
TOLERANCE OPERAND(#  2) = CMA3      VALUE =   0.59052139E-01
(FOCUS CRITERIA (FOCRIT) DATA)
FOCRIT(#  1) = PY            FOCRIT STARTING VALUE =   0.33194494E-03
FOCRIT(#  1) = PY      FOCRIT FINAL RESTORED VALUE =   0.33195599E-03
(COMPENSATOR VARIABLE DATA)
COMPENSATOR VARIABLE(#  1) = TH      MOTION =   0.29823930
COMPENSATOR VARIABLE SURFACE #  8
******************************************************************************
TOLERANCE VARIABLE NAME   = RD       TOLERANCE VARIABLE # =   1
TOLERANCE VARIABLE SURFACE #  =   2
TOLERANCE VARIABLE % CHANGE = -0.20000000
TOLERANCE VARIABLE CHANGE VALUE = -0.81880001E-01 MM
(TOLERANCE OPERAND SENSITIVITIES)
TOLERANCE OPERAND(#  1) = SA3     *CHANGE =  -0.11099570E-01
TOLERANCE OPERAND(#  1) = SA3       VALUE =  -0.47782041
TOLERANCE OPERAND(#  2) = CMA3    *CHANGE =  -0.78544811E-02
TOLERANCE OPERAND(#  2) = CMA3      VALUE =   0.43310999E-01
(FOCUS CRITERIA (FOCRIT) DATA)
FOCRIT(#  1) = PY            FOCRIT STARTING VALUE =   0.33194494E-03
FOCRIT(#  1) = PY      FOCRIT FINAL RESTORED VALUE =   0.33194089E-03
(COMPENSATOR VARIABLE DATA)
COMPENSATOR VARIABLE(#  1) = TH      MOTION =  -0.29802909
COMPENSATOR VARIABLE SURFACE #  8
******************************************************************************
TOLERANCE VARIABLE NAME   = CV_FR    TOLERANCE VARIABLE # =   2
TOLERANCE VARIABLE SURFACE #  =   3
TOLERANCE VARIABLE CHANGE (FRINGE) =   4.0000000
TOLERANCE VARIABLE CHANGE VALUE =  0.63824689E-05 (1/MM)
(TOLERANCE OPERAND SENSITIVITIES)
TOLERANCE OPERAND(#  1) = SA3     *CHANGE =   0.97302000E-03
TOLERANCE OPERAND(#  1) = SA3       VALUE =  -0.46574782
TOLERANCE OPERAND(#  2) = CMA3    *CHANGE =  -0.13187210E-02
TOLERANCE OPERAND(#  2) = CMA3      VALUE =   0.49846759E-01
(FOCUS CRITERIA (FOCRIT) DATA)
FOCRIT(#  1) = PY            FOCRIT STARTING VALUE =   0.33194494E-03
FOCRIT(#  1) = PY      FOCRIT FINAL RESTORED VALUE =   0.33194495E-03
(COMPENSATOR VARIABLE DATA)
COMPENSATOR VARIABLE(#  1) = TH      MOTION =   0.32869032E-01
COMPENSATOR VARIABLE SURFACE #  8
******************************************************************************
TOLERANCE VARIABLE NAME   = CV_FR    TOLERANCE VARIABLE # =   2
TOLERANCE VARIABLE SURFACE #  =   3
TOLERANCE VARIABLE CHANGE (FRINGE) =  -4.0000000
TOLERANCE VARIABLE CHANGE VALUE = -0.63824689E-05 (1/MM)
(TOLERANCE OPERAND SENSITIVITIES)
TOLERANCE OPERAND(#  1) = SA3     *CHANGE =  -0.97351377E-03
TOLERANCE OPERAND(#  1) = SA3       VALUE =  -0.46769435
TOLERANCE OPERAND(#  2) = CMA3    *CHANGE =   0.13206987E-02
TOLERANCE OPERAND(#  2) = CMA3      VALUE =   0.52486179E-01
(FOCUS CRITERIA (FOCRIT) DATA)
FOCRIT(#  1) = PY            FOCRIT STARTING VALUE =   0.33194494E-03
FOCRIT(#  1) = PY      FOCRIT FINAL RESTORED VALUE =   0.33194494E-03
(COMPENSATOR VARIABLE DATA)
COMPENSATOR VARIABLE(#  1) = TH      MOTION =  -0.32850706E-01
COMPENSATOR VARIABLE SURFACE #  8
******************************************************************************
TOLERANCE VARIABLE NAME   = TH       TOLERANCE VARIABLE # =   3
TOLERANCE VARIABLE SURFACE #  =   2
TOLERANCE VARIABLE CHANGE VALUE =  0.50000000E-02 MM
(TOLERANCE OPERAND SENSITIVITIES)
TOLERANCE OPERAND(#  1) = SA3     *CHANGE =  -0.31193728E-03
TOLERANCE OPERAND(#  1) = SA3       VALUE =  -0.46703278
TOLERANCE OPERAND(#  2) = CMA3    *CHANGE =   0.10750874E-03
TOLERANCE OPERAND(#  2) = CMA3      VALUE =   0.51272989E-01
(FOCUS CRITERIA (FOCRIT) DATA)
FOCRIT(#  1) = PY            FOCRIT STARTING VALUE =   0.33194494E-03
FOCRIT(#  1) = PY      FOCRIT FINAL RESTORED VALUE =   0.33194494E-03
(COMPENSATOR VARIABLE DATA)
COMPENSATOR VARIABLE(#  1) = TH      MOTION =  -0.69511347E-02
COMPENSATOR VARIABLE SURFACE #  8
******************************************************************************
TOLERANCE VARIABLE NAME   = TH       TOLERANCE VARIABLE # =   3
TOLERANCE VARIABLE SURFACE #  =   2
TOLERANCE VARIABLE CHANGE VALUE = -0.50000000E-02 MM
```

```
(TOLERANCE OPERAND SENSITIVITIES)
TOLERANCE OPERAND(#  1) = SA3     *CHANGE =   0.31189257E-03
TOLERANCE OPERAND(#  1) = SA3       VALUE =  -0.46640895
TOLERANCE OPERAND(#  2) = CMA3    *CHANGE =  -0.10739960E-03
TOLERANCE OPERAND(#  2) = CMA3      VALUE =   0.51058081E-01
(FOCUS CRITERIA (FOCRIT) DATA)
FOCRIT(#  1) = PY            FOCRIT STARTING VALUE =   0.33194494E-03
FOCRIT(#  1) = PY      FOCRIT FINAL RESTORED VALUE =   0.33194494E-03
(COMPENSATOR VARIABLE DATA)
COMPENSATOR VARIABLE(#  1) = TH      MOTION =   0.69512490E-02
COMPENSATOR VARIABLE SURFACE #  8
******************************************************************************
                  ****** SENSITIVITY ANALYSIS COMPLETED ******
```

INVSENSI (GENERATES THE FOLLOWING INVERSE SENSITIVITY OUTPUT)

```
                   ****** INVERSE SENSITIVITY ANALYSIS ******

******************************************************************************
TOLERANCE VARIABLE NAME   = RD       TOLERANCE VARIABLE # =   1
TOLERANCE VARIABLE SURFACE #  =   2
TOLERANCE VARIABLE % CHANGE =  0.20000000
TOLERANCE VARIABLE CHANGE VALUE =  0.81880001E-01 MM
(TOLERANCE OPERAND SENSITIVITIES)
TOLERANCE OPERAND(#  1) = SA3     *CHANGE =   0.11054431E-01
TOLERANCE OPERAND(#  1) = SA3       VALUE =  -0.45566641
TOLERANCE OPERAND(#  2) = CMA3    *CHANGE =   0.78866589E-02
TOLERANCE OPERAND(#  2) = CMA3      VALUE =   0.59052139E-01
(FOCUS CRITERIA (FOCRIT) DATA)
FOCRIT(#  1) = PY            FOCRIT STARTING VALUE =   0.33194494E-03
FOCRIT(#  1) = PY      FOCRIT FINAL RESTORED VALUE =   0.33194494E-03
(COMPENSATOR VARIABLE DATA)
COMPENSATOR VARIABLE(#  1) = TH       MOTION =   0.29823930
COMPENSATOR VARIABLE SURFACE #  8
(INVERSE SESITIVITY TOLERANCE VARIABLE CHANGE PROJECTION)
TOLERANCE OPERAND(#  1) = SA3      DESIRED CHANGE =   0.30000000E-02
TOLERANCE VARIABLE(#  1) = RD      REQUIRED MOTION =   0.22220955E-01
TOLERANCE OPERAND(#  2) = CMA3     DESIRED CHANGE =   0.30000000E-02
TOLERANCE VARIABLE(#  1) = RD      REQUIRED MOTION =   0.31146270E-01
******************************************************************************
TOLERANCE VARIABLE NAME   = RD       TOLERANCE VARIABLE # =   1
TOLERANCE VARIABLE SURFACE #  =   2
TOLERANCE VARIABLE % CHANGE = -0.20000000
TOLERANCE VARIABLE CHANGE VALUE = -0.81880001E-01 MM
(TOLERANCE OPERAND SENSITIVITIES)
TOLERANCE OPERAND(#  1) = SA3     *CHANGE =  -0.11099570E-01
TOLERANCE OPERAND(#  1) = SA3       VALUE =  -0.47782041
TOLERANCE OPERAND(#  2) = CMA3    *CHANGE =  -0.78544811E-02
TOLERANCE OPERAND(#  2) = CMA3      VALUE =   0.43310999E-01
(FOCUS CRITERIA (FOCRIT) DATA)
FOCRIT(#  1) = PY            FOCRIT STARTING VALUE =   0.33194494E-03
FOCRIT(#  1) = PY      FOCRIT FINAL RESTORED VALUE =   0.33194494E-03
(COMPENSATOR VARIABLE DATA)
COMPENSATOR VARIABLE(#  1) = TH       MOTION =  -0.29802909
COMPENSATOR VARIABLE SURFACE #  8

(INVERSE SESITIVITY TOLERANCE VARIABLE CHANGE PROJECTION)
TOLERANCE OPERAND(#  1) = SA3      DESIRED CHANGE =   0.30000000E-02
TOLERANCE VARIABLE(#  1) = RD      REQUIRED MOTION =  -0.22130588E-01
TOLERANCE OPERAND(#  2) = CMA3     DESIRED CHANGE =   0.30000000E-02
TOLERANCE VARIABLE(#  1) = RD      REQUIRED MOTION =  -0.31273868E-01
******************************************************************************
TOLERANCE VARIABLE NAME   = CV_FR    TOLERANCE VARIABLE # =   2
TOLERANCE VARIABLE SURFACE #  =   3
TOLERANCE VARIABLE CHANGE (FRINGE) =   4.0000000
TOLERANCE VARIABLE CHANGE VALUE =  0.63824689E-05 (1/MM)
(TOLERANCE OPERAND SENSITIVITIES)
TOLERANCE OPERAND(#  1) = SA3     *CHANGE =   0.97302000E-03
TOLERANCE OPERAND(#  1) = SA3       VALUE =  -0.46574782
TOLERANCE OPERAND(#  2) = CMA3    *CHANGE =  -0.13187210E-02
TOLERANCE OPERAND(#  2) = CMA3      VALUE =   0.49846759E-01
(FOCUS CRITERIA (FOCRIT) DATA)
FOCRIT(#  1) = PY            FOCRIT STARTING VALUE =   0.33194494E-03
FOCRIT(#  1) = PY      FOCRIT FINAL RESTORED VALUE =   0.33194494E-03
(COMPENSATOR VARIABLE DATA)
COMPENSATOR VARIABLE(#  1) = TH       MOTION =   0.32869032E-01
COMPENSATOR VARIABLE SURFACE #  8

(INVERSE SESITIVITY TOLERANCE VARIABLE CHANGE PROJECTION)
```

```
TOLERANCE OPERAND(#  1) = SA3      DESIRED CHANGE =   0.30000000E-02
TOLERANCE VARIABLE(#  2) = CV_FR   REQUIRED MOTION =   0.19678328E-04
TOLERANCE OPERAND(#  2) = CMA3     DESIRED CHANGE =   0.30000000E-02
TOLERANCE VARIABLE(#  2) = CV_FR   REQUIRED MOTION =   0.14519680E-04
******************************************************************************
TOLERANCE VARIABLE NAME   = CV_FR    TOLERANCE VARIABLE # =   2
TOLERANCE VARIABLE SURFACE #  =   3
TOLERANCE VARIABLE CHANGE (FRINGE) =  -4.0000000
TOLERANCE VARIABLE CHANGE VALUE = -0.63824689E-05 (1/MM)
(TOLERANCE OPERAND SENSITIVITIES)
TOLERANCE OPERAND(#  1) = SA3     *CHANGE =  -0.97351377E-03
TOLERANCE OPERAND(#  1) = SA3       VALUE =  -0.46769435
TOLERANCE OPERAND(#  2) = CMA3    *CHANGE =   0.13206987E-02
TOLERANCE OPERAND(#  2) = CMA3      VALUE =   0.52486179E-01
(FOCUS CRITERIA (FOCRIT) DATA)
FOCRIT(#  1) = PY            FOCRIT STARTING VALUE =   0.33194494E-03
FOCRIT(#  1) = PY      FOCRIT FINAL RESTORED VALUE =   0.33194494E-03
(COMPENSATOR VARIABLE DATA)
COMPENSATOR VARIABLE(#  1) = TH       MOTION =  -0.32850706E-01
COMPENSATOR VARIABLE SURFACE #  8

(INVERSE SESITIVITY TOLERANCE VARIABLE CHANGE PROJECTION)
TOLERANCE OPERAND(#  1) = SA3      DESIRED CHANGE =   0.30000000E-02
TOLERANCE VARIABLE(#  2) = CV_FR   REQUIRED MOTION =  -0.19668347E-04
TOLERANCE OPERAND(#  2) = CMA3     DESIRED CHANGE =   0.30000000E-02
TOLERANCE VARIABLE(#  2) = CV_FR   REQUIRED MOTION =  -0.14497937E-04
******************************************************************************
TOLERANCE VARIABLE NAME   = TH       TOLERANCE VARIABLE # =   3
TOLERANCE VARIABLE SURFACE #  =   2
TOLERANCE VARIABLE CHANGE VALUE =  0.50000000E-02 MM
(TOLERANCE OPERAND SENSITIVITIES)
TOLERANCE OPERAND(#  1) = SA3     *CHANGE =  -0.31193728E-03
TOLERANCE OPERAND(#  1) = SA3       VALUE =  -0.46703278
TOLERANCE OPERAND(#  2) = CMA3    *CHANGE =   0.10750874E-03
TOLERANCE OPERAND(#  2) = CMA3      VALUE =   0.51272989E-01
(FOCUS CRITERIA (FOCRIT) DATA)
FOCRIT(#  1) = PY            FOCRIT STARTING VALUE =   0.33194494E-03
FOCRIT(#  1) = PY      FOCRIT FINAL RESTORED VALUE =   0.33194494E-03
(COMPENSATOR VARIABLE DATA)
COMPENSATOR VARIABLE(#  1) = TH       MOTION =  -0.69511347E-02
COMPENSATOR VARIABLE SURFACE #  8

(INVERSE SESITIVITY TOLERANCE VARIABLE CHANGE PROJECTION)
TOLERANCE OPERAND(#  1) = SA3      DESIRED CHANGE =   0.30000000E-02
TOLERANCE VARIABLE(#  3) = TH      REQUIRED MOTION =   0.48086589E-01
TOLERANCE OPERAND(#  2) = CMA3     DESIRED CHANGE =   0.30000000E-02
TOLERANCE VARIABLE(#  3) = TH      REQUIRED MOTION =   0.13952354
WARINING:
PROJECTED VARIABLE CHANGE IS 10 OR MORE TIMES
GREATER THAN THE INPUT "DELTA" FOR THE CURRENT
VARIABLE. LINEARITY MAY NOT BE VALID.
******************************************************************************
TOLERANCE VARIABLE NAME   = TH       TOLERANCE VARIABLE # =   3
TOLERANCE VARIABLE SURFACE #  =   2
TOLERANCE VARIABLE CHANGE VALUE = -0.50000000E-02 MM
(TOLERANCE OPERAND SENSITIVITIES)
TOLERANCE OPERAND(#  1) = SA3     *CHANGE =   0.31189257E-03
TOLERANCE OPERAND(#  1) = SA3       VALUE =  -0.46640895
TOLERANCE OPERAND(#  2) = CMA3    *CHANGE =  -0.10739960E-03
TOLERANCE OPERAND(#  2) = CMA3      VALUE =   0.51058081E-01
(FOCUS CRITERIA (FOCRIT) DATA)
FOCRIT(#  1) = PY            FOCRIT STARTING VALUE =   0.33194494E-03
FOCRIT(#  1) = PY      FOCRIT FINAL RESTORED VALUE =   0.33194494E-03
(COMPENSATOR VARIABLE DATA)
COMPENSATOR VARIABLE(#  1) = TH       MOTION =   0.69512490E-02
COMPENSATOR VARIABLE SURFACE #  8

(INVERSE SESITIVITY TOLERANCE VARIABLE CHANGE PROJECTION)
TOLERANCE OPERAND(#  1) = SA3      DESIRED CHANGE =   0.30000000E-02
TOLERANCE VARIABLE(#  3) = TH      REQUIRED MOTION =  -0.48093483E-01
TOLERANCE OPERAND(#  2) = CMA3     DESIRED CHANGE =   0.30000000E-02
TOLERANCE VARIABLE(#  3) = TH      REQUIRED MOTION =  -0.13966533
WARINING:
PROJECTED VARIABLE CHANGE IS 10 OR MORE TIMES
GREATER THAN THE INPUT "DELTA" FOR THE CURRENT
VARIABLE. LINEARITY MAY NOT BE VALID.
******************************************************************************
              ****** INVERSE SENSITIVITY ANALYSIS COMPLETED ******
```

MONTE (GENERATES THE FOLLOWING MONTE-CARLO OUTPUT)

```
                       ****** MONTE-CARLO ANALYSIS ******

******************************************************************************
(TOLERANCE OPERAND VALUES)
TOLERANCE OPERAND(#  1) = SA3      *CHANGE =  -0.11131760E-01
TOLERANCE OPERAND(#  1) = SA3      * VALUE =  -0.47785262

TOLERANCE OPERAND(#  2) = CMA3     *CHANGE =  -0.65268567E-02
TOLERANCE OPERAND(#  2) = CMA3     * VALUE =   0.44638783E-01

(FOCUS CRITERIA (FOCRIT) DATA)
FOCRIT(#  1) = PY            FOCRIT STARTING VALUE =   0.33312394E-03
FOCRIT(#  1) = PY      FOCRIT FINAL RESTORED VALUE =   0.33312394E-03

(COMPENSATOR VARIABLE DATA)
COMPENSATOR VARIABLE(#  1) = TH      MOTION =  -0.30127549
******************************************************************************
                         ****** MONTE-CARLO SUMMARY ******
TOTAL NUMBER OF MONTE-CARLO CYCLES =          1
    FOR TOLERANCE OPERAND #  1
AVERAGE OPERAND CHANGE VALUE = -0.11131760E-01
     WITH STANDARD DEVIATION =   0.0000000
    FOR TOLERANCE OPERAND #  2
AVERAGE OPERAND CHANGE VALUE = -0.65268567E-02
     WITH STANDARD DEVIATION =   0.0000000
          FOR COMPENSATOR #  1
AVERAGE COMPENSATOR VALUE = -0.30127549
  WITH STANDARD DEVIATION =   0.0000000
               FOR FOCRIT #  1
             FOCRIT CHANGE= -0.13005828E-08
  WITH STANDARD DEVIATION =   0.0000000
******************************************************************************
                  ****** MONTE-CARLO ANALYSIS COMPLETED ******
```

LESSON #13 - Beam Footprint Analysis - Beam footprints may be easily drawn and may include clear apertures. The following sequence of commands causes an off-axis bundle of rays to be plotted on surface #2 of the COOK Triplet lens stored in lens library file #1. The first string of commands causes a beam footprint to be drawn which is unvignetted by any clear apertures or obscurations assigned to any surfaces other than the reference surface. It could be used to determine how much larger to make the clear aperture on surface 2 so as to not clip the beam.

PLOT NEW
PLOT SCALE 2 2
ORIENT 2
PLOT CLAP 2 2
FOB 1
FOOT 2
PLOT FOOT
DRAW

The next string of commands causes a beam footprint to be drawn which is vignetted by clear apertures and obscurations assigned to any surface. It could be used to determine the area of the vignetted beam.

PLOT NEW
PLOT SCALE 2 2
ORIENT 2
PLOT CLAP 2 2
FOB 1
FOOT APE 2
PLOT FOOT
DRAW

The "ORIENT 2" command sets the "look" vector to be normal to surface 2. The "PLOT SCALE 2 2" command just sets a convenient scale. Remember, look up all these commands in the reference manual or you won't learn as much as you should from this lesson. After each DRAW command, additional beams may be traced and drawn on the same plots.

LESSON #13 - NSS (non-sequential systems) - From the program main CMD level, type "NSSREST" which will retrieve a simple non-sequential system stored in the NSSDIR sub-directory and named TEST.NSS. Typing "NSSTRACE" will trace a single ray through the system. Typing:

PLOT NEW
PLOT LOOK , 1 , 1 , 1
PLOT NSSSCALE , .2
PLOT NSSSURFS
PLOT NSSRAYS
DRAW

will generate an orthographic view of the system. Read the NSS manual section and play with this NSS system and then try changing it. More will be said later.